

Remote Imagery

A Technical Treatise



Compiled By
David Childers

Foreward

According to Wikipedia, remote sensing is the ability to acquire information about an object without making physical contact in contrast to obtaining information via on-site examination. This acquired information can be composed of several types, which depends on the actual data requirements.

Remote imagery is composed of photographic image data acquired by distant methods, such as satellite or aircraft. This photographic imagery can also be divided into several classes, such as spectral, infrared, color, black, and white. The information required from the imagery generally dictates the type of imagery data used.

Remote imagery requires the ability to fully interpret or analyze the graphical representation to understand the information provided within the image's context. This informational context can provide details regarding structure locations, vehicle or pedestrian travel areas, vegetative cover areas, soil conditions, or locations of bodies of water such as lakes, rivers, or streams.

Remote imagery should be an essential element within any civil engineering project's research and planning objectives, whether it is new construction or modifications of an existing structure. Remote imagery can provide insightful information to the project manager, engineering, architectural design, and environmental services team. Ground-level site observations can yield a limited amount of data, whereas aerial observations can provide a comprehensive understanding of the site and environmental requirements. Pre and post imagery analysis can also provide detailed information that can be used as a basis for future project planning in surrounding areas.

With the enhanced environmental requirements being implemented at the Federal, State, County, and City level, it is essential to have all relevant information available to facilitate proper planning to safeguard the proposed project site's environmental conditions. Detailed project site imagery can also provide a wealth of information for planning the work site entrances, exits, storage, and specialty work areas.

As the old adage goes, "An ounce of prevention is worth a pound of cure," remote imagery can provide managers, supervisors, and workers with an enhanced understanding of relevant site conditions that may not be easily observed or understood otherwise.

It is my sincere wish that the reader will gain both insight and knowledge from the contents of this publication.

David Childers

Sapere Aude!

27 December 2020

No thief, however skillful, can rob one of knowledge, and that is why knowledge is the best and safest treasure to acquire.

L. Frank Baum

Cover Image

eros.usgs.gov/doi-remote-sensing-activities/2012/usgs/escalante-river-utah-change-detection

Dedication

Hats off to the Klondike lads at the Dominion of Dysfunctionality, aka Palace of Puzzles.

Inspired by Midge Ure and the melodic "If I Was".

A-ți Pica Fisa Elena!

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Executive Summary

The purpose of this treatise is to collate technical information applicable to the field of Remote Imagery. Remote imagery is the ability to capture detailed graphical imagery information of locations and or objects.

The following areas are covered in detail:

- Functionality.
- Methodology.
- Analysis.
- Usage.

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-	
(11) Fundamentals of Aquatic Remote Sensing National Aeronautics and Space Administration	1779
(12) The Measurement of Water Depth by Remote Sensing Techniques United States Naval Oceanographic Office	1842
-	
(13) Remote Sensing of Agriculture NASS' Cropland Data Layer Program United States Department of Agriculture	1890
-	
(14) Aerial - Photo Interpretation In Classifying And Mapping Soils Agricultural Handbook 294 United States Department of Agriculture	1926
(15) Digital Soil Mapping Primer United States Department of Agriculture	2020
-	
(16) Forester's Guide To Aerial Photo Interpretation Agriculture Handbook No. 308 U.S. Department of Agriculture	2058
(17) USGS-NPS National Vegetation Mapping Program: Sunset Crater Volcano National Monument, Arizona, Vegetation Classification and Distribution United States Geological Survey	2105
(18) The Use of Aerial Photographs in Studies of Marsh Vegetation Bulletin 13, Technical Series Maine Agricultural Experiment Station	2294

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(19) Earth Science Applied to Military Use of Natural Terrain 2357
United States Air force

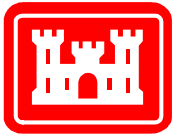
(20) FM 5-33 2570
Terrain Analysis
Headquarters, Department of the Army

-

(21) Photo Point Monitoring Handbook: 2776
Part A – Field Procedures
Part B – Concepts and Analysis
General Technical Report PNW-GTR-526
United States Department of Agriculture

(22) Ground-Based Photographic Monitoring 2929
United States Department of Agriculture

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1 October 2003

**US Army Corps
of Engineers**

ENGINEERING AND DESIGN

Remote Sensing

ENGINEER MANUAL

CECW-EE

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
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Manual
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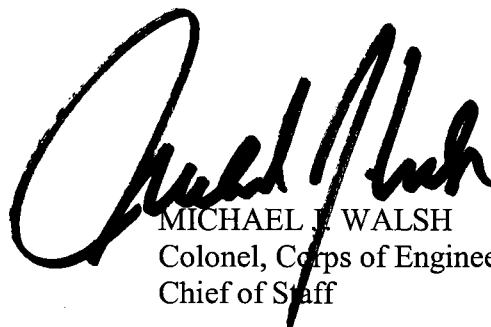
1 October 2003

Engineering and Design
REMOTE SENSING

1. **Purpose.** This EM is intended to promote effective use of remotely sensed data by all USACE divisions and districts.
2. **Applicability.** This EM applies to all HQUSACE elements and USACE commands responsible for integrating remotely sensed and geospatial data into Civil Works Projects.
3. **Distribution.** Approved for public release, distribution is unlimited.
4. **References.** References are listed in Appendix A.
5. **Discussion.** The theory, practice, and use of remote sensing are comprehensively presented in this EM. Focus is placed on the U.S. Army Corps of Engineers 9 - Civil Works Business Practice Areas.

FOR THE COMMANDER:

9 Appendices
(See Table of Contents)



MICHAEL J. WALSH
Colonel, Corps of Engineers
Chief of Staff

This manual supersedes Engineer Pamphlet 70-1-1, Remote Sensing Applications Guide, Planning and Management Guidance, dated October 1979.

CECW-EE

DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
Washington, D.C. 20314-1000

EM 1110-2-2907

Engineer Manual
No. 1110-2-2907

1 October 2003

Engineering and Design
REMOTE SENSING

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Chapter 1

Introduction to Remote Sensing

1-1 Purpose of this Manual.

a. This manual reviews the theory and practice of remote sensing and image processing. As a Geographical Information System (GIS) tool, remote sensing provides a cost effective means of surveying, monitoring, and mapping objects at or near the surface of the Earth. Remote sensing has rapidly been integrated among a variety of U.S. Army Corps Engineers (USACE) applications, and has proven to be valuable in meeting Civil Works business program requirements.

b. A goal of the Remote Sensing Center at the USACE Cold Regions Research Engineering Laboratory (CRREL) is to enable effective use of remotely sensed data by all USACE divisions and districts.

c. The practice of remote sensing has become greatly simplified by useful and affordable commercial software, which has made numerous advances in recent years. Satellite and airborne platforms provide local and regional perspective views of the Earth's surface. These views come in a variety of resolutions and are highly accurate depictions of surface objects. Satellite images and image processing allow researchers to better understand and evaluate a variety of Earth processes occurring on the surface and in the hydrosphere, biosphere, and atmosphere.

1-2 Contents of this Manual.

a. The objective of this manual is to provide both theoretical and practical information to aid acquiring, processing, and interpreting remotely sensed data. Additionally, this manual provides reference materials and sources for further study and information.

b. Included in this work is a background of the principles of remote sensing, with a focus on the physics of electromagnetic waves and the interaction of electromagnetic waves with objects. Aerial photography and history of remote sensing are briefly discussed.

c. A compendium of sensor types is presented together with practical information on obtaining image data. Corps data acquisition is discussed, including the protocol for securing archived data through the USACE Topographic Engineering Center (TEC) Image Office (TIO).

d. The fundamentals of image processing are presented along with a summary of map projection and information extraction. Helpful examples and tips are presented to clarify concepts and to enable the efficient use of image processing. Examples focus on the use of images from the Landsat series of satellite sensors, as this series has the longest and most continuous record of Earth surface multispectral data.

e. Examples of remote sensing applications used in the Corps of Engineers mission areas are presented. These missions include land use, forestry, geology, hydrology, geography, meteorology, oceanography, and archeology.

f. A glossary of remote sensing terms is presented at the end of this manual, also see <http://rst.gsfc.nasa.gov/AppD/glossary.html>.

g. The Remote Sensing GIS Center at CRREL supports new and promising remote sensing and GIS (Geographical Information Systems) technologies. Introductory and advanced remote sensing and GIS PROSPECT courses are offered through the Center. For more information regarding the Remote Sensing GIS Center, please contact Andrew J. Bruzewicz, Director, or Timothy Pangburn, Branch Chief of Remote Sensing GIS and Water Resources, at 603-646-4372 and 603-646-4296.

h. This manual represents the combined efforts of individuals from Science and Technology Corporation (STC), Dartmouth College, and USACE-ERDC-CRREL. Principal contributors include Lorin J. Amidon (STC), Emily S. Bryant (Dartmouth College), Dr. Robert L. Bolus (ERDC-CRREL), and Brian T. Tracy (ERDC-CRREL).

Chapter 2

Principles Of Remote Sensing Systems

2-1 Introduction. The principles of remote sensing are based primarily on the properties of the electromagnetic spectrum and the geometry of airborne or satellite platforms relative to their targets. This chapter provides a background on the physics of remote sensing, including discussions of energy sources, electromagnetic spectra, atmospheric effects, interactions with the target or ground surface, spectral reflectance curves, and the geometry of image acquisition.

2-2 Definition of Remote Sensing.

a. Remote sensing describes the collection of data about an object, area, or phenomenon from a distance with a device that is not in contact with the object. More commonly, the term remote sensing refers to imagery and image information derived by both airborne and satellite platforms that house sensor equipment. The data collected by the sensors are in the form of electromagnetic energy (EM). Electromagnetic energy is the energy emitted, absorbed, or reflected by objects. Electromagnetic energy is synonymous to many terms, including electromagnetic radiation, radiant energy, energy, and radiation.

b. Sensors carried by platforms are engineered to detect variations of emitted and reflected electromagnetic radiation. A simple and familiar example of a platform carrying a sensor is a camera mounted on the underside of an airplane. The airplane may be a high or low altitude platform while the camera functions as a sensor collecting data from the ground. The data in this example are reflected electromagnetic energy commonly known as visible light. Likewise, spaceborne platforms known as satellites, such as Landsat Thematic Mapper (Landsat TM) or SPOT (Satellite Pour l'Observation de la Terra), carry a variety of sensors. Similar to the camera, these sensors collect emitted and reflected electromagnetic energy, and are capable of recording radiation from the visible and other portions of the spectrum. The type of platform and sensor employed will control the image area and the detail viewed in the image, and additionally they record characteristics of objects not seen by the human eye.

c. For this manual, remote sensing is defined as the acquisition, processing, and analysis of surface and near surface data collected by airborne and satellite systems.

2-3 Basic Components of Remote Sensing.

a. The overall process of remote sensing can be broken down into five components. These components are: 1) an energy source; 2) the interaction of this energy with particles in the atmosphere; 3) subsequent interaction with the ground target; 4) energy recorded by a sensor as data; and 5) data displayed digitally for visual and numerical interpretation. This chapter examines components 1–4 in detail. Component 5 will be discussed in Chapter 5. Figure 2-1 illustrates the basic elements of airborne and satellite remote sensing systems.

b. Primary components of remote sensing are as follows:

- Electromagnetic energy is emitted from a source.
- This energy interacts with particles in the atmosphere.
- Energy interacts with surface objects.
- Energy is detected and recorded by the sensor.
- Data are displayed digitally for visual and numerical interpretation on a computer.

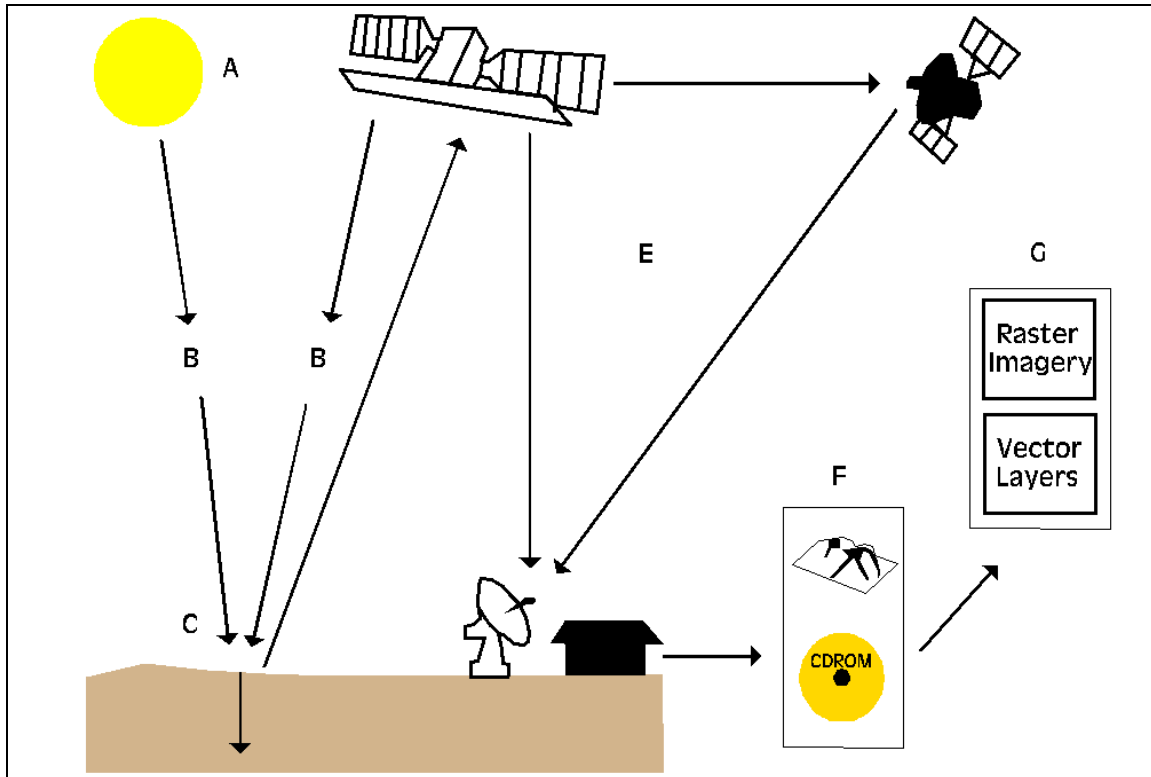


Figure 2-1. The satellite remote sensing process. A—Energy source or illumination (electromagnetic energy); B—radiation and the atmosphere; C—interaction with the target; D—recording of energy by the sensor; E—transmission, reception, and processing; F—interpretation and analysis; G—application. Modified from http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter1/chapter1_1_e.html, courtesy of the Natural Resources Canada.

2-4 Component 1: Electromagnetic Energy Is Emitted From A Source.

a. *Electromagnetic Energy: Source, Measurement, and Illumination.* Remote sensing data become extremely useful when there is a clear understanding of the physical principles that govern what we are observing in the imagery. Many of these physical principles have been known and understood for decades, if not hundreds of years. For this manual, the discussion will be limited to the critical elements that contribute to our understanding of remote sensing principles. If you should need further explanation, there are numerous works that expand upon the topics presented below (see Appendix A).

b. Summary of Electromagnetic Energy. Electromagnetic energy or radiation is derived from the subatomic vibrations of matter and is measured in a quantity known as wavelength. The units of wavelength are traditionally given as micrometers (μm) or nanometers (nm). Electromagnetic energy travels through space at the speed of light and can be absorbed and reflected by objects. To understand electromagnetic energy, it is necessary to discuss the origin of radiation, which is related to the temperature of the matter from which it is emitted.

c. Temperature. The origin of all energy (electromagnetic energy or radiant energy) begins with the vibration of subatomic particles called photons (Figure 2-2). All objects at a temperature above absolute zero vibrate and therefore emit some form of electromagnetic energy. Temperature is a measurement of this vibrational energy emitted from an object. Humans are sensitive to the thermal aspects of temperature; the higher the temperature is the greater is the sensation of heat. A “hot” object emits relatively large amounts of energy. Conversely, a “cold” object emits relatively little energy.

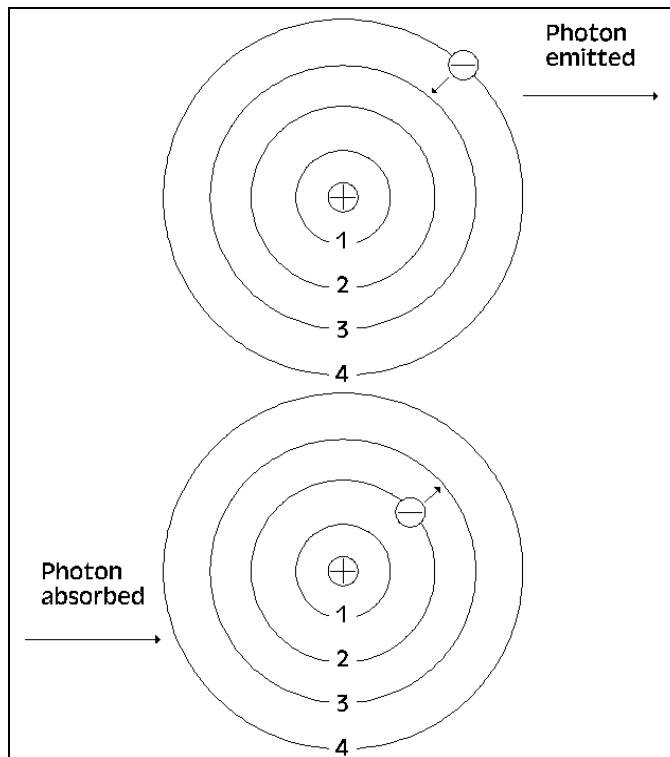


Figure 2-2. As an electron jumps from a higher to lower energy level, shown in top figure, a photon of energy is released. The absorption of photon energy by an atom allows electrons to jump from a lower to a higher energy state.

d. Absolute Temperature Scale. The lowest possible temperature has been shown to be -273.2°C and is the basis for the absolute temperature scale. The absolute temperature scale, known as Kelvin, is adjusted by assigning -273.2°C to 0 K (“zero Kelvin”); no de-

gree sign). The Kelvin scale has the same temperature intervals as the Celsius scale, so conversion between the two scales is simply a matter of adding or subtracting 273 (Table 2-1). Because all objects with temperatures above, or higher than, zero Kelvin emit electromagnetic radiation, it is possible to collect, measure, and distinguish energy emitted from adjacent objects.

Table 2-1
Different scales used to measure object temperature. Conversion formulas are listed below.

Object	Fahrenheit (°F)	Celsius (°C)	Kelvin (K)
Absolute Zero	-459.7	-273.2	0.0
Frozen Water	32.0	0.0	273.16
Boiling Water	212.0	100.0	373.16
Sun	9981.0	5527.0	5800.0
Earth	46.4	8.0	281.0
Human body	98.6	37.0	310.0

Conversion Formulas:

Celsius to Fahrenheit: $F^{\circ} = (1.8 \times C^{\circ}) + 32$

Fahrenheit to Celsius: $C^{\circ} = (F^{\circ} - 32)/1.8$

Celsius to Kelvin: $K = C^{\circ} + 273$

Fahrenheit to Kelvin: $K = [(F^{\circ} - 32)/1.8] + 273$

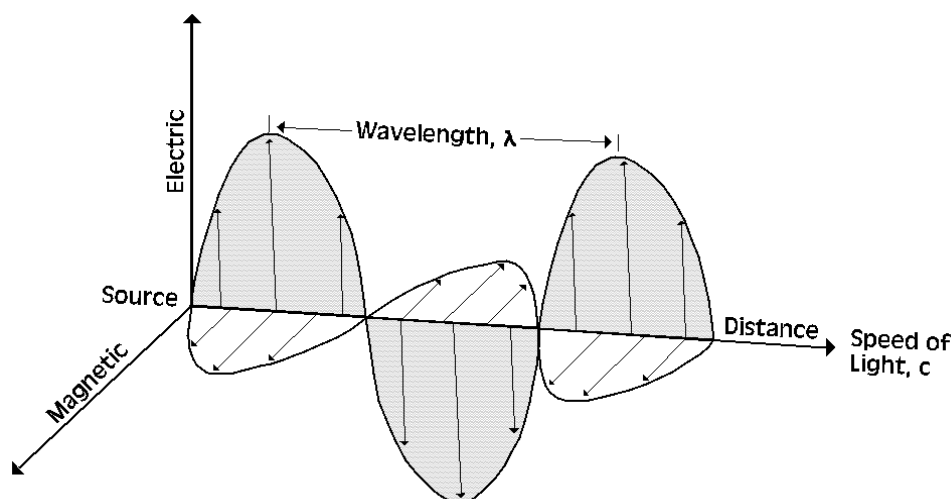


Figure 2-3. Propagation of the electromagnetic and magnetic field. Waves vibrate perpendicular to the direction of motion; electric and magnetic fields are at right angle to each other. These fields travel at the speed of light.

e. Nature of Electromagnetic Waves. Electromagnetic energy travels along the path of a sinusoidal wave (Figure 2-3). This wave of energy moves at the speed of light (3.00×10^8 m/s). All emitted and reflected energy travels at this rate, including light. Electromagnetic energy has two components, the electric and magnetic fields. This energy is defined by its wavelength (λ) and frequency (ν); see below for units. These fields are in-phase, perpendicular to one another, and oscillate normal to their direction of propagation (Figure 2-3). Familiar forms of radiant energy include X-rays, ultraviolet rays, visible

light, microwaves, and radio waves. All of these waves move and behave similarly; they differ only in radiation intensity.

f. Measurement of Electromagnetic Wave Radiation.

(1) *Wavelength.* Electromagnetic waves are measured from wave crest to wave crest or conversely from trough to trough. This distance is known as wavelength (λ or "lambda"), and is expressed in units of micrometers (μm) or nanometers (nm) (Figures 2-4 and 2-5).

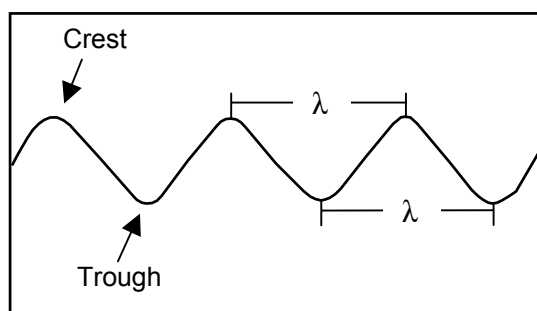


Figure 2-4. Wave morphology—wavelength (λ) is measured from crest-to-crest or trough-to-trough.

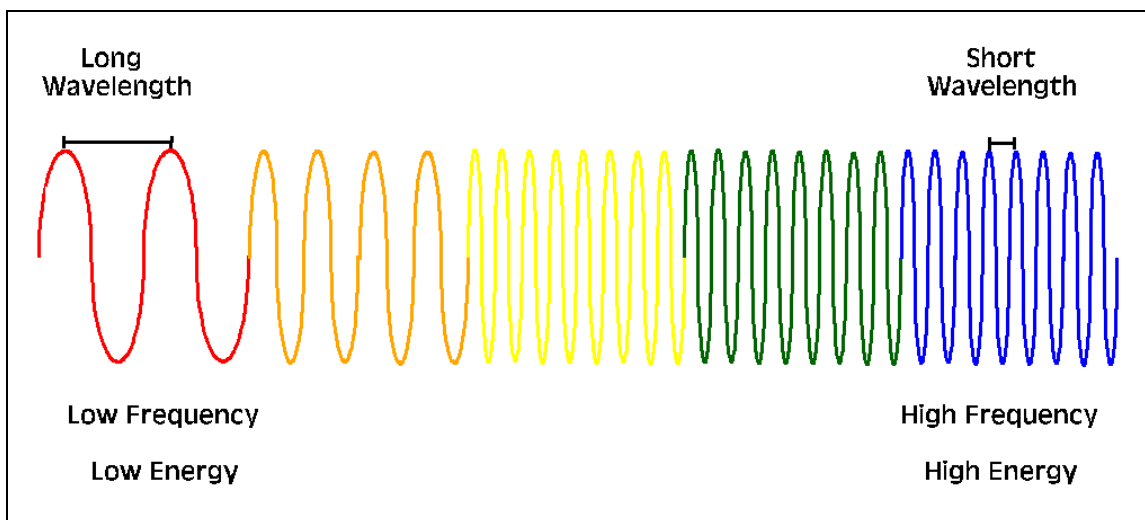


Figure 2-5. Long wavelengths maintain a low frequency and lower energy state relative to the short wavelengths.

(2) *Frequency.* The rate at which a wave passes a fixed point is known as the wave frequency and is denoted as ν ("nu"). The units of measurement for frequency are given as Hertz (Hz), the number of wave cycles per second (Figures 2-5 and 2-6).

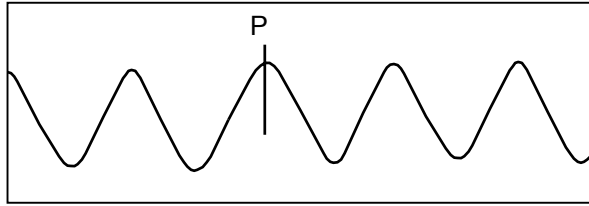


Figure 2-6. Frequency (ν) refers to the number of crests of waves of the same wavelength that pass by a point (P) in each second.

(3) *Speed of electromagnetic radiation (or speed of light).* Wavelength and frequency are inversely related to one another, in other words as one increases the other decreases. Their relationship is expressed as:

$$c = \lambda \nu \quad (2-1)$$

where

$c = 3.00 \times 10^8$ m/s, the speed of light

λ = the wavelength (m)

ν = frequency (cycles/second, Hz).

This mathematical expression also indicates that wavelength (λ) and frequency (ν) are both proportional to the speed of light (c). Because the speed of light (c) is constant, radiation with a small wavelength will have a high frequency; conversely, radiation with a large wavelength will have a low frequency.

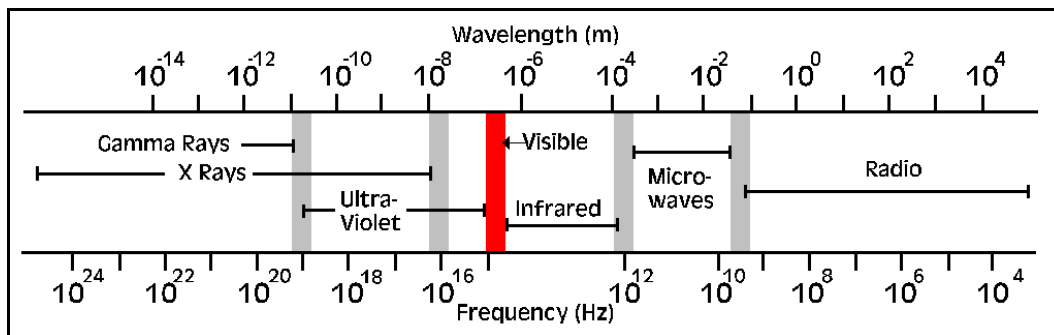


Figure 2-7. Electromagnetic spectrum displayed in meter and Hz units. Short wavelengths are shown on the left, long wavelength on the right. The visible spectrum shown in red.

g. Electromagnetic Spectrum. Electromagnetic radiation wavelengths are plotted on a logarithmic scale known as the electromagnetic spectrum. The plot typically increases in increments of powers of 10 (Figure 2-7). For convenience, regions of the electromagnetic spectrum are categorized based for the most part on methods of sensing their wavelengths. For example, the visible light range is a category spanning 0.4–0.7 μm . The

minimum and maximum of this category is based on the ability of the human eye to sense radiation energy within the 0.4- to 0.7- μm wavelength range.

(1) Though the spectrum is divided up for convenience, it is truly a continuum of increasing wavelengths with no inherent differences among the radiations of varying wavelengths. For instance, the scale in Figure 2-8 shows the color blue to be approximately in the range of 435 to 520 nm (on other scales it is divided out at 446 to 520 nm). As the wavelengths proceed in the direction of green they become increasingly less blue and more green; the boundary is somewhat arbitrarily fixed at 520 nm to indicate this gradual change from blue to green.

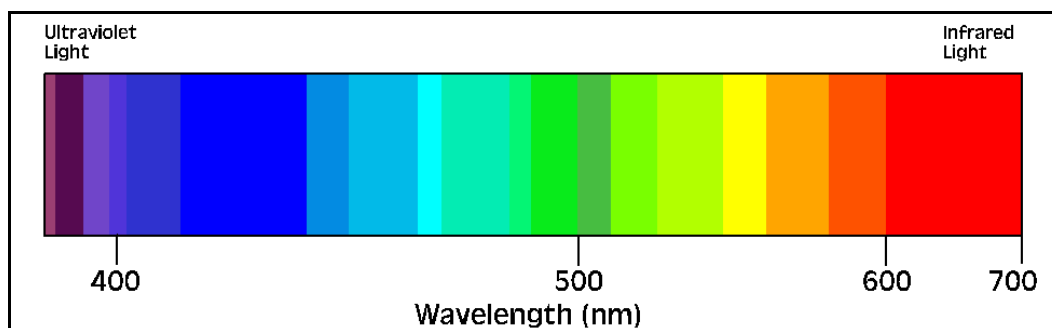


Figure 2-8. Visible spectrum illustrated here in color.

(2) Be aware of differences in the manner in which spectrum scales are drawn. Some authors place the long wavelengths to the right (such as those shown in this manual), while others place the longer wavelengths to the left. The scale can also be drawn on a vertical axis (Figure 2-9). Units can be depicted in meters, nanometers, micrometers, or a combination of these units. For clarity some authors add color in the visible spectrum to correspond to the appropriate wavelength.

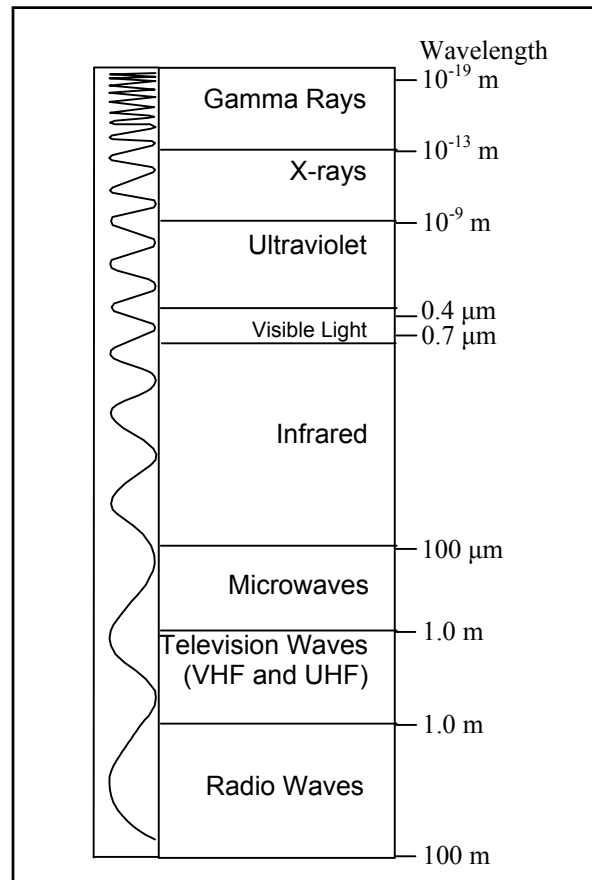


Figure 2-9. Electromagnetic spectrum on a vertical scale.

h. Regions of the Electromagnetic Spectrum. Different regions of the electromagnetic spectrum can provide discrete information about an object. The categories of the electromagnetic spectrum represent groups of measured electromagnetic radiation with similar wavelength and frequency. Remote sensors are engineered to detect specific spectrum wavelength and frequency ranges. Most sensors operate in the visible, infrared, and microwave regions of the spectrum. The following paragraphs discuss the electromagnetic spectrum regions and their general characteristics and potential use (also see Appendix B). The spectrum regions are discussed in order of increasing wavelength and decreasing frequency.

(1) *Ultraviolet.* The ultraviolet (UV) portion of the spectrum contains radiation just beyond the violet portion of the visible wavelengths. Radiation in this range has short wavelengths (0.300 to 0.446 μm) and high frequency. UV wavelengths are used in geologic and atmospheric science applications. Materials, such as rocks and minerals, fluoresce or emit visible light in the presence of UV radiation. The fluorescence associated with natural hydrocarbon seeps is useful in monitoring oil fields at sea. In the upper at-

mosphere, ultraviolet light is greatly absorbed by ozone (O₃) and becomes an important tool in tracking changes in the ozone layer.

(2) *Visible Light.* The radiation detected by human eyes is in the spectrum range aptly named the visible spectrum. Visible radiation or light is the only portion of the spectrum that can be perceived as colors. These wavelengths span a very short portion of the spectrum, ranging from approximately 0.4 to 0.7 μm . Because of this short range, the visible portion of the spectrum is plotted on a linear scale (Figure 2-8). This linear scale allows the individual colors in the visible spectrum to be discretely depicted. The shortest visible wavelength is violet and the longest is red.

(a) The visible colors and their corresponding wavelengths are listed below (Table 2-2) in micrometers and shown in nanometers in Figure 2.8.

Table 2-2	
Wavelengths of the primary colors of the visible spectrum	
Color	Wavelength
Violet	0.4–0.446 μm
Blue	0.446–0.500 μm
Green	0.500–0.578 μm
Yellow	0.578–0.592 μm
Orange	0.592–0.620 μm
Red	0.620–0.7 μm

(b) Visible light detected by sensors depends greatly on the surface reflection characteristics of objects. Urban feature identification, soil/vegetation discrimination, ocean productivity, cloud cover, precipitation, snow, and ice cover are only a few examples of current applications that use the visible range of the electromagnetic spectrum.

(3) *Infrared.* The portion of the spectrum adjacent to the visible range is the infrared (IR) region. The infrared region, plotted logarithmically, ranges from approximately 0.7 to 100 μm , which is more than 100 times as wide as the visible portion. The infrared region is divided into two categories, the reflected IR and the emitted or thermal IR; this division is based on their radiation properties.

(a) *Reflected Infrared.* The reflected IR spans the 0.7- to 3.0- μm wavelengths. Reflected IR shares radiation properties exhibited by the visible portion and is thus used for similar purposes. Reflected IR is valuable for delineating healthy verses unhealthy or fallow vegetation, and for distinguishing among vegetation, soil, and rocks.

(b) *Thermal Infrared.* The thermal IR region represents the radiation that is emitted from the Earth's surface in the form of thermal energy. Thermal IR spans the 3.0- to 100- μm range. These wavelengths are useful for monitoring temperature variations in land, water, and ice.

(4) *Microwave.* Beyond the infrared is the microwave region, ranging on the spectrum from 1 μm to 1 m (bands are listed in Table 2-3). Microwave radiation is the longest

wavelength used for remote sensing. This region includes a broad range of wavelengths; on the short wavelength end of the range, microwaves exhibit properties similar to the thermal IR radiation, whereas the longer wavelengths maintain properties similar to those used for radio broadcasts.

Table 2-3
Wavelengths of various bands in the microwave range

Band	Frequency (MHz)	Wavelength (cm)
Ka	40,000–26,000	0.8–1.1
K	26,500–18,500	1.1–1.7
X	12,500–8000	2.4–3.8
C	8000–4000	3.8–7.5
L	2000–1000	15.0–30.0
P	1000–300	30.0–100.0

(a) Microwave remote sensing is used in the studies of meteorology, hydrology, oceans, geology, agriculture, forestry, and ice, and for topographic mapping. Because microwave emission is influenced by moisture content, it is useful for mapping soil moisture, sea ice, currents, and surface winds. Other applications include snow wetness analysis, profile measurements of atmospheric ozone and water vapor, and detection of oil slicks.

(b) For more information on spectrum regions, see Appendix B.

i. *Energy as it Relates to Wavelength, Frequency, and Temperature.* As stated above, energy can be quantified by its wavelength and frequency. It is also useful to measure the intensity exhibited by electromagnetic energy. Intensity can be described by Q and is measured in units of Joules.

(1) *Quantifying Energy.* The energy released from a radiating body in the form of a vibrating photon traveling at the speed of light can be quantified by relating the energy's wavelength with its frequency. The following equation shows the relationship between wavelength, frequency, and amount of energy in units of Joules:

$$Q = h \nu \quad (2-2)$$

Because $c = \lambda \nu$, Q also equals

$$Q = h c / \lambda$$

where

- Q = energy of a photon in Joules (J)
- h = Planck's constant (6.6×10^{-34} J s)
- c = 3.00×10^8 m/s, the speed of light
- λ = wavelength (m)
- ν = frequency (cycles/second, Hz).

The equation for energy indicates that, for long wavelengths, the amount of energy will be low, and for short wavelengths, the amount of energy will be high. For instance, blue light is on the short wavelength end of the visible spectrum (0.446 to 0.050 μm) while red is on the longer end of this range (0.620 to 0.700 μm). Blue light is a higher energy radiation than red light. The following example illustrates this point:

Example: Using $Q = h c/\lambda$, which has more energy blue or red light?

Solution: Solve for Q_{blue} (energy of blue light) and Q_{red} (energy of red light) and compare.

Calculation: $\lambda_{\text{blue}}=0.425 \mu\text{m}$, $\lambda_{\text{red}}=0.660 \mu\text{m}$ (From Table 2-2)

$$h = 6.6 \times 10^{-34} \text{ J s}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

* Don't forget to convert length μm to meters (not shown here)

Blue

$$Q_{\text{blue}} = 6.6 \times 10^{-34} \text{ J s } (3.00 \times 10^8 \text{ m/s}) / 0.425 \mu\text{m}$$

$$Q_{\text{blue}} = 4.66 \times 10^{-31} \text{ J}$$

Red

$$Q_{\text{red}} = 6.6 \times 10^{-34} \text{ J seconds } (3.00 \times 10^8 \text{ m/s}) / 0.660 \mu\text{m}$$

$$Q_{\text{red}} = 3.00 \times 10^{-31} \text{ J}$$

Answer: Because $4.66 \times 10^{-31} \text{ J}$ is greater than $3.00 \times 10^{-31} \text{ J}$ *blue* has more energy.

This explains why the blue portion of a fire is hotter than the red portions.

(2) *Implications for Remote Sensing.* The relationship between energy and wavelengths has implications for remote sensing. For example, in order for a sensor to detect low energy microwaves (which have a large λ), it will have to remain fixed over a site for a relatively long period of time, known as dwell time. Dwell time is critical for the collection of an adequate amount of radiation. Conversely, low energy microwaves can be detected by “viewing” a larger area to obtain a detectable microwave signal. The latter is typically the solution for collecting lower energy microwaves.

j. Black Body Emission. Energy emitted from an object is a function of its surface temperature (refer to Paragraph 2-4c and d). An idealized object called a black body is used to model and approximate the electromagnetic energy emitted by an object. A black body completely absorbs and re-emits all radiation incident (striking) to its surface. A black body emits electromagnetic radiation at all wavelengths if its temperature is above 0 Kelvin. The Wien and Stefan-Boltzmann Laws explain the relationship between temperature, wavelength, frequency, and intensity of energy.

(1) *Wien's Displacement Law*. In Equation 2-2 wavelength is shown to be an inverse function of energy. It is also true that wavelength is inversely related to the temperature of the source. This is explained by Wein's displacement law (Equation 2-3):

$$L_m = A/T \quad (2-3)$$

where

$$\begin{aligned} L_m &= \text{maximum wavelength} \\ A &= 2898 \mu\text{m Kelvin} \\ T &= \text{temperature Kelvin emitted from the object.} \end{aligned}$$

Using this formula (Equation 2-3), we can determine the temperature of an object by measuring the wavelength of its incoming radiation.

Example: Using $L_m = A/T$, what is the maximum wavelength emitted by a human?

Solution: Solve for L_m given T from Table 2-1

Calculation: $T = 98.6^\circ\text{C}$ or 310 K (From Table 2-1)
 $A = 2898 \mu\text{m Kelvin}$

$$L_m = 2898 \mu\text{m K}/310\text{K}$$

$$L_m = 9.3 \mu\text{m}$$

Answer: Humans emit radiation at a maximum wavelength of $9.3 \mu\text{m}$; this is well beyond what the eye is capable of seeing. Humans can see in the visible part of the electromagnetic spectrum at wavelengths of $0.4\text{--}0.7\mu\text{m}$.

(2) *The Stefan-Boltzmann Law*. The Stefan-Boltzmann Law states that the total energy radiated by a black body per volume of time is proportional to the fourth power of temperature. This can be represented by the following equation:

$$M = \sigma T^4 \quad (2-4)$$

where

$$\begin{aligned} M &= \text{radiant surface energy in watts (w)} \\ \sigma &= \text{Stefan-Boltzmann constant } (5.6697 \times 10^{-8} \text{ w/m}^2\text{K}^4) \\ T &= \text{temperature in Kelvin emitted from the object.} \end{aligned}$$

This simply means that the total energy emitted from an object rapidly increases with only slight increases in temperature. Therefore, a hotter black body emits more radiation at each wavelength than a cooler one (Figure 2-10).

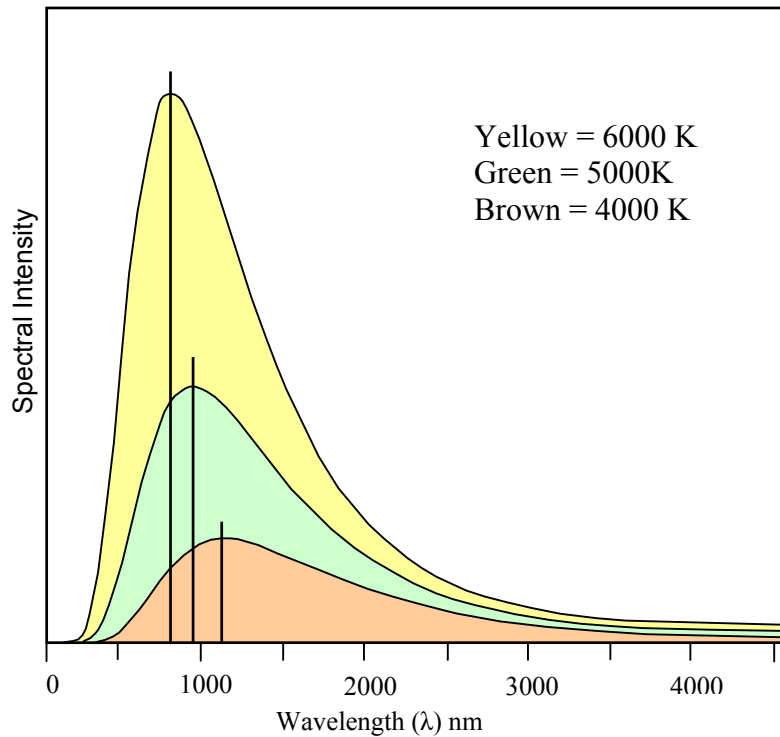


Figure 2-10. Spectral intensity of different emitted temperatures. The horizontal axis is wavelength in nm and the vertical axis is spectral intensity. The vertical bars denote the peak intensity for the temperatures presented. These peaks indicate a shift toward higher energies (lower wavelengths) with increasing temperatures. Modified from <http://rst.gsfc.nasa.gov/Front/overview.html>.

(3) *Summary.* Together, the Wien and Stefan-Boltzmann Laws are powerful tools. From these equations, temperature and radiant energy can be determined from an object's emitted radiation. For example, ocean water temperature distribution can be mapped by measuring the emitted radiation; discrete temperatures over a forest canopy can be detected; and surface temperatures of distant solar system objects can be estimated.

k. The Sun and Earth as Black Bodies. The Sun's surface temperature is 5800 K; at that temperature much of the energy is radiated as visible light (Figure 2-11). We can therefore see much of the spectra emitted from the sun. Scientists speculate the human eye has evolved to take advantage of the portion of the electromagnetic spectrum most readily available (i.e., sunlight). Also, note from the figure the Earth's emitted radiation peaks between 6 to 16 μm ; to "see" these wavelengths one must use a remote sensing detector.

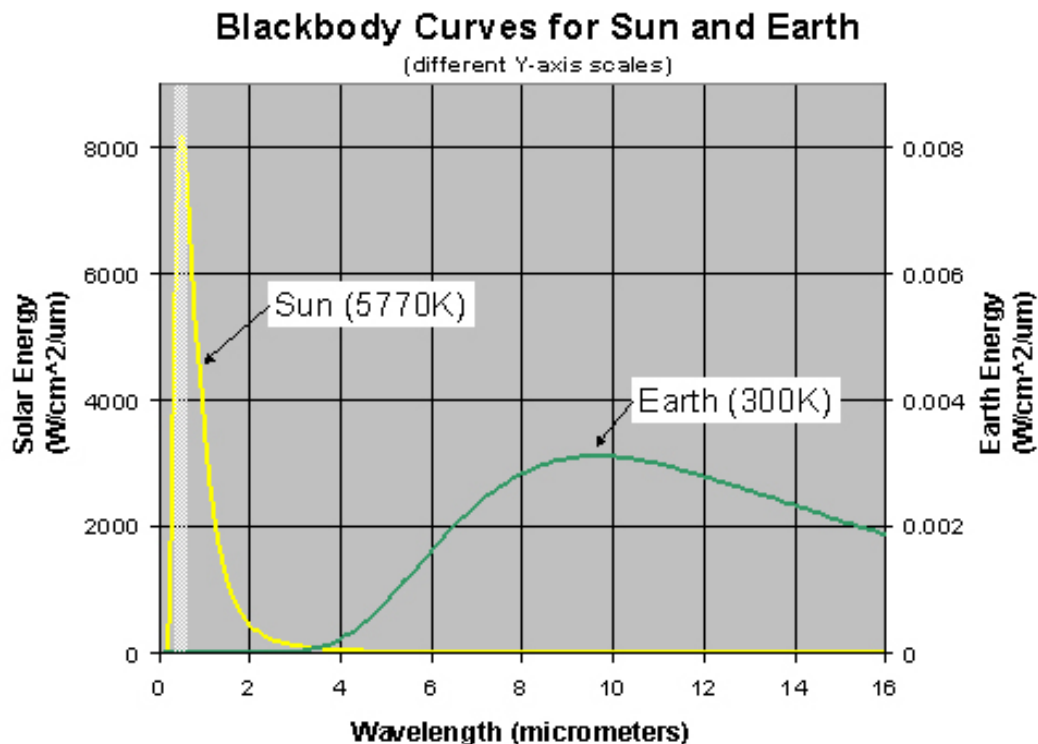


Figure 2-11. The Sun and Earth both emit electromagnetic radiation. The Sun's temperature is approximately 5770 Kelvin, the Earth's temperature is centered on 300 Kelvin.

1. Passive and Active Sources. The energy referred to above is classified as passive energy. Passive energy is emitted directly from a natural source. The Sun, rocks, ocean, and humans are all examples of passive sources. Remote sensing instruments are capable of collecting energy from both passive and active sources (Figure 2-1; path B). Active energy is energy generated and transmitted from the sensor itself. A familiar example of an active source is a camera with a flash. In this example visible light is emitted from a flash to illuminate an object. The reflected light from the object being photographed will return to the camera where it is recorded onto film. Similarly, active radar sensors transmit *their own* microwave energy to the surface terrain; the strength of energy returned to the sensor is recorded as representing the surface interaction. The Earth and Sun are the most common sources of energy used in remote sensing.

2-5 Component 2: Interaction of Electromagnetic Energy With Particles in the Atmosphere.

a. Atmospheric Effects. Remote sensing requires that electromagnetic radiation travel some distance through the Earth's atmosphere from the source to the sensor. Radiation from the Sun or an active sensor will initially travel through the atmosphere, strike the ground target, and pass through the atmosphere a second time before it reaches a sensor

(Figure 2-1; path B). The total distance the radiation travels in the atmosphere is called the path length. For electromagnetic radiation emitted from the Earth, the path length will be half the path length of the radiation from the sun or an active source.

(1) As radiation passes through the atmosphere, it is greatly affected by the atmospheric particles it encounters (Figure 2-12). This effect is known as atmospheric scattering and atmospheric absorption and leads to changes in intensity, direction, and wavelength size. The change the radiation experiences is a function of the atmospheric conditions, path length, composition of the particle, and the wavelength measurement relative to the diameter of the particle.

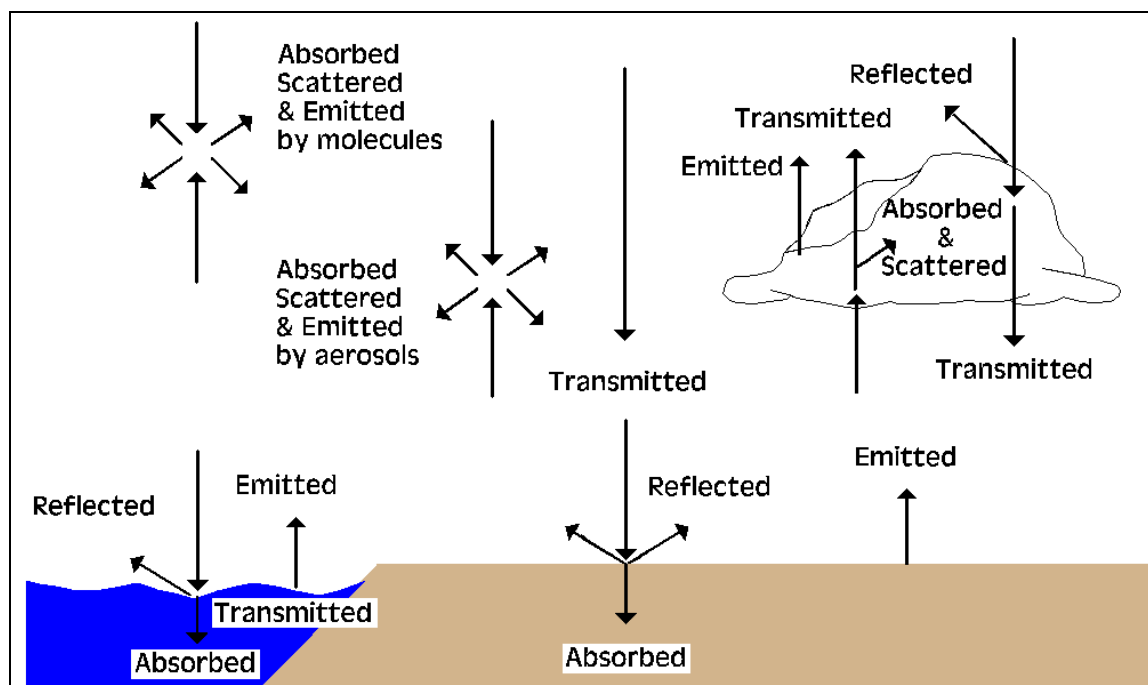


Figure 2-12. Various radiation obstacles and scatter paths. Modified from two sources, <http://orbit-net.nesdis.noaa.gov/arad/fpdt/tutorial/12-atmra.gif> and http://rst.gsfc.nasa.gov/Intro/Part2_4.html.

(2) Rayleigh scattering, Mie scattering, and nonselective scattering are three types of scatter that occur as radiation passes through the atmosphere (Figure 2-12). These types of scatter lead to the redirection and diffusion of the wavelength in addition to making the path of the radiation longer.

b. Rayleigh Scattering. Rayleigh scattering dominates when the diameter of atmospheric particles are much smaller than the incoming radiation wavelength ($\phi < \lambda$). This leads to a greater amount of short wavelength scatter owing to the small particle size of atmospheric gases. Scattering is inversely proportional to wavelength by the 4th power, or...

$$\text{Rayleigh Scatter} = 1/\lambda^4 \quad (2-5)$$

where λ is the wavelength (m). This means that short wavelengths will undergo a large amount of scatter, while large wavelengths will experience little scatter. Smaller wavelength radiation reaching the sensor will appear more diffuse.

c. *Why the sky is blue?* Rayleigh scattering accounts for the Earth's blue sky. We see predominately blue because the wavelengths in the blue region (0.446–0.500 μm) are more scattered than other spectra in the visible range. At dusk, when the sun is low in the horizon creating a longer path length, the sky appears more red and orange. The longer path length leads to an increase in Rayleigh scatter and results in the depletion of the blue wavelengths. Only the longer red and orange wavelengths will reach our eyes, hence beautiful orange and red sunsets. In contrast, our moon has no atmosphere; subsequently, there is no Rayleigh scatter. This explains why the moon's sky appears black (shadows on the moon are more black than shadows on the Earth for the same reason, see Figure 2-13).

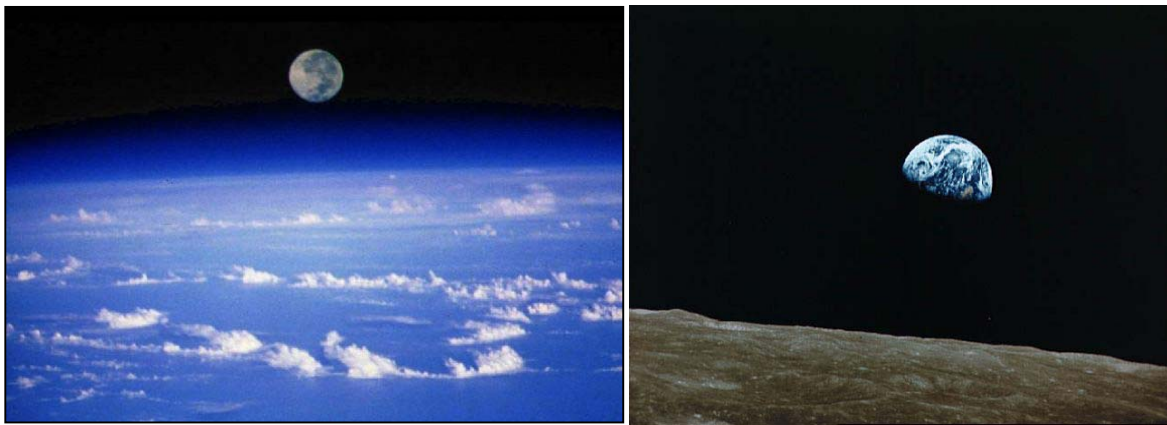


Figure 2-13. Moon rising in the Earth's horizon (left). The Earth's atmosphere appears blue due to Rayleigh Scatter. Photo taken from the moon's surface shows the Earth rising (right). The Moon has no atmosphere, thus no atmospheric scatter. Its sky appears black. Images taken from: <http://antwrp.gsfc.nasa.gov/apod/ap001028.html>, and <http://antwrp.gsfc.nasa.gov/apod/ap001231.html>.

d. *Mie Scattering.* Mie scattering occurs when an atmospheric particle diameter is equal to the radiation's wavelength ($\phi = \lambda$). This leads to a greater amount of scatter in the long wavelength region of the spectrum. Mie scattering tends to occur in the presence of water vapor and dust and will dominate in overcast or humid conditions. This type of scattering explains the reddish hues of the sky following a forest fire or volcanic eruption.

e. *Nonselective Scattering.* Nonselective scattering dominates when the diameter of atmospheric particles (5–100 μm) is much larger than the incoming radiation wavelength ($\phi \gg \lambda$). This leads to the scatter of visible, near infrared, and mid-infrared. All these wavelengths are equally scattered and will combine to create a white appearance in the sky; this is why clouds appear white (Figure 2-14).



Figure 2-14. Non-selective scattering by larger atmospheric particles (like water droplets) affects all wavelengths, causing white clouds.

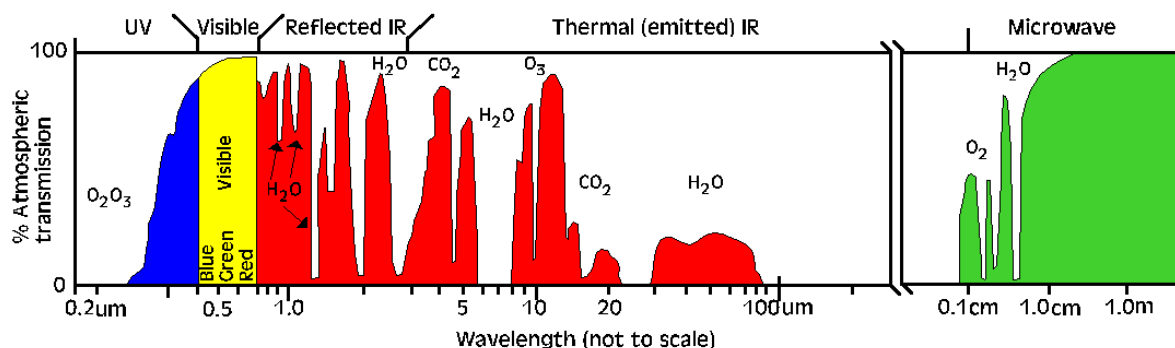


Figure 2-15. Atmospheric windows with wavelength on the x-axis and percent transmission measured in hertz on the y-axis. High transmission corresponds to an “atmospheric window,” which allows radiation to penetrate the Earth’s atmosphere. The chemical formula is given for the molecule responsible for sunlight absorption at particular wavelengths across the spectrum. Modified from http://earthobservatory.nasa.gov:81/Library/RemoteSensing/remote_04.html.

f. Atmospheric Absorption and Atmospheric Windows. Absorption of electromagnetic radiation is another mechanism at work in the atmosphere. This phenomenon occurs as molecules absorb radiant energy at various wavelengths (Figure 2-12). Ozone (O_3), carbon dioxide (CO_2), and water vapor (H_2O) are the three main atmospheric compounds that absorb radiation. Each gas absorbs radiation at a particular wavelength. To a lesser extent, oxygen (O_2) and nitrogen dioxide (NO_2) also absorb radiation (Figure 2-15). Be-

low is a summary of these three major atmospheric constituents and their significance in remote sensing.

g. The role of atmospheric compounds in the atmosphere.

(1) *Ozone.* Ozone (O₃) absorbs harmful ultraviolet radiation from the sun. Without this protective layer in the atmosphere, our skin would burn when exposed to sunlight.

(2) *Carbon Dioxide.* Carbon dioxide (CO₂) is called a greenhouse gas because it greatly absorbs thermal infrared radiation. Carbon dioxide thus serves to trap heat in the atmosphere from radiation emitted from both the Sun and the Earth.

(3) *Water vapor.* Water vapor (H₂O) in the atmosphere absorbs incoming long-wave infrared and shortwave microwave radiation (22 to 1 μm). Water vapor in the lower atmosphere varies annually from location to location. For example, the air mass above a desert would have very little water vapor to absorb energy, while the tropics would have high concentrations of water vapor (i.e., high humidity).

(4) *Summary.* Because these molecules absorb radiation in very specific regions of the spectrum, the engineering and design of spectral sensors are developed to collect wavelength data not influenced by atmospheric absorption. The areas of the spectrum that are not severely influenced by atmospheric absorption are the most useful regions, and are called atmospheric windows.

h. Summary of Atmospheric Scattering and Absorption. Together atmospheric scatter and absorption place limitations on the spectra range useful for remote sensing. Table 2-4 summarizes the causes and effects of atmospheric scattering and absorption due to atmospheric effects.

i. Spectrum Bands. By comparing the characteristics of the radiation in atmospheric windows (Figure 2-15; areas where reflectance on the y-axis is high), groups or bands of wavelengths have been shown to effectively delineate objects at or near the Earth's surface. The visible portion of the spectrum coincides with an atmospheric window, and the maximum emitted energy from the Sun. Thermal infrared energy emitted by the Earth corresponds to an atmospheric window around 10 μm, while the large window at wavelengths larger than 1 mm is associated with the microwave region (Figure 2-16).

Table 2-4
Properties of Radiation Scatter and Absorption in the Atmosphere

Atmospheric Scattering	Diameter (φ) of particle relative to incoming wavelength (λ)	Result
Rayleigh scattering	$\phi < \lambda$	Short wavelengths are scattered
Mie scattering	$\phi = \lambda$	Long wavelengths are scattered
Nonselective scattering	$\phi > \lambda$	All wavelengths are equally scattered
Absorption	No relationship	CO ₂ , H ₂ O, and O ₃ remove wavelengths

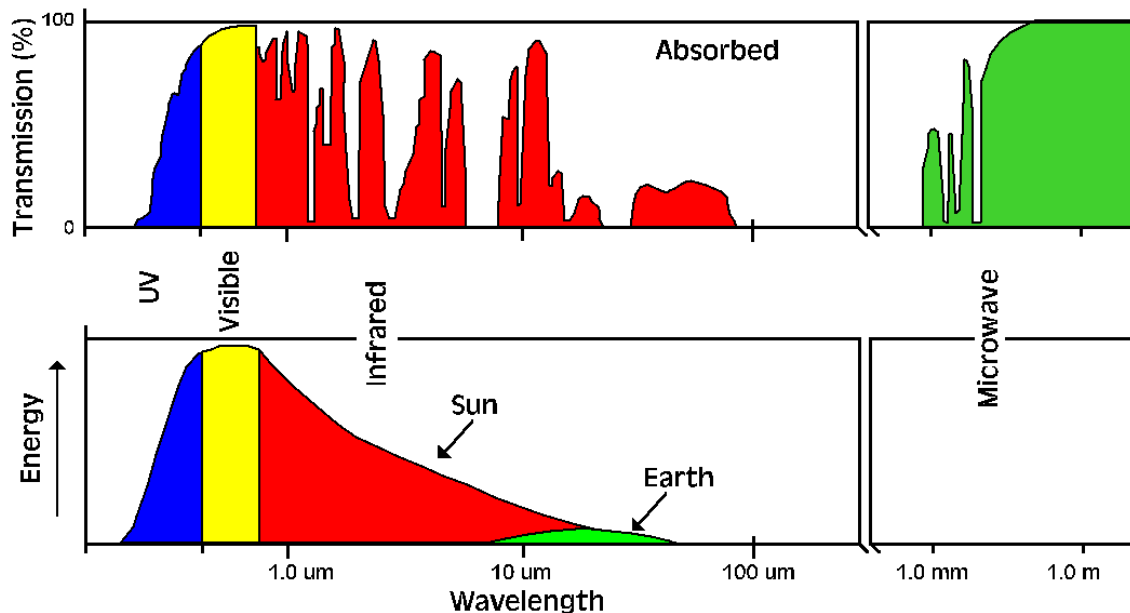


Figure 2-16. Atmospheric windows related to the emitted energy supplied by the sun and the Earth. Notice that the sun's maximum output (shown in yellow) coincides with an atmospheric window in the visible range of the spectrum. This phenomenon is important in optical remote sensing. Modified from

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter1/chapter1_4_e.html.

j. Geometric Effects. Random and non-random error occurs during the acquisition of radiation data. Error can be attributed to such causes as sun angle, angle of sensor, elevation of sensor, skew distortion from the Earth's rotation, and path length. Malfunctions in the sensor as it collects data and the motion of the platform are additional sources of error. As the sensor collects data, it can develop sweep irregularities that result in hundreds of meters of error. The pitch, roll, and yaw of platforms can create hundreds to thousands of meters of error, depending on the altitude and resolution of the sensor. Geometric corrections are typically applied by re-sampling an image, a process that shifts and recalculates the data. The most commonly used re-sampling techniques include the use of ground control points (see Chapter 5), applying a mathematical model, or re-sampling by nearest neighbor or cubic convolution.

k. Atmospheric and Geometric Corrections. Data correction is required for calculating reflectance values from radiance values (see Equation 2-5 below) recorded at a sensor and for reducing positional distortion caused by known sensor error. It is extremely important to make corrections when comparing one scene with another and when performing a temporal analysis. Corrected data can then be evaluated in relation to a spectral data library (see Paragraph 2-6b) to compare an object to its standard. Corrections are not necessary if objects are to be distinguished by relative comparisons within an individual scene.

l. Atmospheric Correction Techniques. Data can be corrected by re-sampling with the use of image processing software such as ERDAS Imagine or ENVI, or by the use of specialty software. In many of the image processing software packages, atmospheric correction models are included as a component of an import process. Also, data may have some corrections applied by the vendor. When acquiring data, it is important to be aware of any corrections that may have been applied to the data (see Chapter 4). Correction models can be mathematically or empirically derived.

m. Empirical Modeling Corrections. Measured or empirical data collected on the ground at the time the sensor passes overhead allows for a comparison between ground spectral reflectance measurements and sensor radiation reflectance measurements. Typical data collection includes spectral measurements of selected objects within a scene as well as a sampling of the atmospheric properties that prevailed during sensor acquisition. The empirical data are then compared with image data to interpolate an appropriate correction. Empirical corrections have many limitations, including cost, spectral equipment availability, site accessibility, and advanced preparation. It is critical to time the field spectral data collection to coincide with the same day and time the satellite collects radiation data. This requires knowledge of the satellite's path and revisit schedule. For archived data it is impossible to collect the field spectral measurements needed for developing an empirical model that will correct atmospheric error. In such a case, a mathematical model using an estimate of the field parameters must complete the correction.

n. Mathematical Modeling Corrections. Alternatively, corrections that are mathematically derived rely on estimated atmospheric parameters from the scene. These parameters include visibility, humidity, and the percent and type of aerosols present in the atmosphere. Data values or ratios are used to determine the atmospheric parameters. Subsequently a mathematical model is extracted and applied to the data for re-sampling. This type of modeling can be completed with the aid of software programs such as 6S, MODTRAN, and ATREM (see <http://atol.ucsd.edu/~pflatau/rtelib/> for a list and description of correction modeling software).

2-6 Component 3: Electromagnetic Energy Interacts with Surface and Near Surface Objects.

a. Energy Interactions with the Earth's Surface. Electromagnetic energy that reaches a target will be absorbed, transmitted, and reflected. The proportion of each depends on the composition and texture of the target's surface. Figure 2-17 illustrates these three interactions. Much of remote sensing is concerned with reflected energy.

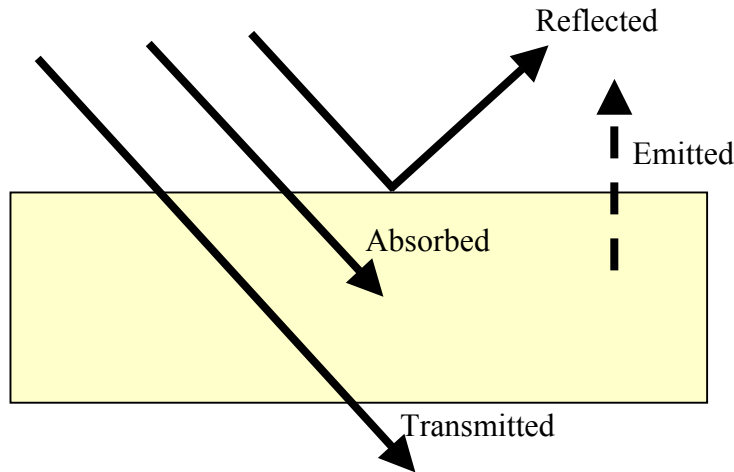


Figure 2-17. Radiation striking a target is reflected, absorbed, or transmitted through the medium. Radiation is also emitted from ground targets.

(1) *Absorption.* Absorption occurs when radiation penetrates a surface and is incorporated into the molecular structure of the object. All objects absorb incoming incident radiation to some degree. Absorbed radiation can later be emitted back to the atmosphere. Emitted radiation is useful in thermal studies, but will not be discussed in detail in this work (see Lillisand and Keifer [1994] *Remote Sensing and Image Interpretation* for information on emitted energy).

(2) *Transmission.* Transmission occurs when radiation passes through material and exits the other side of the object. Transmission plays a minor role in the energy's interaction with the target. This is attributable to the tendency for radiation to be absorbed before it is entirely transmitted. Transmission is a function of the properties of the object.

(3) *Reflection.* Reflection occurs when radiation is neither absorbed nor transmitted. The reflection of the energy depends on the properties of the object and surface roughness relative to the wavelength of the incident radiation. Differences in surface properties allow the distinction of one object from another.

(a) Absorption, transmission, and reflection are related to one another by

$$E_I = E_A + E_T + E_R \quad (2-6)$$

where

- E_I = incident energy striking an object
- E_A = absorbed radiation
- E_T = transmitted energy
- E_R = reflected energy.

(b) The amount of each interaction will be a function of the incoming wavelength, the composition of the material, and the smoothness of the surface.

(4) *Reflectance of Radiation.* Reflectance is simply a measurement of the percentage of incoming or incident energy that a surface reflects

$$\text{Reflectance} = \text{Reflected energy} / \text{Incident energy} \quad (2-7)$$

where incident energy is the amount of incoming radiant energy and reflected energy is the amount of energy bouncing off the object. Or from equation 2-5:

$$E_I = E_A + E_T + E_R$$

$$\text{Reflectance} = E_R / E_I \quad (2-8)$$

Reflectance is a fixed characteristic of an object. Surface features can be distinguished by comparing the reflectance of different objects at each wavelength. Reflectance comparisons rely on the unchanging proportion of reflected energy relative to the sum of incoming energy. This permits the distinction of objects regardless of the amount of incident energy. Unique objects reflect differently, while similar objects only reflect differently if there has been a physical or chemical change. **Note:** reflectance is not the same as reflection.

Specular and diffuse reflection

The nature of reflectance is controlled by the wavelength of the radiation relative to the surface texture. Surface texture is defined by the roughness or bumpiness of the surface relative to the wavelength. Objects display a range of reflectance from diffuse to specular. Specular reflectance is a mirror-like reflection, which occurs when an object with a smooth surface reflects in one direction. The incoming radiation will reflect off a surface at the same angle of incidence (Figure 2-18). Diffuse or Lambertian reflectance reflects in all directions owing to a rough surface. This type of reflectance gives the most information about an object.

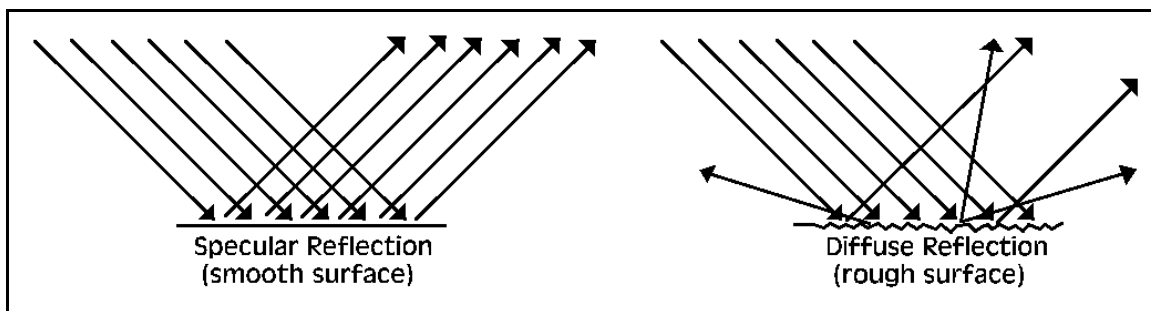


Figure 2-18. Specular reflection or mirror-like reflection (left) and diffuse reflection (right).

(5) *Spectral Radiance*. As reflected energy radiates away from an object, it moves in a hemi-spherical path. The sensor measures only a small portion of the reflected radiation—the portion along the path between the object and the sensor (Figure 2-19). This measured radiance is known as the spectral radiance (Equation 2-9).

$$I = \text{Reflected radiance} + \text{Emitted radiance}$$

2-9

where I = radiant intensity in watts per steradian (W sr^{-1}). (Steradian is the unit of cone angle, abbreviated sr, 1 sr equals 4π . See the following for more details on steradian.)

http://whatis.techtarget.com/definition/0%2C%2Csid9_gci528813%2C00.html

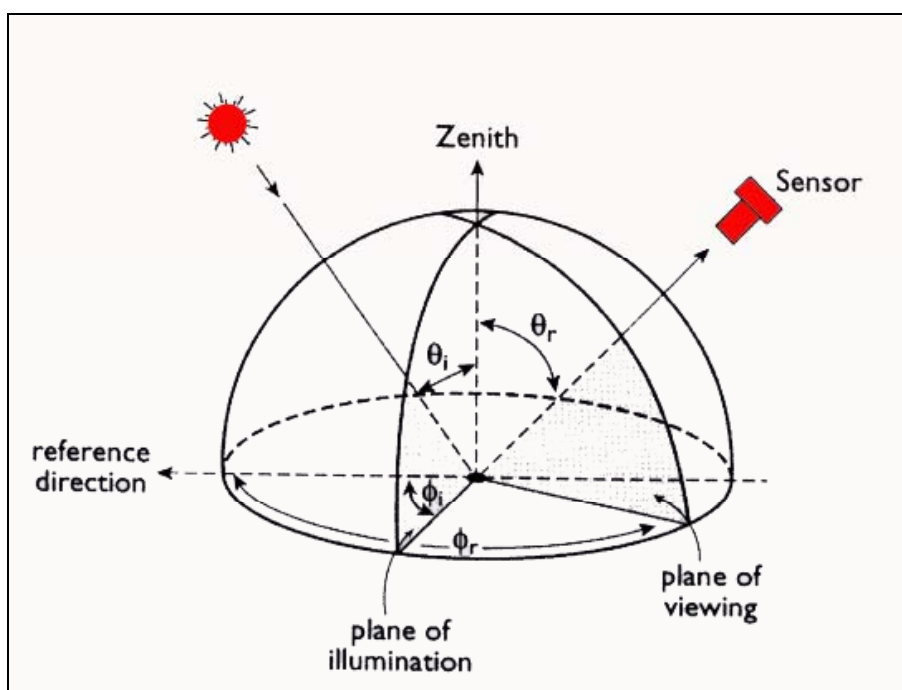


Figure 2-19. Diffuse reflection of radiation from a single target point. Radiation moves outward in a hemispherical path. Notice the sensor only samples radiation from a single vector. Modified after http://rst.gsfc.nasa.gov/Intro/Part2_3html.html.

(6) *Summary.* Spectral radiance is the amount of energy received at the sensor per time, per area, in the direction of the sensor (measured in steradian), and it is measured per wavelength. The sensor therefore measures the fraction of reflectance for a given area/time for every wavelength as well as the emitted. Reflected and emitted radiance is calculated by the integration of energy over the reflected hemisphere resulting from diffuse reflection (see <http://rsd.gsfc.nasa.gov/goes/text/reflectance.pdf> for details on this complex calculation). Reflected radiance is orders of magnitude greater than emitted radiance. The following paragraphs, therefore, focus on reflected radiance.

b. Spectral Reflectance Curves.

(1) Background.

(a) Remote sensing consists of making spectral measurements over space: how much of what “color” of light is coming from what place on the ground. One thing that a remote sensing applications scientist hopes for, but which is not always true, is that surface features of interest will have different colors so that they will be distinct in remote sensing data.

(b) A surface feature’s color can be characterized by the *percentage* of incoming electromagnetic energy (illumination) it reflects at each wavelength across the electromagnetic spectrum. This is its spectral reflectance curve or “spectral signature”; it is an unchanging property of the material. For example, an object such as a leaf may reflect 3% of incoming blue light, 10% of green light and 3% of red light. The amount of light it reflects depends on the amount and wavelength of incoming illumination, but the percents are constant. Unfortunately, remote sensing instruments do not record reflectance directly, rather radiance, which is the *amount* (not the percent) of electromagnetic energy received in selected wavelength bands. A change in illumination, more or less intense sun for instance, will change the radiance. Spectral signatures are often represented as plots or graphs, with wavelength on the horizontal axis, and the reflectance on the vertical axis (Figure 2-20 provides a spectral signature for snow).

(2) *Important Reflectance Curves and Critical Spectral Regions.* While there are too many surface types to memorize all their spectral signatures, it is helpful to be familiar with the basic spectral characteristics of green vegetation, soil, and water. This in turn helps determine which regions of the spectrum are most important for distinguishing these surface types.

(3) *Spectral Reflectance of Green Vegetation.* Reflectance of green vegetation (Figure 2-21) is low in the visible portion of the spectrum owing to chlorophyll absorption, high in the near IR due to the cell structure of the plant, and lower again in the shortwave IR due to water in the cells. Within the visible portion of the spectrum, there is a local reflectance peak in the green (0.55 μm) between the blue (0.45 μm) and red (0.68 μm) chlorophyll absorption valleys (Samson, 2000; Lillesand and Kiefer, 1994).

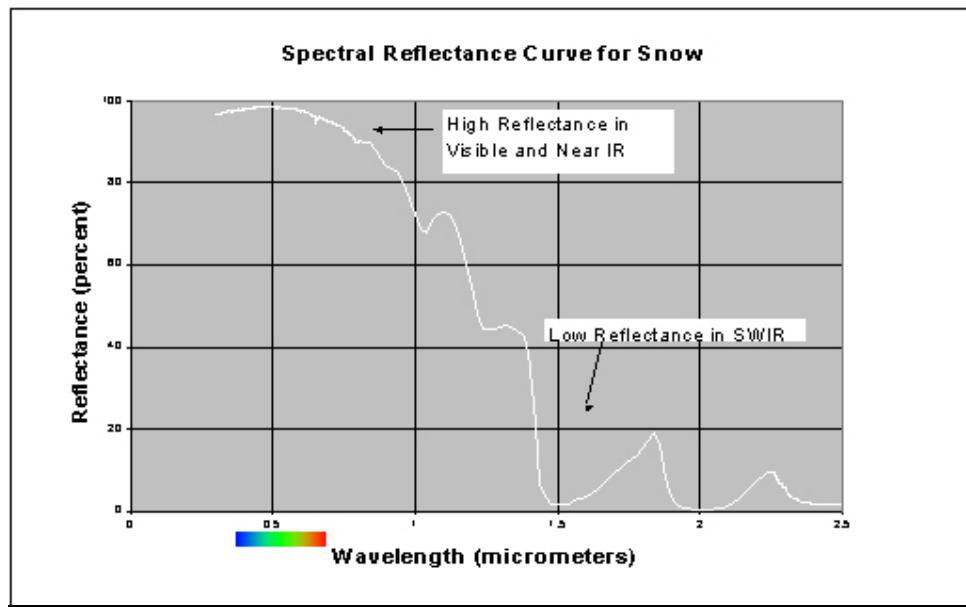


Figure 2-20. Spectral reflectance of snow. Graph developed for Prospect (2002 and 2003) using Aster Spectral Library (<http://speclib.jpl.nasa.gov/>) data

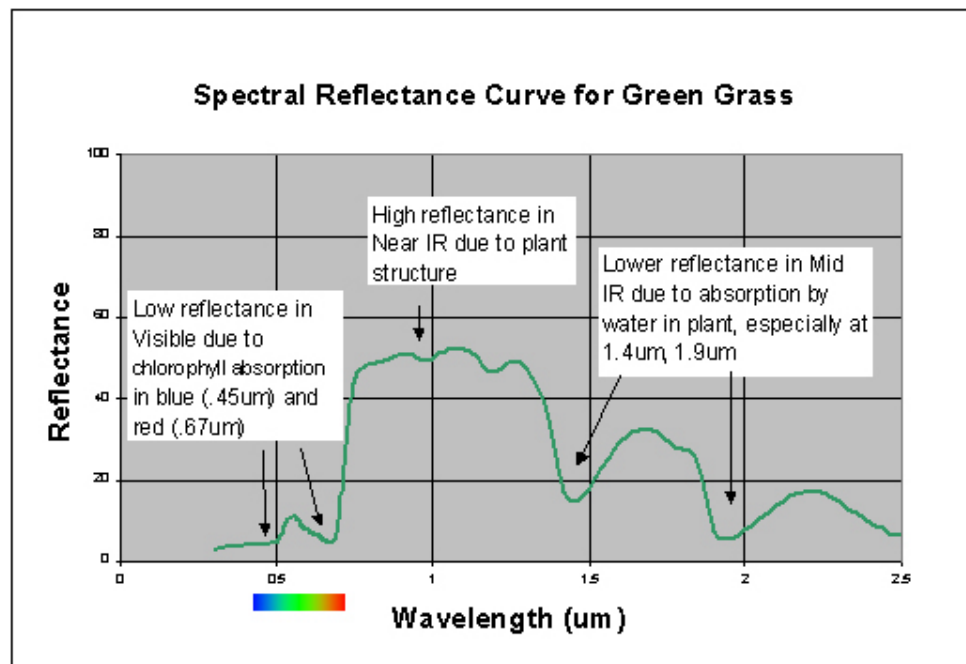


Figure 2-21. Spectral reflectance of healthy vegetation. Graph developed for Prospect (2002 and 2003) using Aster Spectral Library (<http://speclib.jpl.nasa.gov/>) data

(4) *Spectral Reflectance of Soil.* Soil reflectance (Figure 2-22) typically increases with wavelength in the visible portion of the spectrum and then stays relatively constant in the near-IR and shortwave IR, with some local dips due to water absorption at 1.4 and 1.9 μm and due to clay absorption at 1.4 and 2.2 μm (Lillesand and Kiefer, 1994).

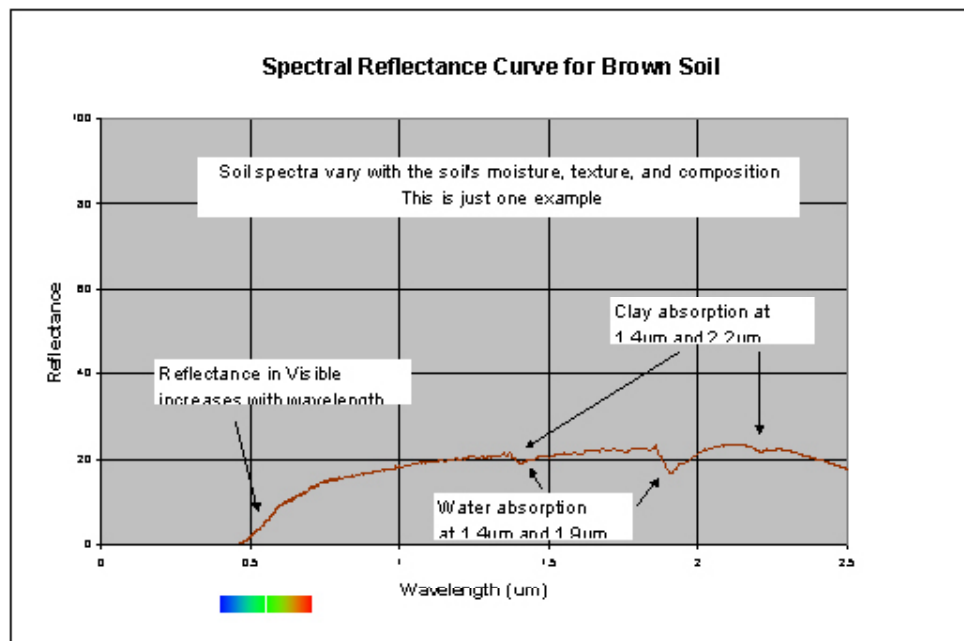


Figure 2-22. Spectral reflectance of one variety of soil. Graph developed for Prospect (2002 and 2003) using Aster Spectral Library (<http://speclib.jpl.nasa.gov/>) data

(5) *Spectral Reflectance of Water.* Spectral reflectance of clear water (Figure 2-23) is low in all portions of the spectrum. Reflectance increases in the visible portion when materials are suspended in the water (Lillesand and Kiefer, 1994).

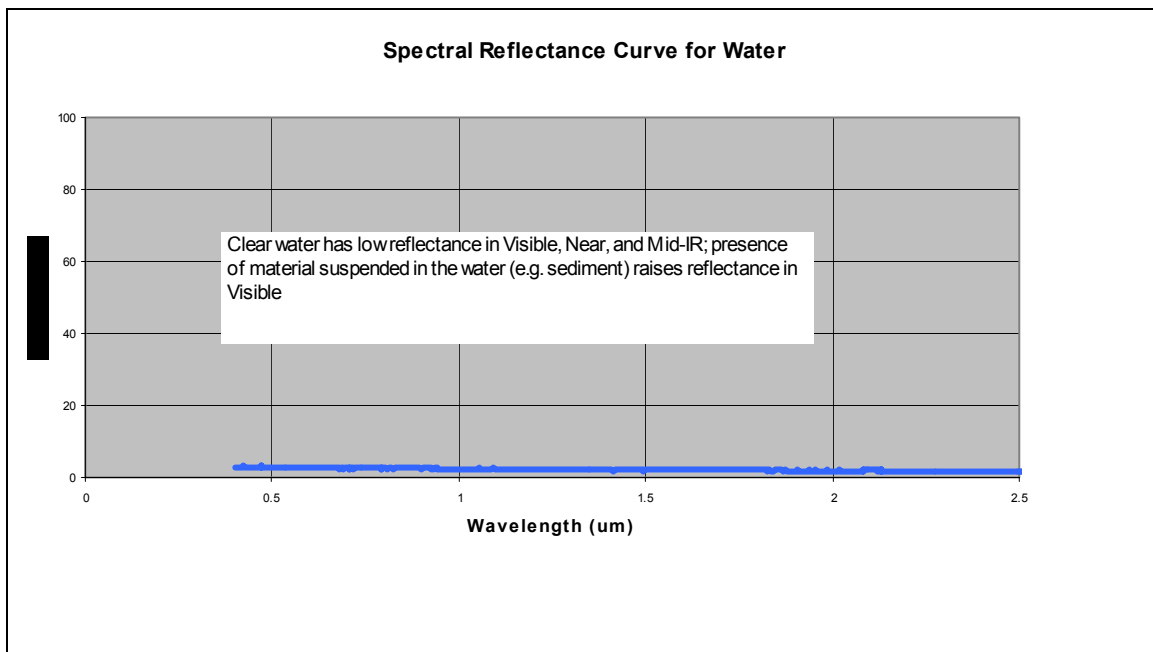


Figure 2-23. Spectral reflectance of water. Graph developed for Prospect (2002 and 2003) using Aster Spectral Library (<http://speclib.jpl.nasa.gov/>) data

(6) *Critical Spectral Regions.* The spectral regions that will be most useful in a remote sensing application depend on the spectral signatures of the surface features to be distinguished. The figure below (Figure 2-24) shows that the visible blue region is not very useful for separating vegetation, soil, and water surface types, since all three have similar reflectance, but visible red wavelengths separate soil and vegetation. In the near-IR (refers to 0.7 to 2.5 μm), all three types are distinct, with vegetation high, soil intermediate, and water low in reflectance. In the shortwave IR, water is distinctly low, while vegetation and soil exchange positions across the spectral region. When spectral signatures cross, the spectral regions on either side of the intersection are especially useful. For instance, green vegetation and soil signatures cross at about 0.7 μm , so the 0.6- (visible red) and 0.8- μm and larger wavelengths (near IR) regions are of particular interest in separating these types. In general, vegetation studies include near IR and visible red data, water vs. land distinction include near IR or SW IR. Water quality studies might include the visible portion of the spectrum to detect suspended materials.

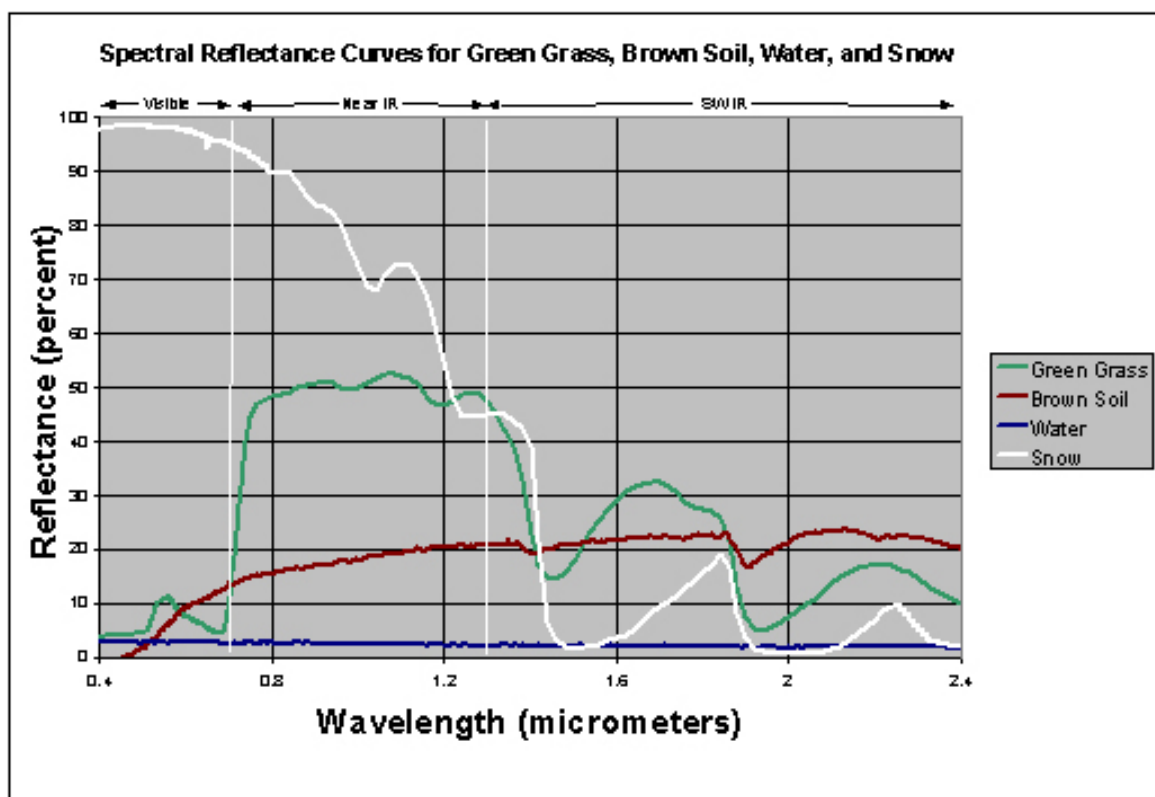


Figure 2-24. Spectral reflectance of grass, soil, water, and snow. Graph developed for Prospect (2002 and 2003) using Aster Spectral Library (<http://speclib.jpl.nasa.gov/>) data

(7) *Spectral Libraries.* As noted above, detailed spectral signatures of known materials are useful in determining whether and in what spectral regions surface features are distinct. Spectral reflectance curves for many materials (especially minerals) are available in existing reference archives (spectral libraries). Data in spectral libraries are gathered under controlled conditions, quality checked, and documented. Since these are re-

flectance curves, and reflectance is theoretically an unvarying property of a material, the spectra in the spectral libraries should match those of the same materials at other times or places.

(a) If data in spectral libraries are not appropriate, reflectance curves can be acquired using a spectrometer. The instrument is aimed at a known target and records the radiance reflected from the target over a fixed range of the spectrum (the 0.4- to 2.5- μm range is relatively common). The instrument must also measure the radiance coming in to the target, so that the reflected radiance can be divided by incoming radiance at each wavelength to determine spectral reflectance of the target. Given the time and expense of gathering spectra data, it is best to check spectral libraries first.

(b) Two major spectral libraries available on the internet (where spectra can be downloaded and processed locally if needed) include:

- US Geological Survey Digital Spectral Library (Clark et al. 1993)

<http://speclab.cr.usgs.gov/spectral-lib.html>

“Researchers at the Spectroscopy lab have measured the spectral reflectance of hundreds of materials in the lab and have compiled a spectral library. The libraries are used as references for material identification in remote sensing images.”

- ASTER Spectral Library (Jet Propulsion Laboratory, 1999)

<http://speclib.jpl.nasa.gov/>

“Welcome to the ASTER spectral library, a compilation of almost 2000 spectra of natural and man made materials.”

(c) The ASTER spectral library includes data from three other spectral libraries: the Johns Hopkins University (JHU) Spectral Library, the Jet Propulsion Laboratory (JPL) Spectral Library, and the United States Geological Survey (USGS—Reston) Spectral Library.”

(8) *Real Life and Spectral Signatures.* Knowledge of spectral reflectance curves is useful if you are searching a remote sensing image for a particular material, or if you want to identify what material a particular pixel represents. Before comparing image data with spectral library reflectance curves, however, you must be aware of several things.

(a) Image data, which often measure radiance above the atmosphere, may have to be corrected for atmospheric effects and converted to reflectance.

(b) Spectral reflectance curves, which typically have hundreds or thousands of spectral bands, may have to be resampled to match the spectral bands of the remote sensing image (typically a few to a couple of hundred).

(c) There is spectral variance within a surface type that a single spectral library reflectance curve does not show. For instance, the Figure 2-25 below shows spectra for a number of different soil types. Before depending on small spectral distinctions to separate

surface types, a note of caution is required: make sure that differences within a type do not drown out the differences between types.

(d) While spectral libraries have known targets that are “pure types,” a pixel in a remote sensing image very often includes a mixture of pure types: along edges of types (e.g., water and land along a shoreline), or interspersed within a type (e.g., shadows in a tree canopy, or soil background behind an agricultural crop).

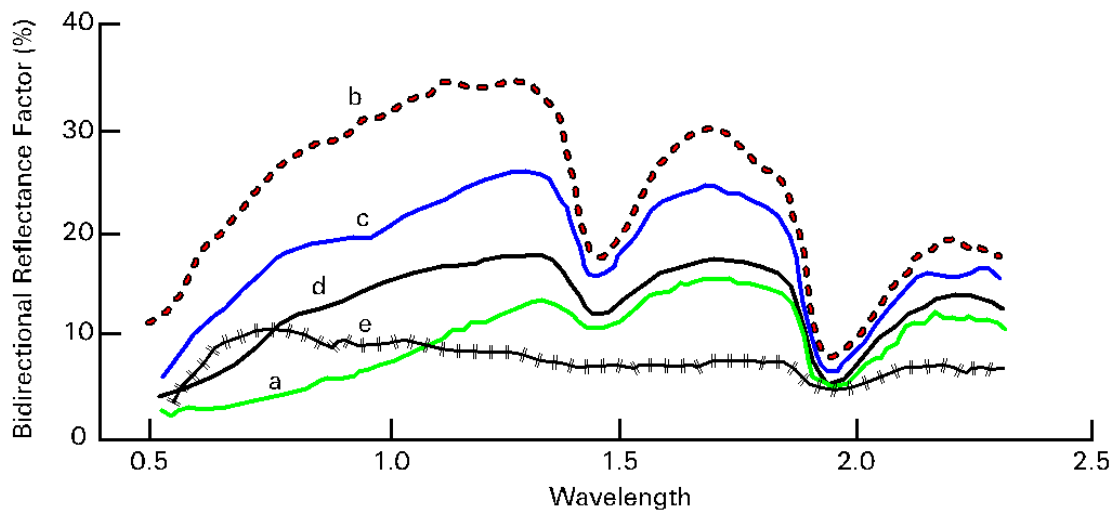


Figure 2-25. Reflectance spectra of five soil types: A—soils having > 2% organic matter content (OMC) and fine texture; B— soils having < 2% OMC and low iron content; C—soils having < 2% OMC and medium iron content; D—soils having > 2% OMC, and coarse texture; and E— soil having fine texture and high iron-oxide content (> 4%).

2-7 Component 4: Energy is Detected and Recorded by the Sensor. Earlier paragraphs of this chapter explored the nature of emitted and reflected energy and the interactions that influence the resultant radiation as it traverses from source to target to sensor. This paragraph will examine the steps necessary to transfer radiation data from the satellite to the ground and the subsequent conversion of the data to a useable form for display on a computer.

a. Conversion of the Radiation to Data. Data collected at a sensor are converted from a continuous analog to a digital number. This is a necessary conversion, as electromagnetic waves arrive at the sensor as a continuous stream of radiation. The incoming radiation is sampled at regular time intervals and assigned a value (Figure 2-26). The value given to the data is based on the use of a 6-, 7-, 8-, 9-, or 10-bit binary computer coding scale; powers of 2 play an important role in this system. Using this coding allows a computer to store and display the data. The computer translates the sequence of binary numbers, given as ones and zeros, into a set of instructions with only two possible outcomes (1 or 0, meaning “on” or “off”). The binary scale that is chosen (i.e., 8 bit data) will depend on the level of brightness that the radiation exhibits. The brightness level is determined by measuring the voltage of the incoming energy. Below in Table 2-5 is a list of select bit integer binary scales and their corresponding number of brightness levels. The ranges are derived by exponentially raising the base of 2 by the number of bits.

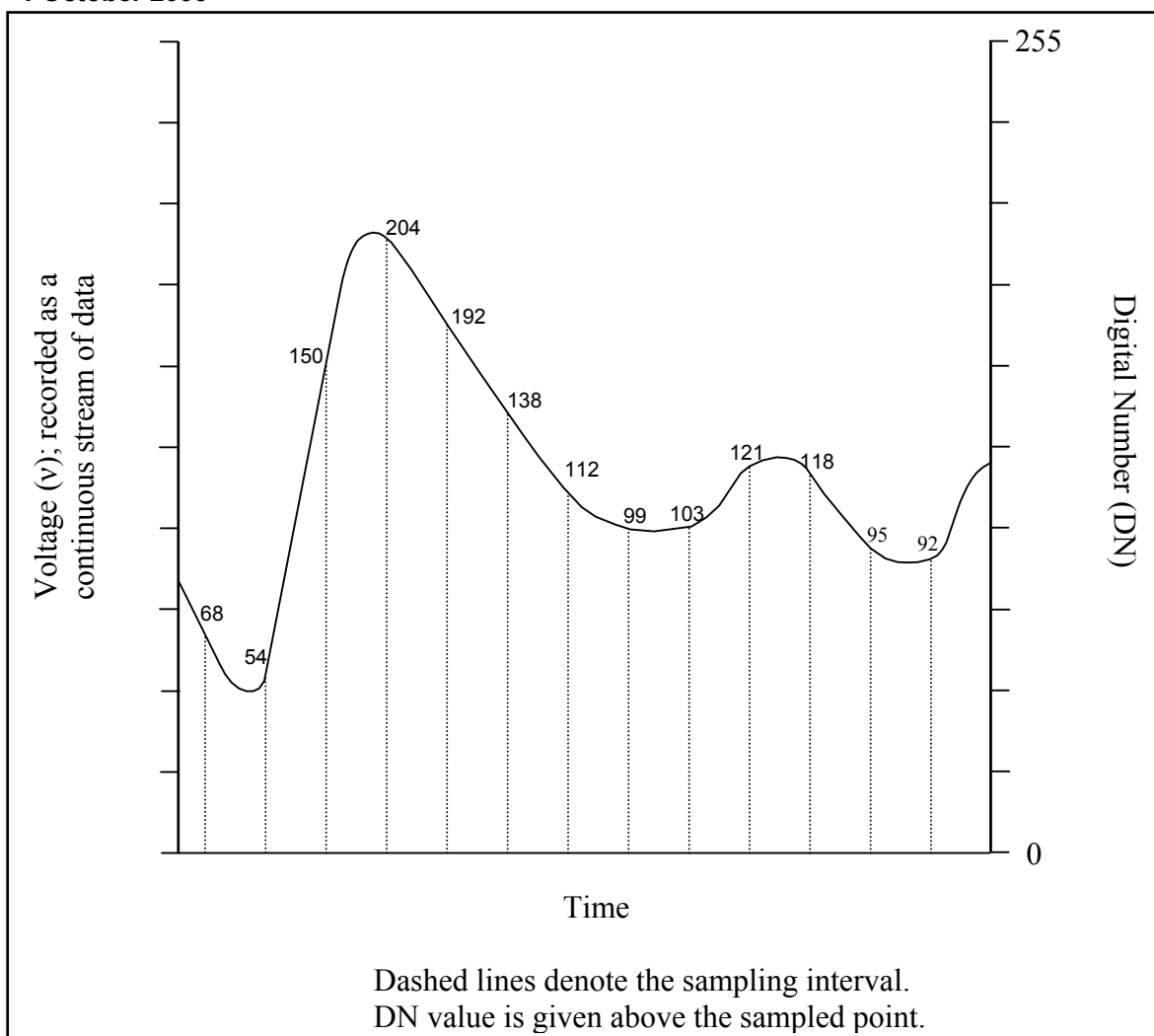


Figure 2-26. Diagram illustrates the digital sampling of continuous analog voltage data. The DN values above the curve represent the digital output values for that line segment.

Table 2-5
Digital number value ranges for various bit data

Number of bits	Exponent of 2	Digital Number (DN)	Value Range
6	2^6	64	0–63
8	2^8	256	0–255
10	2^{10}	1024	0–1023
16	2^{16}	65536	0–65535

b. *Diversion on Data Type.* Digital number values for raw remote sensing data are usually integers. Occasionally, data can be expressed as a decimal. The most popular code for representing real numbers (a number that contains a fraction, i.e., 0.5, which is one-half) is called the IEEE (Institute of Electrical and Electronics Engineers, pronounced I-triple-E) Floating-Point Standard. ASCII text (American Standard Code for Information Interchange; pronounced *ask-ee*) is another alternative computing value sys-

tem. This system is used for text data. You may need to be aware of the type of data used in an image, particularly when determining the digital number in a pixel.

c. Transferring the Data from the Satellite to the Ground. The transfer of data stored in the sensor from the satellite to the user is similar to the transmission of more familiar signals, such as radio and television broadcasts and cellular phone conversations. Everything we see and hear, whether it is a TV program with audio or a satellite image, originates as a form of electromagnetic radiation. To transfer satellite data from the sensor to a location on the ground, the radiation is coded (described in Paragraph 2-7a) and attached to a signal. The signal is generally a high frequency electromagnetic wave that travels at the speed of light. The data are instantaneously transferred and detected with the use of an appropriate antenna and receiver.

d. Satellite Receiving Stations.

(1) Satellite receiving stations are positioned throughout the world. Each satellite program has its own fleet of receiving stations with a limited range from which it can pick up the satellite signal. For an example of locations and coverage of SPOT receiving stations go to

<http://www.spotimage.fr/home/system/introexp/station/welcome.htm>.

(2) Satellites can only transmit data when in range of a receiving station. When outside of a receiving range, satellites will store data until they fly within range of the next receiving station. Some satellite receiving stations are mobile and can be placed on airplanes for swift deployment. A mobile receiving station is extremely valuable for the immediate acquisition of data relating to an emergency situation (flooding, forest fire, military strikes).

e. Data is Prepared for User. Once transmitted the carrier signal is filtered from the data, which are decoded and recorded onto a high-density digital tape (HDDT) or a CD-ROM, and in some cases transferred via file transfer protocol (FTP). The data can then undergo geometric and radiometric preprocessing, generally by the vendor. The data are subsequently recorded onto tape or CD compatible for a computer.

f. Hardware and Software Requirements. The hardware and software needed for satellite image analysis will depend on the type of data to be processed. A number of free image processing software programs are available and can be downloaded from the internet. Some vendors provide a free trial or free tutorials. Highly sophisticated and powerful software packages are also available for purchase. These packages require robust hardware systems to sustain extended use. Software and hardware must be capable of managing the requirements of a variety of data formats and file sizes. A single satellite image file can be 300 MB prior to enhancement processing. Once processed and enhanced, the resulting data files will be large and will require storage for continued analysis. Because of the size of these files, software and hardware can be pushed to its limits. Regularly save and back up your data files as software and hardware pushed to its limits can crash,

losing valuable information. Be sure to properly match your software requirements with appropriate hardware capabilities.

g. Turning Digital Data into Images.

(1) Satellite data can be displayed as an image on a computer monitor by an array of pixels, or picture elements, containing digital numbers. The composition of the image is simply a grid of continuous pixels, known as a raster image (Figure 2-27). The digital number (DN) of a pixel is the result of the spatial, spectral, and radiometric averaging of reflected/emitted radiation from a given area of ground cover (see below for information on spatial, spectral, and radiometric resolution). The DN of a pixel is therefore the average radiance of the surface area the pixel represents.

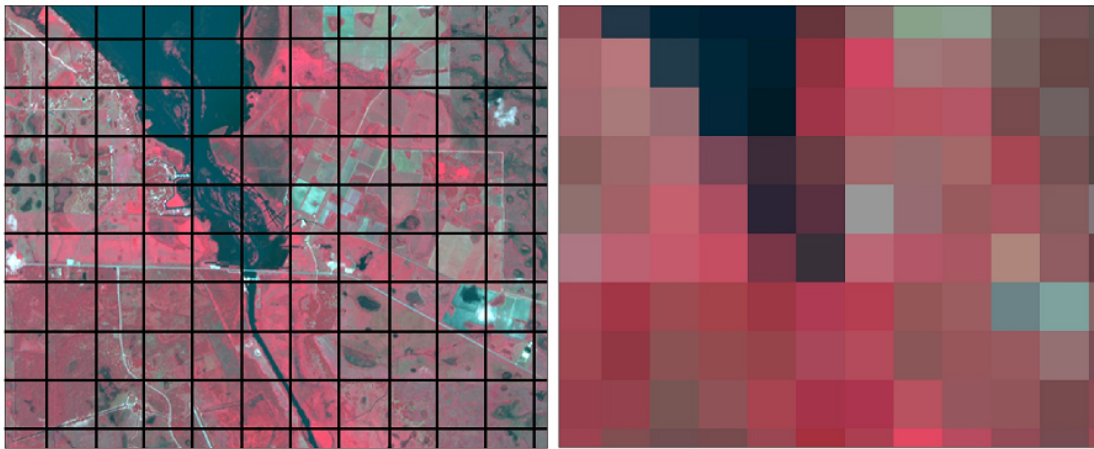


Figure 2-27. Figure illustrates the collection of raster data. Black grid (left) shows what area on the ground is covered by each pixel in the image (right). A sensor measures the average spectrum from each pixel, recording the photons coming in from that area. ASTER data of Lake Kissimmee, Florida, acquired 2001-08-18. Image developed for Prospect (2002 and 2003).

(2) The value given to the DN is based on the brightness value of the radiation (see explanation above and Figure 2-28). For most radiation, an 8-bit scale is used that corresponds to a value range of 0–255 (Table 2-4). This means that 256 levels of brightness (DN values are sometimes referred to as brightness values— B_v) can be displayed, each representing the intensity of the reflected/emitted radiation. On the image this translates to varying shades of grays. A pixel with a brightness value of zero ($B_v = 0$) will appear black; a pixel with a B_v of 255 will appear white (Figure 2-29). All brightness values in the range of $B_v = 1$ to 254 will appear as increasingly brighter shades of gray. In Figure 2-30, the dark regions represent water-dominated pixels, which have low reflectance/ B_v , while the bright areas are developed land (agricultural and forested), which has high reflectance.

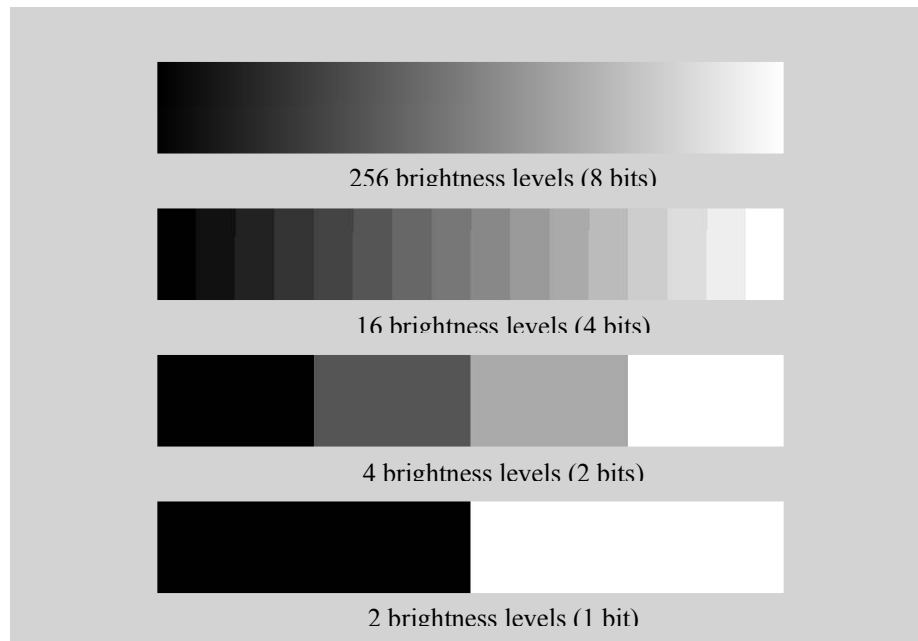


Figure 2-28. Brightness levels at different radiometric resolutions. Image developed for USACE Prospect #196 (2002).

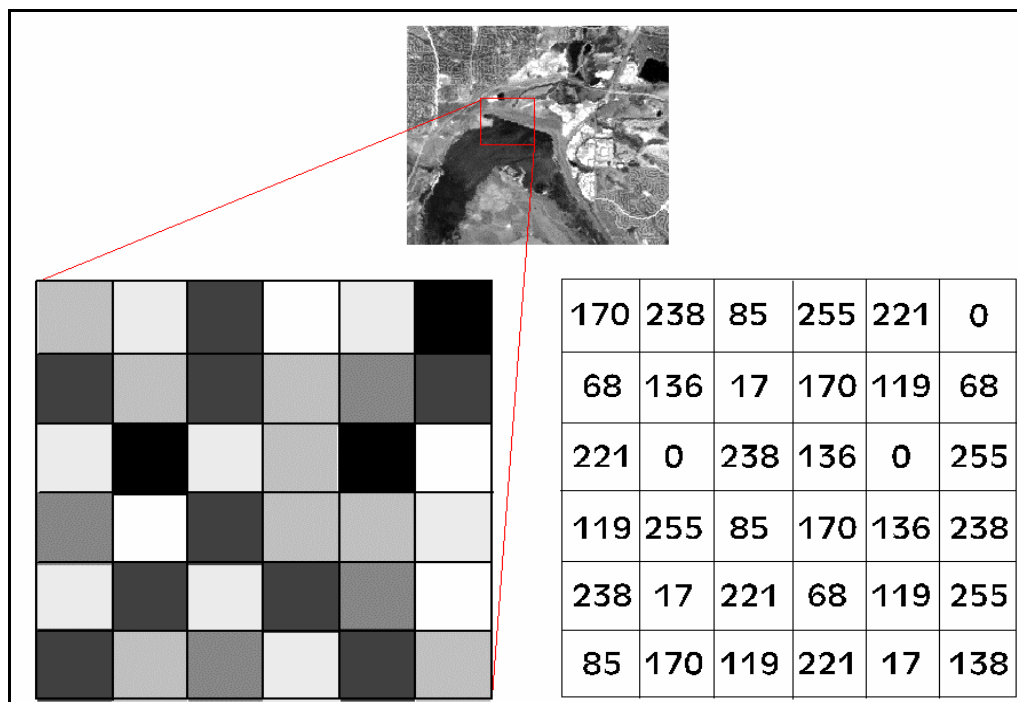


Figure 2-29. Raster array and accompanying digital number (DN) values for a single band image. Dark pixels have low DN values while bright pixels have high values. Modified from Natural Resources Canada image

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter1/chapter1_7_e.html.



Figure 2-30. Landsat MSS band 5 data of San Francisco, California. The black pixels represent water; the various levels of gray to bright pixels represent different vegetation and ground cover types across the landscape. Image taken from http://sfbay.wr.usgs.gov/access/change_detect/Satellite/Images2.html.

h. Converting Digital Numbers to Radiance. Conversion of a digital number to its corresponding radiance is necessary when comparing images from different satellite sensors or from different times. Each satellite sensor has its own calibration parameter, which is based on the use of a linear equation that relates the minimum and maximum radiation brightness. Each spectrum band (see Paragraph 2-7*i*) also has its own radiation minimum and maximum.

(1) Information pertaining to the minimum and maximum brightness ($L_{\min}$ and $L_{\max}$ respectively) is usually found in the metadata (see Chapter 5). The equation for determining radiance from the digital number is:

$$L = (L_{\max} - L_{\min}) / 255 \times DN + L_{\min} \quad (2-10)$$

where

- L = radiance expressed in $\text{Wm}^{-2} \text{sr}^{-1}$
- $L_{\min}$ = spectral radiance corresponding to the minimum digital number
- $L_{\max}$ = spectral radiance corresponding to the maximum digital number
- DN = digital number given a value based on the bit scale used.

(2) This conversion can also be used to enhance the visual appearance of an image by reassigning the DN values so they span the full gray scale range (see Paragraph 5-20).

i. Spectral Bands.

(1) Sensors collect wavelength data in bands. A number or a letter is typically assigned to a band. For instance, radiation that spans 0.45 to 0.52 μm is designated as band 1 for Landsat 7 data; in the microwave region radiation spanning 15 to 30 cm is termed the L-band. Not all bands are created equally. Landsat band 1 (B1) does not represent the same wavelengths as SPOT's B1.

(2) Band numbers are not the same as sensor numbers. For instance Landsat 4 *does not* refer to band 4. It instead refers to the fourth satellite sensor placed into orbit by the Landsat program. This can be confusing, as each satellite program has a fleet of satellites (in or out of commission at different times), and each satellite program will define bands differently. Two different satellites from the same program may even be collecting radiation at a slightly difference wavelength range for the same band (Table 2-6). It is, therefore, important to know which satellite program and which sensor collected the data.

Table 2-6
Landsat Satellites and Sensors

The following table lists Landsat satellites 1-7, and provides band information and pixel size. The band numbers for one sensor does not necessarily imply the same wavelength range. For example, notice that band 4 in Landsat 1-2 and 3 differ from the band 4 in Landsat 4-5 and Landsat 7. Source: http://landsat.gsfc.nasa.gov/guides/LANDSAT-7_dataset.html#8.

Satellite	Sensor	Band number	Band wavelengths	Pixel Size
Landsats 1-2	RBV	1)	0.45 to 0.57	80
		2)	0.58 to 0.68	80
		3)	0.70 to 0.83	80
	MSS	4)	0.5 to 0.6	79
		5)	0.6 to 0.7	79
		6)	0.7 to 0.8	79
		7)	0.8 to 1.1	79
Landsat 3	RBV	1)	0.45 to 0.52	40

Satellite	Sensor	Band number	Band wavelengths	Pixel Size
	MSS	4)	0.5 to 0.6	79
		5)	0.6 to 0.7	79
		6)	0.7 to 0.8	79
		7)	0.8 to 1.1	79
		8)	10.4 to 12.6	240
Landsat 4-5	MSS	4)	0.5 to 0.6	82
		5)	0.6 to 0.7	82
		6)	0.7 to 0.8	82
		7)	0.8 to 1.1	82
	TM	1)	0.45 to 0.52	30
		2)	0.52 to 0.60	30
		3)	0.63 to 0.69	30
		4)	0.76 to 0.90	30
		5)	1.55 to 1.75	30
		6)	10.4 to 12.5	120
		7)	2.08 to 2.35	30
	ETM	1)	0.45 to 0.52	30
		2)	0.52 to 0.60	30
		3)	0.63 to 0.69	30
		4)	0.76 to 0.90	30
		5)	1.55 to 1.75	30
		6)	10.4 to 12.5	150
		7)	2.08 to 2.35	30
	PAN	4)	0.50 to 0.90	15

j. Color in the Image. Computers are capable of imaging three primary colors: red, green, and blue (RGB). This is different from the color system used by printers, which uses magenta, cyan, yellow, and black. The color systems are unique because of differences in the nature of the application of the color. In the case of color on a computer monitor, the monitor is black and the color is projected (called additive color) onto the screen. Print processes require the application of color to paper. This is known as a subtractive process owing to the removal of color by other pigments. For example, when white light that contains all the visible wavelengths hits a poster with an image of a yellow flower, the yellow pigment will remove the blue and green and will reflect yellow. Hence, the process is termed subtractive. The different color systems (additive vs. subtractive) account for the dissimilarities in color between a computer image and the corresponding printed image.

(1) Similar to the gray scale, color can also be displayed as an 8-bit image with 256 levels of brightness. Dark pixels have low values and will appear black with some color, while bright pixels will contain high values and will contain 100% of the designated color. In Figure 2-31, the 7 bands of a Landsat image are separated to show the varying DNs for each band.

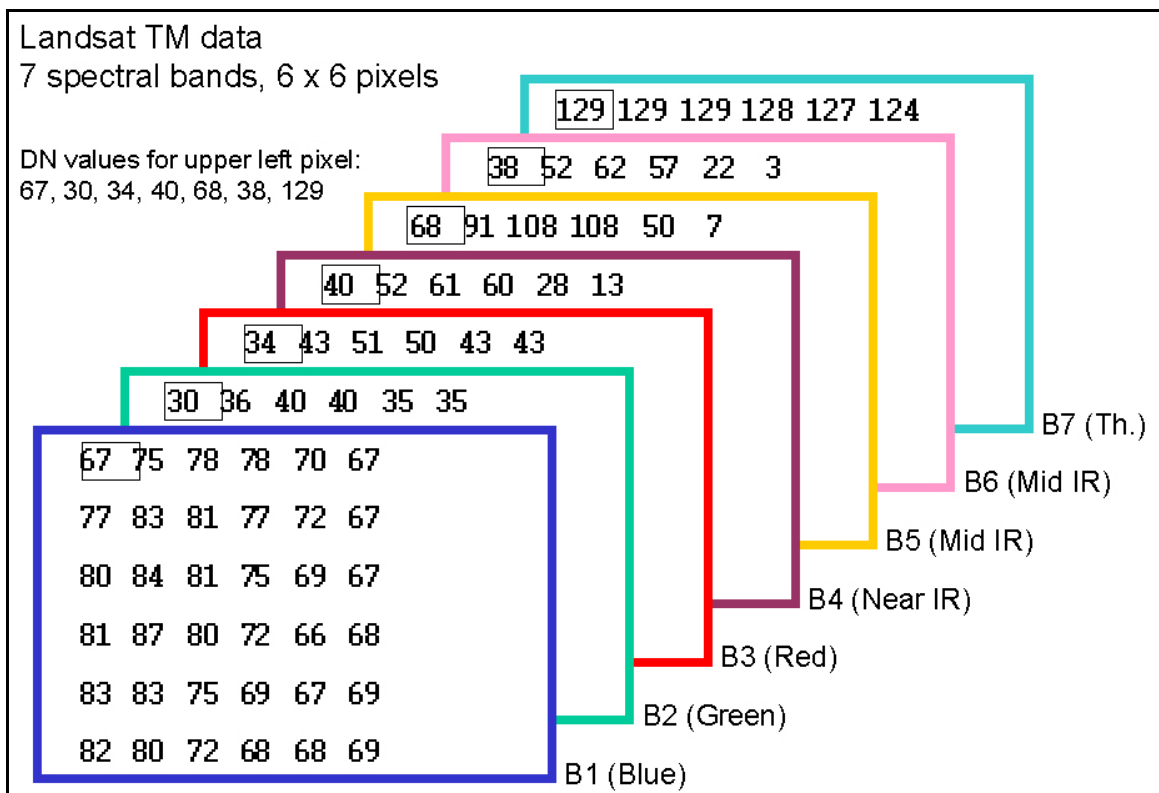
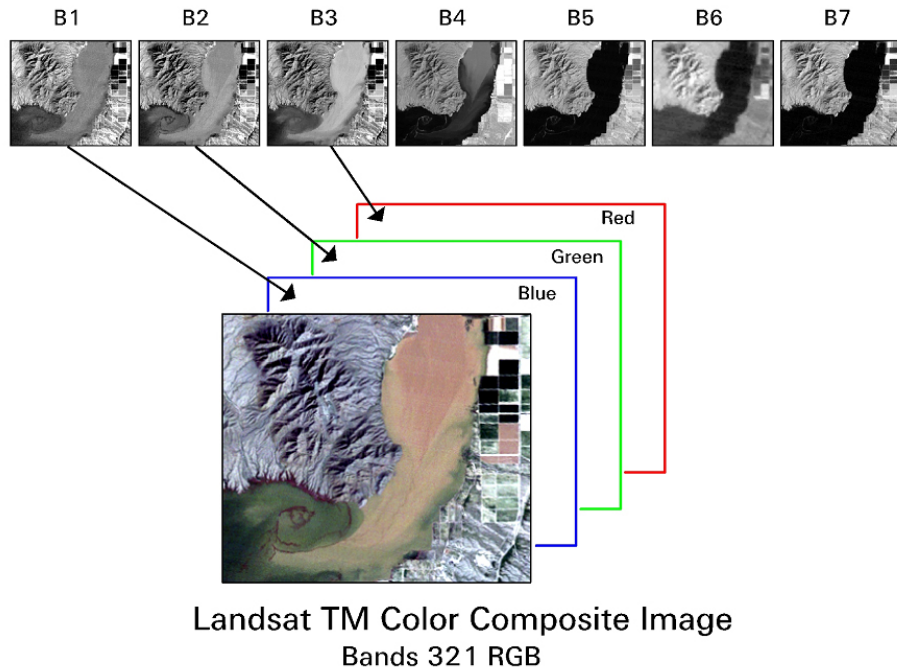


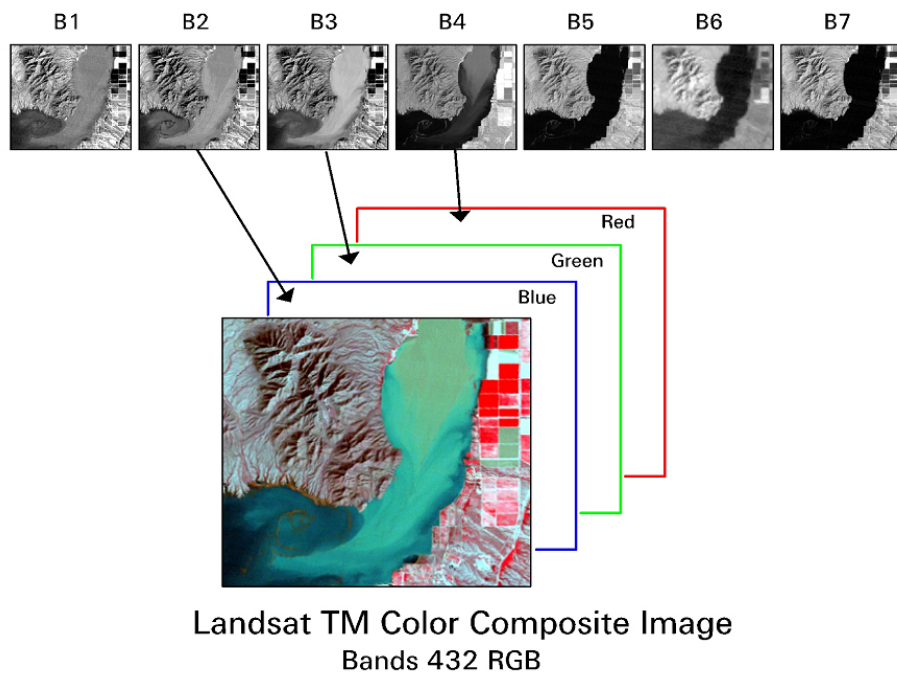
Figure 2-31. Individual DNs can be identified in each spectral band of an image. In this example the seven bands of a subset from a Landsat image are displayed. Image developed for Prospect (2002 and 2003).

(2) When displaying an image on a computer monitor, the software allows a user to assign a band to a particular color (this is termed as “loading the band”). Because there are merely three possible colors (red, green, and blue) only three bands of spectra can be displayed at a time. The possible band choices coupled with the three-color combinations creates a seemingly endless number of possible color display choices.

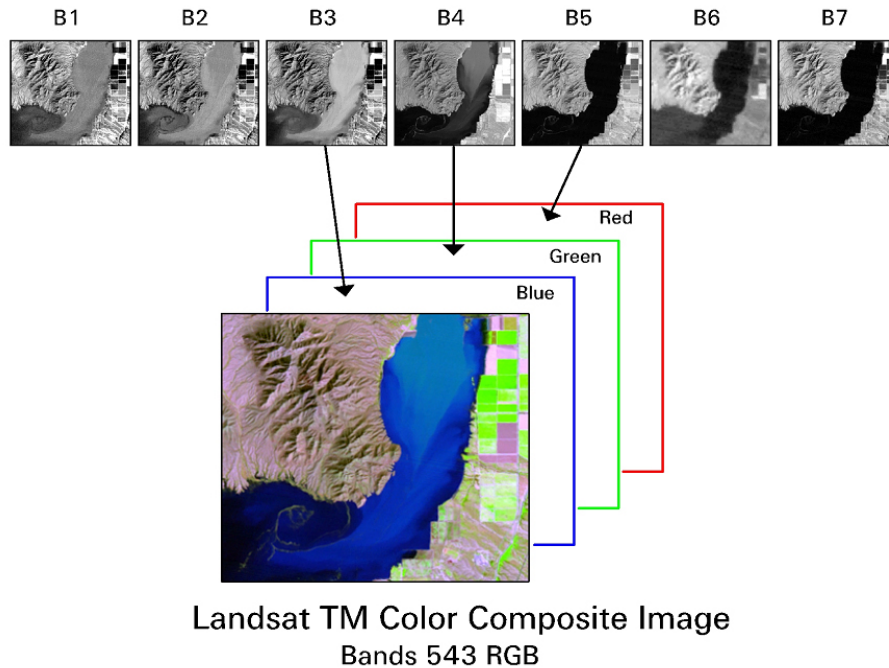
(3) The optimal band choice for display will depend of the spectral information needed (see Paragraph 2-6b(7)). The color you designate for each band is somewhat arbitrary, though preferences and standards do exist. For example, a typical color/band designation of red/green/blue in bands 3/2/1 of Landsat displays the imagery as true-color. These three bands are all in the visible part of the spectrum, and the imagery appears as we see it with our eyes (Figure 2-32a). In Figure 2-32b, band 4 (B4) is displayed in the red (called “red-gun” or “red-plane”) layer of the bands 4/3/2, and vegetation in the agricultural fields appear red due to the infrared location on the spectrum. In Figure 2-32c, band 4 (B4) is displayed as green. Green is a logical choice for band 4 as it represents the wavelengths reflected by vegetation.



a. The true color image appears with these bands in the visible part of the spectrum.



b. Using the near infra-red (NIR) band (4) in the red gun, healthy vegetation appears red in the imagery.



c. Moving the NIR band into the green gun and adding band 5 to the red gun changes the vegetation to green.

Figure 2-32. Three band combinations of Landsat imagery of 3/2/1, 4/3/2, and 5/4/3 in the RGB. Images developed for Prospect (2002 and 2003).

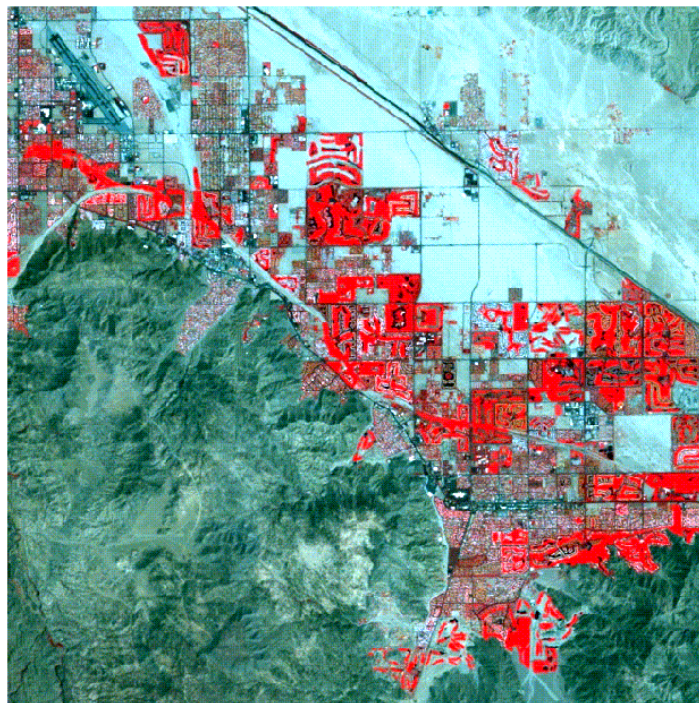
k. Interpreting the Image. When interpreting the brightness of a gray scale image (Figure 2-33), the brightness simply represents the amount of reflectance. For bright pixels the reflectance is high, while dark pixels represent areas of low reflectance. By example, in a gray scale display of Landsat 7 band 4, the brightest pixels represent areas where there is a high reflectance in the wavelength range of 0.76 to 0.90 μm . This can be interpreted to indicate the presence of healthy vegetation (lawns and golf courses).

(1) A color composite can be somewhat difficult to interpret owing to the mixing of color. Similar to gray scale, the bright regions have high reflectance, and dark areas have low reflectance. The interpretation becomes more difficult when we combine different bands of data to produce what is known as false-color composites (Figure 2-33).

(2) White and black are the end members of the band color mixing. White pixels in a color composite represent areas where reflectance is high in all three of the bands displayed. White is produced when 100% of each color (red, green, and blue) are mixed in equal proportions. Black pixels are areas where there is an absence of color due to the low DN or reflectance. The remaining color variations represent the mixing of three band DNs. A magenta pixel is one that contains equal portions of blue and red, while lacking green. Yellow pixels are those that are high in reflectance for the bands in the green and red planes. (Go to Appendix C for a paper model of the color cube/space.)



a



b

Figure 2-33. Landsat 7 image of southern California (a). Landsat TM band 4 image, the gray to bright white pixels represent the presence of healthy vegetation and urban development. (b). Landsat TM bands 4, 3, 2 (RGB) image, a false color composite, highlights vegetation in red. Images are taken from http://landsat.gsfc.nasa.gov/data/Browse/Comparisons/L7_BandComparison.html.

l. Data Resolution. A major consideration when choosing a sensor type is the definition of resolution capabilities. “Resolution” in remote sensing refers to the ability of a sensor to distinguish or resolve objects that are physically near or spectrally similar to other adjacent objects. The term high or fine resolution suggests that there is a large degree of distinction in the resolution. High resolution will allow a user to distinguish small, adjacent targets. Low or coarse resolution indicates a broader averaging of radiation over a larger area (on the ground or spectrally). Objects and their boundaries will be difficult to pinpoint in images with coarse resolution. The four types of resolution in remote sensing include spatial, spectral, radiometric, and temporal.

(1) *Spatial Resolution.*

(a) An increase in spatial resolution corresponds to an increase in the ability to resolve one feature physically from another. It is controlled by the geometry and power of the sensor system and is a function of sensor altitude, detector size, focal size, and system configuration.

(b) Spatial resolution is best described by the size of an image pixel. A pixel is a two-dimensional square-shaped picture element displayed on a computer. The dimensions on the ground (measured in meters or kilometers) projected in the instantaneous field of view (IFOV) will determine the ratio of the pixel size to ground coverage. As an example, for a SPOT image with 20- ×20-m pixels, one pixel in the digital image is equivalent to 20 m square on the ground. To gauge the resolution needed to discern an object, the spatial resolution should be half the size of the feature of interest. For example, if a project requires the discernment of individual tree, the spatial resolution should be a minimum of 15 m. If you need to know the percent of timber stands versus clearcuts, a resolution of 30 m will be sufficient.

Table 2-7
Minimum image resolution required for various sized objects.

Resolution (m)	Feature Object (m)
0.5	1.0
1.0	2.0
1.5	3.0
2.0	4.0
2.5	5.0
5.0	10.0
10.0	20.0
15.0	30.0
20.0	40.0
25.0	50.0

(2) *Spectral Resolution.* Spectral resolution is the size and number of wavelengths, intervals, or divisions of the spectrum that a system is able to detect. Fine spectral resolution generally means that it is possible to resolve a large number of similarly sized wavelengths, as well as to detect radiation from a variety of regions of the spectrum. A

coarse resolution refers to large groupings of wavelengths and tends to be limited in the frequency range.

(3) *Radiometric Resolution.* Radiometric resolution is a detector's ability to distinguish differences in the strength of emitted or reflected electromagnetic radiation. A high radiometric resolution allows for the distinction between subtle differences in signal strength.

(4) *Temporal Resolution.*

(a) Temporal resolution refers to the frequency of data collection. Data collected on different dates allows for a comparison of surface features through time. If a project requires an assessment of change, or change detection, it is important to know: 1) how many data sets already exist for the site; 2) how far back in time the data set ranges; and 3) how frequently the satellite returns to acquire the same location.

(b) Most satellite platforms will pass over the same spot at regular intervals that range from days to weeks, depending on their orbit and spatial resolution (see Chapter 3). A few examples of projects that require change detection are the growth of crops, deforestation, sediment accumulation in estuaries, and urban development.

(5) *Determine the Appropriate Resolution for the Project.* Increasing resolution tends to lead to more accurate and useful information; however, this is not true for every project. The downside to increased resolution is the need for increased storage space and more powerful hardware and software. High-resolution satellite imagery may not be the best choice when all that is needed is good quality aerial photographs. It is, therefore, important to determine the minimum resolution requirements needed to accomplish a given task from the outset. This may save both time and funds.

2-8 Aerial Photography. A traditional form of mapping and surface analysis by remote sensing is the use of aerial photographs. Low altitude aerial photographs have been in use since the Civil War, when cameras mounted on balloons surveyed battlefields. Today, they provide a vast amount of surface detail from a low to high altitude, vertical perspective. Because these photographs have been collected for a longer period of time than satellite images, they allow for greater temporal monitoring of spatial changes. Roads, buildings, farmlands, and lakes are easily identifiable and, with experience, surface terrain, rock bodies, and structural faults can be identified and mapped. In the field, photographs can aid in precisely locating target sites on a map.

a. Aerial photographs record objects in the visible and near infrared and come in a variety of types and scales. Photos are available in black and white, natural color, false color infrared, and low to high resolution.

b. Resolution in aerial photographs is defined as the resolvable difference between adjacent line segments. Large-scale aerial photographs maintain a fine resolution that

allows users to isolate small objects such as individual trees. Photographs obtained at high altitudes produce a small-scale, which gives a broader view of surface features.

c. In addition to the actual print or digital image, aerial photographs typically include information pertaining to the photo acquisition. This information ideally includes the date, flight, exposure, origin/focus, scale, altitude, fiducial marks, and commissioner (Figure 2-34). If the scale is not documented on the photo, it can be determined by taking the ratio of the distance of two objects measured on the photo vs. the distance of the same two objects calculated from measurements taken from a map.

$$\text{Photo scale} = \text{photo distance/ground distance} = d/D \quad (2-11)$$



Figure 2-34. Aerial photograph of a predominately agricultural area near Modesto, California. Notice the ancillary data located on the upper and right side margins. These data provide information regarding the location and acquisition of the photo.

d. The measurement is best taken from one end of the photo to the other, passing through the center (because error in the image increases away from the focus point). For precision, it is best to average a number of ratios from across the image.

e. Photos are interpreted by recognizing various elements in a photo by the distinction of tone, texture, size, shape, pattern, shadow, site, and association. For instance, airport landing strips can look like roads, but their large widths, multiple intersections at small angles, and the positioning of airport hangers and other buildings allow the interpreter to correctly identify these “roads” as a special use area.

f. Aerial-photos are shot in a sequence with 60% overlap; this creates a stereo view when two photos are viewed simultaneously. Stereoscopic viewing geometrically corrects photos by eliminating errors attributable to camera tilt and terrain relief. Images are most easily seen in stereo by viewing them through a stereoscope. With practice it is possible to see in stereo without the stereoscope. This view will produce a three-dimensional image, allowing you to see topographic relief and resistant vs. recessive rock types.

g. To maintain accuracy it is important to correlate objects seen in the image with the actual object in the field. This verification is known as ground truth. Without ground truth you may not be able to differentiate two similarly toned objects. For instance, two very different but recessive geologic units could be mistakenly grouped together. Ground truth will also establish the level of accuracy that can be attributed to the maps created based solely on photo interpretations.

h. For information on aerial photograph acquisition, see Chapter 4. Chapter 5 presents a discussion on the digital display and use of aerial photos in image processing.

2-9 Brief History of Remote Sensing. Remote sensing technologies have been built upon by the work of researchers from a variety of disciplines. One must look further than 100 years ago to understand the foundations of this technology. For a timeline history of the development of remote sensing see http://rst.gsfc.nasa.gov/Intro/Part2_8.html. The chronology shows that remote sensing has matured rapidly since the 1970s. This advancement has been driven by both the military and commercial sectors in an effort to effectively model and monitor Earth processes. For brevity, this overview focuses on camera use in remote sensing followed by the development of two NASA programs and France’s SPOT system. To learn more about the development of remote sensing and details of other satellite programs see <http://rst.gsfc.nasa.gov/Front/tofc.html>.

a. *The Camera.* The concept of imaging the Earth’s surface has its roots in the development of the camera, a black box housing light sensitive film. A small aperture allows light reflected from objects to travel into the black box. The light then “exposes” film, positioned in the interior, by activating a chemical emulsion on the film surface. After exposure, the film negative (bright and dark are reversed) can be used to produce a positive print or a visual image of a scene.

b. Aerial Photography. The idea of mounting a camera on platforms above the ground for a “birds-eye” view came about in the mid-1800s. In the 1800’s there were few objects that flew or hovered above ground. During the US Civil War, cameras were mounted on balloons to survey battlefield sites. Later, pigeons carrying cameras were employed (<http://www2.oneonta.edu/~baumanpr/ncge/rstf.htm>), a platform with obvious disadvantages. The use of balloons and other platforms created geometric problems that were eventually solved by the development of a gyro-stabilized camera mounted on a rocket. This gyro-stabilizer was created by the German scientist Maul and was launched in 1912.

c. First Satellites. The world’s first artificial satellite, Sputnik 1, was launched on 4 October 1957 by the Soviet Union. It was not until NASA’s meteorological satellite TIROS –1 was launched that the first satellite images were produced (<http://www.earth.nasa.gov/history/tiros/tiros1.html>). Working on the same principles as the camera, satellite sensors collect reflected radiation in a range of spectra and store the data for eventual image processing (see above, this chapter).

d. NASA’s First Weather Satellites. NASA’s first satellite missions involved study of the Earth’s weather patterns. TIROS (Television Infrared Operational Satellite) missions launched 10 experimental satellites in the early 1960’s in an effort to prepare for a permanent weather bureau satellite system known as TOS (TIROS Operating System). TIROS-N (next generation) satellites currently monitor global weather and variations in the Earth’s atmosphere. The goal of TIROS-N is to acquire high resolution, diurnal data that includes vertical profile measurements of temperature and moisture.

e. Landsat Program. The 1970’s brought the introduction of the Landsat series with the launching of ERTS-1 (also known as Landsat 1) by NASA. The Landsat program was the first attempt to image whole earth resources, including terrestrial (land based) and marine resources. Images from the Landsat series allowed for detailed mapping of land-masses on a regional and continental scale.

(1) The Landsat imagery continues to provide a wide variety of information that is highly useful for identifying and monitoring resources, such as fresh water, timberland, and minerals. Landsat imagery is also used to assess hazards such as floods, droughts, forest fire, and pollution. Geographers have used Landsat images to map previously unknown mountain ranges in Antarctica and to map changes in coastlines in remote areas.

(2) A notable event in the history of the Landsat program was the addition of TM (Thematic Mapper) first carried by Landsat 4 (for a summary of Landsat satellites see <http://geo.arc.nasa.gov/sge/landsat/lpsum.html>). The Thematic Mapper provides a resolution as low as 30 m, a great improvement over the 70-m resolution of earlier sensors. The TM device collects reflected radiation in the visible, infrared (IR), and thermal (IR) region of the spectrum.

(3) In the late 1970’s, the regulation of Landsat was transferred from NASA to NOAA, and was briefly commercialized in the 1980s. The Landsat program is now oper-

ated by the USGS EROS Data Center (US Geological Survey Earth Resources Observation Systems; see <http://landsat7.usgs.gov/index.html>).

(4) As government sponsored programs have become increasingly commercialized and other countries develop their own remote sensors, NASA's focus has shifted from sensor development to data sharing. NASA's Data Acquisition Centers serves as a clearing-house for satellite data; these data can now be shared via the internet.

f. France's SPOT Satellite System. As a technology, remote sensing continues to advance globally with the introduction of satellite systems in other countries such as France, Japan, and India. France's SPOT (Satellite Pour l'Observation de la Terra) has provided reliable high-resolution (20 to 10 m resolution) image data since 1986.

(1) The SPOT 1, 2, and 3 offer both panchromatic data (P or PAN) and three bands of multispectral (XS) data. The panchromatic data span the visible spectrum without the blue (0.51-0.73 μm) and maintains a 10-m resolution. The multispectral data provide 20-m resolution, broken into three bands: Band 1 (Green) spans 0.50–0.59 μm , Band 2 (Red) spans 0.61–0.68 μm , and Band 3 (Near Infrared) spans 0.79–0.89 μm . SPOT 4 also supplies a 20-m resolution shortwave Infrared (mid IR) band (B4) covering 1.58 to 1.75 μm . SPOT 5, launched in spring 2002, provides color imagery, elevation models, and an impressive 2.5-m resolution. It houses scanners that collect panchromatic data at 5 m resolution and four band multispectral data at 10-m resolution (see Appendix D-“SPOT” file).

(2) SPOT 3 was decommissioned in 1996. SPOT 1, 2, 4, and 5 are operational at the time of this writing. For information on the SPOT satellites go to <http://www.spotimage.fr/home/system/introsat/seltec/welcome.htm>.

g. Future of Remote Sensing. The improved availability of satellite images coupled with the ease of image processing has lead to numerous and creative applications. Remote sensing has dramatically brought about changes in the methodology associated with studying earth processes on both regional and global scales. Advancements in sensor resolution, particularly spatial, spectral, and temporal resolution, broaden the possible applications of satellite data.

(1) Government agencies around the world are pushing to meet the demand for reliable and continuous satellite coverage. Continuous operation improves the temporal data needed to assess local and global change. Researchers are currently able to perform a 30-year temporal analysis using satellite images on critical areas around the globe. This time frame can be extended back with the incorporation of digital aerial photographs.

(2) Remote sensing has established itself as a powerful tool in the assessment and management of U.S. lands. The Army Corps of Engineers has already incorporated this technology into its nine business practice areas, demonstrating the tremendous value of remote sensing in civil works projects.

Chapter 3 Sensors and Systems

3-1 Introduction. Remotely sensed data are collected by a myriad of satellite and airborne systems. A general understanding of the sensors and the platforms they operate on will help in determining the most appropriate data set to choose for any project. This chapter reviews the nine business practice areas in USACE Civil Works and examines the leading questions to be addressed before the initiation of a remote sensing project. Airborne and satellite sensor systems are presented along with operational details such as flight path/orbits, swath widths, acquisition, and post processing options. Ground-based remote sensing GPR (Ground Penetrating Radar) is also introduced. This chapter concludes with a summary of remote sensing and GIS matches for each of the nine civil works business practice areas.

a. Industry Perspective on Image Acquisition. In the past 30 years, selection of remotely sensed imagery was confined by system constraints and only provided by a few vendors. Imagery that was available from archive, or that would become available due to orbital frequency, maintained numerous constraints; consequently ground coverage, rather than image resolution, was the primary concern. Additionally, minor consideration was given to the spectral characteristics of the target and the spectral bands available, as there were a limited number of imaging platforms. To an extent projects had to be tailored to fit the limitations of the data. This is no longer the case however, with significant technologic improvements and numerous product choices. Creative researchers are finding new applications in the on-going advancement of remote sensing.

b. Image Improvements. Satellite sensor system developers continue to improve image cost, resolution, spectral band choices, spectral data library sets, and value-added products or post-processing methods. Improvements in sensor development and affordability can be attributed to the commercialization and subsequent expansion of the remote sensing industry. NASA, other US governmental agencies, and foreign space agencies, such as those in Canada, France, India, and Japan, progressively enhance the industry by furthering current technologic advances in the remote sensing field. Consequently, the resolution constraints on data that existed 20 or more years ago are no longer an obstacle with the addition of these affordable higher resolution systems. Listed here are just a few examples of airborne and satellite data costs:

- AVHRR scene at 1 km GSD for < \$50
- Landsat TM scene at 30 m GSD for \$625
- Landsat ETM scene can be acquired for \$800
- ERS-1 SAR scene at 25 m GSD for \$2000
- ERS-2 SAR scene at 25 m GSD for \$1500.
- Vendors of high-resolution satellite imaging systems products (such as IKONOS or QUICKBIRD or other products with <4 m GSD [ground sampling distance is the spatial resolution measurement]) charge on a per area basis. The minimum area is 11 km² for approximately \$2000.

c. Archive Imagery. This can be accessed and purchased at a reduced rate. Some imaging systems can acquire new imagery at reasonable rates as well. It is now possible to tailor acquisitions to meet the specific needs of Corps projects. Costs presented in this manual will fluctuate, but generally become more affordable over time. The downward trend in cost applies to all aspects of remote sensing - data acquisition and the required software and hardware.

3-2 Corps 9—Civil Works Business Practice Areas. The spatial, spectral, and temporal requirements set by the goals in a Corps business practice area should be balanced with the economic limits of the project. To achieve this result, it is helpful to consider a few preliminary steps when planning an image data acquisition. Below is a review of the Corps 9 Civil Works Business Practice Areas. The steps that should be taken to determine the specific data requirements follow each business practice. A list of vendor services is presented along with details on the various platforms (airborne, satellite, and ground penetrating radar). The nine business practice areas in Civil Works of the Corps of Engineers and a listing of their operations follows:

a. Navigation.

- Responsible for navigation channels.
- Dredging for specified width and depth.
- Maintenance of 12,000 miles of inland waterways.
- Maintenance of 235 locks.
- 300 commercial harbors.
- 600 smaller harbors.

b. Flood Damage Reduction.

- Build and maintain levees.
- Maintenance of 383 dams and reservoirs.
- Advice on zoning, regulations and flood warning systems.
- Shore protection—protection from hurricane and coastal storms.
- Construction of jetties, seawalls, and beach sand renourishment.
- Responsibility for dam safety—inspection of Corps and other's dams

c. Environmental Missions.

- Ecosystem restoration—many small ecosystem restoration projects, and the larger Florida Everglades hydrologic restoration project.
- Environmental stewardship—protect forest and wildlife habitat; monitor water quality at reservoirs; operate several fish hatcheries; support national goal of “no net loss of wetlands”; and projects on conservation, preservation, restoration and wetland creation.
- Radioactive site cleanup—FUSRAP (Formerly Used Sites Remedial Action Program).

d. Wetlands and Waterways Regulation and Permitting.

- Support Clean Water Act.

- Authority over dumping, dredging and filling in Waters of the US (WoUS).
- Determine areas for protection as wetlands (under guidelines of 1987 Wetland Delineation Manual), and permitting for land use.
- Water supply—Washington DC aqueduct operation, manage water supply from Corps reservoirs and water use for agriculture in arid regions of South-western US
- Hydroelectric power—Corps operates 75 hydroelectric power plants.

e. Real Estate.

- Full range of services to Army and Air Force.
- Manage Contingency Real Estate Support Team (CREST).
- DOD agent for Recruiting Facilities Program, Homeowners Assistance Program and Defense National Relocation Program.

f. Recreation.

- Operate and maintain 2500 recreation areas at 463 lakes.
- Rangers are Dept. of Army employees.
- Corps is active in National Water Safety Program.

g. Emergency Response.

- Response to hurricanes, tornadoes, flooding, and natural disasters.
- Support to FEMA when activated by Federal Response Plan (FRP).
- Under FRP Corps has lead for public works and engineering missions.

h. Research and Development.

ERDC is composed of seven research laboratories for military, civil works and civilian infrastructure applications:

TEC—Topographic Engineering Center

CERL—Construction Engineering and Research Laboratory

CRREL—Cold Regions Research and Engineering Laboratory

WES-GSL—Waterways Experiment Station-Geotechnical and Structures Laboratory

WES-EL—Waterways Experiment Station-Environmental Laboratory

WES-CHL—Waterways Experiment Station-Coastal Hydraulics Laboratory

WES-ITL—Waterways Experiment Station-Information Technology Laboratory

i. Support to Others. This includes engineering and water resources support to state and Federal agencies, and to foreign countries.

3-3 Sensor Data Considerations (programmatic and technical).

a. Below is a list of preliminary steps and questions to consider when planning an image data acquisition. Answer these questions in light of the Corps Civil Works 9 Business Practice Areas before proceeding.

- What is the primary goal of the project?
Define the problem.
How can remote sensing be applied to assist in solving the problem?
- What spatial resolution is need?
Determine the minimum, maximum, and/ or optimal GSD (ground sampling distance).
- What is the target or what is being mapped?
High-resolution panchromatic (black and white) aerial photography may be sufficient.
Define what spectral bands are needed.
- Will field work be included in the project budget?
What detail is needed from the imagery?
- What spectral resolution is needed?
Set bandwidth and proximity.
- Determine timing and temporal resolution requirements.
Select season(s) and time frequencies.
- How urgent is the data needed?
To capture an emergency event or temporal phenomena an airborne system may need to be promptly employed.
- What repeat cycle do we need?
Each sensor system operates on a different cycle.
- When will ground truth data be collection?
Image data acquisition ideally coincides with ground truth data collection.
- What are the weather and light conditions?
Select radar or optical imagery or adjust acquisition timing to accommodate for variable atmospheric conditions.
- What level of processing will be performed by the vendor?
For example, choose basic processes such as radiometric, atmospheric, and geometric corrections should be considered.
- What accuracy do we want?
Set vertical and horizontal limits.
- Where is the project geographically located?
Specify upper left/ lower right hand corner Latitudes and Longitudes.

- What is the funding situation?
Chose a system and methods that will allow you to cost-effectively follow through on a project.
 - Do we need new or archived data?
Avoid wasting resources by soliciting imagery data that already exists. Contact TEC Image Office (TIO) to determine image data availability and purchasing procedures.
- b.* Here are some ancillary decisions to be made based on answers to the above questions.
- What field of view is needed?
Specify image overlap if one image is not sufficient. Be aware that aircraft and flight line paths control image overlap. Should either be altered then the overlap could be negatively affected (Figure 3-1).
 - What acquisition look direction?
Radar imagery taken in mountainous regions can have layover distortion and shadow regions; whereas nadir looking airborne imagery has less of that effect, so that equal amounts of backscatter and transmission are collected on both sides of the feature.
 - Are commercial analytical services needed?
Will post-processing of the imagery be accomplished in-house, or does this require external expertise — an example is the processing of radar IFSAR into elevation data, which is a very special technique done by dedicated software on dedicated hardware and not generally done in-house. Below are examples of vendor post-processing services.



Figure 3-1. In this CAMIS image a decrease in aircraft altitude (due to circumstances beyond the operators control) reduced the pixel size and subsequently decreased the image scene. After mosaicing the individual scenes the side overlaps created “holidays” or gaps in the data. Taken from Campbell (2003).

3-4 Value Added Products. Examples of post-processing done on imagery are listed here with URLs to some of the companies that do the work (sometimes called level 2 or value added products).

- Earthsat Corporation <http://www.earthsat.com/ip/prodsvc/> offers geocoding, orthorectification, seamless mosaics, data fusion, and spectral transforms including simulated true color, minimum noise fraction (MNF), vegetation suppression, and decorrelation stretch. They offer hyperspectral processing such as atmospheric correction, automatic endmember selection, pixel unmixing, vegetation stress mapping, and aircraft motion compensation.
- The SPOT Corporation <http://www.spot.com/home/proser/welcome.htm> offers SPOTView (image map product), land use/land cover (thematic product), elevation/terrain mapping (3-D products), and vegetation products.
- Vectorization Services <http://www.vectorizationservices.com/services.htm> offers rectification and orthorectification, enhancement, mosaicing, fusion and image interpretation.
- Agricast <http://www.agricast.com/> offers value-added products for precision farming, agriculture, and range management.
- Science Applications International Corporation (SAIC) <http://www.saic.com/imagery/remote.html> offers many value added products for industries from agriculture to utilities. See their web site for the complete list.
- Emerge <http://www.emergeweb.com/Public/info/productsPage.asp> offers digital ortho products and mosaics from airborne imagery.
- The J.W. Sewall Company http://www.jws.com/pages/core_sevices.html offers photogrammetric mapping, cadastral mapping, municipal GIS development, energy and telecommunications services, and natural resources consulting.
- Analytical Imaging and Geophysics <http://www.aigllc.com/research/intro.htm> offers analysis of multispectral, hyperspectral and SAR imagery with map production and field verification.
- Spectral International, Inc. <http://www.pimausa.com/services.html> offers analytical services, consulting and hyperspectral image processing.
- Earthdata <http://www.earthdata.com/index2.htm> offers digital orthophotos, topographic maps, planimetric maps, and LIDAR 3-D elevation data.
- Intermap Technologies <http://www.intermaptechnologies.com/products.htm> offers IFSAR DEMs, DSMs, DTMs, and orthorectified radar images.
- 3Di <http://www.3dicorp.com/rem-products.html> offers LIDAR DEMs, orthorectified imagery, contour mapping, wetlands mapping, vegetation mapping, 3D perspective image drapes, and volumetric analysis.
- Terrapoint <http://www.terrapoint.com/Products2.htm> offers LIDAR elevation data sets, DTMs, DEMs, canopy DTMs, building heights, land records, and floodmaps.
- i-cubed <http://www.i3.com> offers information integration and imaging
- Leica Geosystems <http://www.gis.leica-geosystems.com> offers GIS and mapping.
- PhotoScience, Inc. <http://www.photoscience.com> offers aerial photography, photogrammetry, GPS survey, GIS services, image processing

3-5 Aerial Photography. Aerial photography is a highly useful mapping tool and maintains the highest spatial resolution of any of the remote sensing systems. Standard 9-in. (22.9 cm) aerial photos used for mapping and site identification are collected and made available through commercial companies. USGS generates digital elevation model (DEM) data and stereo classification of ground cover from aerial photography. These data are derived from the National Aerial Photography Program (NAPP), formally the National High Altitude Program (NHAP). The NAPP products are quarter quad-centered photographs of the entire contiguous US, acquired every 5 years over 2-year intervals since 1990. NAPP photography is acquired at 20,000 ft (~600 m) above mean terrain with a 6-in. (~15 cm) focal length lens. The flight lines are quarter quad-centered on the 1:24,000-scale USGS maps. NAPP photographs have an approximate scale of 1:40,000, and collect black-and-white or color infrared, as specified by state or Federal requirements. The St. Louis District of the Corps has several airborne contracts in place as well.

a. Softcopy photogrammetry is the semi-automatic processing of aerial photos after they have been digitally scanned into files and transferred into a computer. Once in digital form, the processes of stereo imaging, stereo compilation, aerial triangulation, topographic mapping, ortho-rectification, generation of DEMs, DTMs, and DSMs and digital map generation can be carried out.

b. Aerial photos are geometrically corrected using the fiducial marks and a camera model and projected into the ground coordinates. Images within a stereo overlap are adjusted using a triangulation algorithm so that they fit within the constraints of the ground control point information. At the end of the triangulation, individual stereo models are mathematically defined between stereo images. Topographic information is extracted from the images using autocorrelation techniques that match image patterns within a defined radius. By using parallax created by the different angle shots, elevation is measured from the distance of matching pixels. A terrain model is used to create an ortho-rectified image from the original photo that is precision geocoded and an ancillary Digital Surface Model (DSM) is available.

c. Some of the companies that contract with USACE for aerial photography include:

- Highland Geographic Inc. <http://www.highlandgeographic.com>
- James W. Sewall Company <http://www.sewall.com>
- Alcor Technologies Limited <http://www.alcortechnologies.com>
- Aero-Metric Inc. <http://www.aerometric.com>
- PhotoScience, Inc. <http://www.photoscience.com>

3-6 Airborne Digital Sensors. The advancement of airborne systems to include high resolution digital sensors is becoming available through commercial companies. These systems are established with onboard GPS for geographic coordinates of acquisitions, and real time image processing. Additionally, by the time the plane lands on the ground, the data can be copied to CDROM and be available for delivery to the customer with a basic level of processing. The data at this level would require image calibration and additional

processing. The data at this level would require image calibration and additional processing. See Appendix F for a list of airborne system sensors.

3-7 Airborne Geometries. There are several ways in which airborne image geometry can be controlled. Transects should always be flown parallel to the principle plane to the sun, such that the BRDF (bi-directional reflectance distribution function) is symmetrical on either side of the nadir direction. The pilot should attempt to keep the plane level and fly straight line transects. But since there are always some attitude disturbances, GPS and IMU (inertial measuring unit) data can be used in post-processing the image data to take out this motion. The only way of guaranteeing nadir look imagery is to have the sensor mounted on a gyro-stabilized platform. Without this, some angular distortion of the imagery will result even if it is post-processed with the plane's attitude data and an elevation model (i.e., sides of buildings and trees will be seen and the areas hidden by these targets will not be imaged). Shadow on one side of the buildings or trees cannot be eliminated and the dynamic range of the imagery may not be great enough to pull anything out of the shadow region. The only way to minimize this effect is to acquire the data at or near solar noon.

3-8 Planning Airborne Acquisitions.

a. Planning airborne acquisitions requires both business and technical skills. For example, to contract with an airborne image acquisition company, a sole source claim must be made that this is the only company that has these special services. If not registered as a prospective independent contractor for a Federal governmental agency, the company may need to file a Central Contractor Registration (CCR) Application, phone (888-227-2423) and request a DUNS number from Dun & Bradstreet, phone (800-333-0505). After this, it is necessary for the contractee to advertise for services in the Federal Business Opportunities Daily (FBO Daily) <http://www.fbodaily.com>. Another way of securing an airborne contractor is by riding an existing Corps contract; the St. Louis District has several in place. A third way is by paying another governmental agency, which has a contract in place. If the contractee is going to act as the lead for a group acquisition among several other agencies, it may be necessary to execute some Cooperative Research and Development Agreements (CRDAs) between the contractee and the other agencies. As a word of caution, carefully spell out in the legal document what happens if the contractor, for any reason, defaults on any of the image data collection areas. A data license should be spelled out in the contract between the parties.

b. Technically, maps must be provided to the contractor of the image acquisition area. They must be in the projection and datum required, for example Geographic and WGS84 (*World Geodetic System* is an earth fixed global reference frame developed in 1984). The collection flight lines should be drawn on the maps, with starting and ending coordinates for each straight-line segment. If an area is to be imaged then the overlap between flight lines must be specified, usually 20%. If the collection technique is that of overlapping frames then both the sidelap and endlap must be specified, between 20 and 30%. It is a good idea to generate these maps as vector coverages because they are easily changed when in that format and can be inserted into formal reports with any caption desired later.

The maximum angle allowable from nadir should be specified. Other technical considerations that will affect the quality of the resulting imagery include: What sun angle is allowable? What lens focal length is allowable? What altitude will the collection be flown? Will the imagery be flown at several resolutions or just one? Who will do the orthorectification and mosaicing of the imagery? Will DEMs, DTMs, or DSMs be used in the orthorectification process? How will unseen and shadow areas be treated in the final product? When planning airborne acquisitions, these questions should be part of the decision process.

3-9 Bathymetric and Hydrographic Sensors.

a. The Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS <http://shoals.sam.usace.army.mil/default.htm>) system is used in airborne lidar bathymetric mapping. The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) is a partnership between the South Atlantic Division, US Army Corps of Engineers (USACE), the Naval Meteorology and Oceanography Command and Naval Oceanographic Office and USACE's Engineer Research and Development Center. JALBTCX owns and operates the SHOALS system. SHOALS flies on small fixed wing aircraft, Twin Otter, or on a Bell 212 helicopter. The SHOALS system can collect data on a 4-m grid with vertical accuracy of 15 cm. In clear water bathymetry can be collected at 2–3 times Secchi depth or 60 m. It does not work in murky or sediment-laden waters.

b. The Corps uses vessels equipped with acoustic transducers for hydrographic surveys. The USACE uses multibeam sonar technology in channel and harbor surveys. Multibeam sonar systems are used for planning the depth of dredging needed in these shallow waters, where the accuracy requirement is critical and the need for correct and thorough calibration is necessary. USACE districts have acquired two types of multibeam transducers from different manufacturers, the Reson Seabat and the Odom Echoscan multibeam. The navigation and acquisition software commonly in use by USACE districts is HYPACK and HYSWEEP, by Coastal Oceanographics Inc. For further information see the web site at https://velvet.tec.army.mil/access/milgov/fact_sheet/multibea.html (due to security restrictions this site can only be accessed by USACE employees).

3-10 Laser Induced Fluorescence.

a. Laser fluorosensors detect a primary characteristic of oil, namely their characteristic fluorescence spectral signature and intensity. There are very few substances in the natural environment that fluoresce, those that do, fluoresce with sufficiently different spectral signatures and intensities that they can be readily identified. The Laser Environmental Airborne Fluorosensor (LEAF) is the only sensor that can positively detect oil in complex environments including, beaches and shorelines, kelp beds, and in ice and snow. In situations where oil contaminates these environments, a laser fluorosensor proves to be invaluable as a result of its ability to positively detect oil http://www.etcentre.org/home/water_e.html.

b. Other uses of laser fluorosensors are to detect uranium oxide present in facilities, abandoned mines, and spill areas that require remediation. See Special Technologies Laboratory of Bechtel, NV, <http://www.nv.doe.gov/business/capabilities/lifi/>.

3-11 Airborne Gamma.

a. An AC-500S Aero Commander aircraft is used by the National Operational Hydrologic Remote Sensing Center (NOHRSC) to conduct aerial snow survey operations in the snow-affected regions of the United States and Canada. During the snow season (January–April), snow water equivalent measurements are gathered over a number of the 1600+ pre-surveyed flight lines using a gamma radiation detection system mounted in the cabin of the aircraft. During survey flights, this system is flown at 500 ft (152 m) above the ground at ground speeds ranging between 100 and 120 knots (~51 to 62 m/s). Gamma radiation emitted from trace elements of potassium, uranium, and thorium radioisotopes in the upper 20 cm of soil is attenuated by soil moisture and water mass in the snow cover. Through careful analysis, differences between airborne radiation measurements made over bare ground are compared to those of snow-covered ground. The radiation differences are corrected for air mass attenuation and extraneous gamma contamination from cosmic sources. Air mass is corrected using output from precision temperature, radar altimeter, and pressure sensors mounted on and within the aircraft. Output from the snow survey system results in a mean areal snow water equivalent value within ± 1 cm. Information collected during snow survey missions, along with other environmental data, is used by the National Weather Service (NWS), and other agencies, to forecast river levels and potential flooding events attributable to snowmelt water runoff (<http://www.aoc.noaa.gov/>).

b. Other companies use airborne gamma to detect the presence of above normal gamma ray count, indicative of uranium, potassium, and thorium elements in the Earth's crust (for example, Edcon, Inc., <http://www.edcon.com>, and the Remote Sensing Laboratory at Bechtel, Nevada). The USGS conducted an extensive survey over the state of Alaska as part of the National Uranium Resource Evaluation (NURE) program that ran from 1974 to 1983, <http://edc.usgs.gov/>.

3-12 Satellite Platforms and Sensors.

a. There are currently over two-dozen satellite platforms orbiting the earth collecting data. Satellites orbit in either a circular geo-synchronous or polar sun-synchronous path. Each satellite carries one or more electromagnetic sensor(s), for example, Landsat 7 satellite carries one sensor, the ETM+, while the satellite ENVISAT carries ten sensors and two microwave antennas. Some sensors are named after the satellite that carries them, for instance IKONOS the satellite houses IKONOS the sensor. See Appendices D and E for a list of satellite platforms, systems, and sensors.

b. Sensors are designed to capture particular spectral data. Nearly 100 sensors have been designed and employed for long-term and short-term use. Appendix D summarizes details on sensor functionality. New sensors are periodically added to the family of ex-

isting sensors while older or poorly designed sensors become decommissioned or de-funct. Some sensors are flown on only one platform; a few, such as MODIS and MSS, are on-board more than one satellite. The spectral data collected may span the visible (optical), blue, green, microwave, MIR/SWIR, NIR, Red, or thermal IR. Sensors can detect single wavelengths or frequencies and/or ranges of the EM spectrum.

3-13 Satellite Orbits.

a. Remote sensing satellites are placed into different orbits for special purposes. The weather satellites are geo-stationary, so that they can image the same spot on the Earth continuously. They have equatorial orbits where the orbital period is the same as that of the Earth and the path is around the Earth's equator. This is similar to the communication satellites that continuously service the same area on the Earth (Figure 3-2).

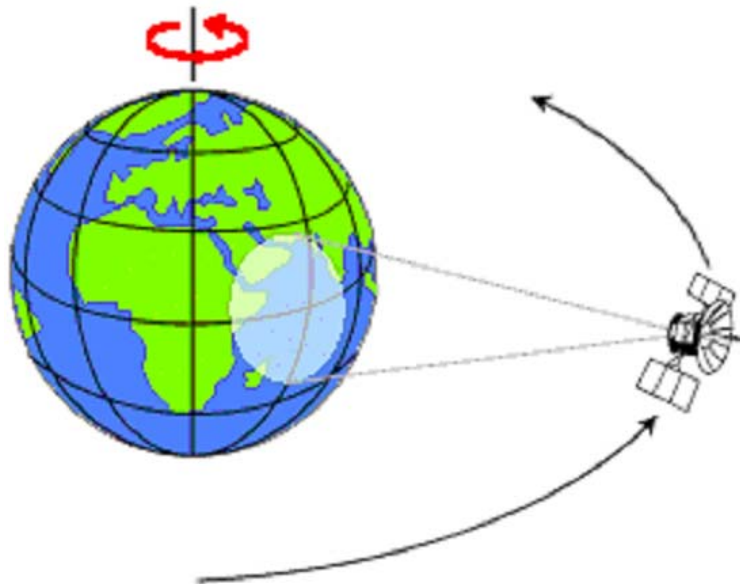


Figure 3-2. Satellite in Geostationary Orbit. Courtesy of the Natural Resources Canada.

b. The remaining remote sensing satellites have near polar orbits and are launched into a sun synchronous orbit (Figure 3-3). They are typically inclined 8 degrees from the poles due to the gravitational pull from the Earth's bulge at the equator; this allows them to remain in orbit. Depending on the swath width of the satellite (if it is non-pointable), the same area on the Earth will be imaged at regular intervals (16 days for Landsat, 24 days for Radarsat).

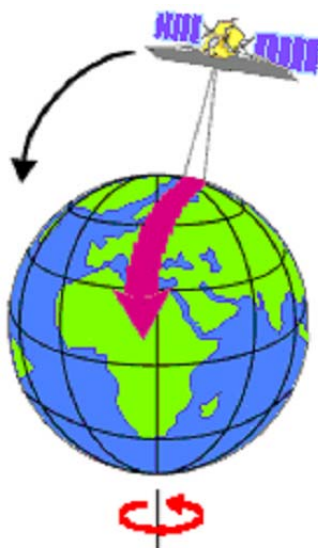


Figure 3-3. Satellite Near Polar Orbit, Courtesy of the Natural Resources Canada.

3-14 Planning Satellite Acquisitions. Corps satellite acquisition must be arranged through the Topographic Engineering Center (TEC) Imagery Office (TIO). It is very easy to transfer the cost of the imagery to TEC via the Corps Financial Management System (CFMS). They will place the order, receive and duplicate the imagery for entry into the National Imagery and Mapping Agency (NIMA) archive called the Commercial Satellite Imagery Library (CSIL), and send the original to the Corps requester. They buy the imagery under a governmental user license contract that licenses free distribution to other government agencies and their contractors, but not outside of these. It is important for Corps personnel to adhere to the conditions of the license. Additional information concerning image acquisition is discussed in Chapter 4 (Section 4-1).

a. Turn Around Time. This is another item to consider. That is the time after acquisition of the image that lapses before it is shipped to TEC-TIO and the original purchaser. Different commercial providers handle this in different ways, but the usual is to charge an extra fee for a 1-week turn around, and another fee for a 1 to 2 day turn around. For example, SPOT Code Red programmed acquisition costs an extra \$1000 and guarantees shipment as soon as acquired. The ERS priority acquisition costs an extra \$800 and guarantees shipment within 7 days, emergency acquisition cost \$1200 and guarantees shipment within 2 days, and near real time costs an extra \$1500 and guarantees shipment as soon as acquired. Also arrangement may be made for ftp image transfers in emergency situations. Costs increase in a similar way with RADARSAT, IKONOS, and QuickBird satellite imaging systems.

b. Swath Planners.

- Landsat acquired daily over the CONUS, use DESCW swath planner on PC running at least Windows 2000 for orbit locations. <http://earth.esa.int/services/descw/>
- ERS, JERS, ENVISAT—not routinely taken, use DESCW swath planner on PC running at least Windows 2000 for orbit locations. <http://earth.esa.int/services/descw/>
- RADARSAT—not routinely acquired, contact the TEC Imagery Office regarding acquisitions of Radarsat data.
- Other commercial imaging systems, contact the TEC Imagery Office regarding acquisitions.

3-15 Ground Penetrating Radar Sensors. Ground penetrating radar (GPR) uses electromagnetic wave propagation and back scattering to image, locate, and quantitatively identify changes in electrical and magnetic properties in the ground. Practical platforms for the GPR include on-the-ground point measurements, profiling sleds, and near-ground helicopter surveys. It has the highest resolution in subsurface imaging of any geophysical method, approaching centimeters. Depth of investigation varies from meters to several kilometers, depending upon material properties. Detection of a subsurface feature depends upon contrast in the dielectric electrical and magnetic properties. Interpretation of ground penetrating radar data can lead to information about depth, orientation, size, and shape of buried objects, and soil water content.

a. GPR is a fully operational Cold Regions Research and Engineering Laboratory (CRREL) resource. It has been used in a variety of projects: e.g., in Antarctica profiling for crevasses, in Alaska probing for subpermafrost water table and contaminant pathways, at Fort Richardson probing for buried chemical and fuel drums, and for the ice bathymetry of rivers and lakes from a helicopter.

b. CRREL has researched the use of radar for surveys of permafrost, glaciers, and river, lake and sea ice covers since 1974. Helicopter surveys have been used to measure ice thickness in New Hampshire and Alaska since 1986. For reports on the use of GPR within cold region environments, a literature search from the CRREL website (<http://www.crrel.usace.army.mil/>) will provide additional information. Current applications of GPR can be found at <http://www.crrel.usace.army.mil/sid/gpr/gpr.html>.

c. A radar pulse is modulated at frequencies from 100 to 1000 MHz, with the lower frequency penetrating deeper than the high frequency, but the high frequency having better resolution than the low frequency. Basic pulse repetition rates are up to 128 Hz on a radar line profiling system on a sled or airborne platform. Radar energy is reflected from both surface and subsurface objects, allowing depth and thickness measurements to be made from two-way travel time differences. An airborne speed of 25 m/s at a low altitude of no more than 3 m allows collection of line profile data at 75 Hz in up to 4 m of depth with a 5-cm resolution on 1-ft (30.5 cm)-grid centers. Playback rates of 1.2 km/min. are possible for post processing of the data.

d. There are several commercial companies that do GPR surveys, such as Blackhawk Geometrics and Geosphere Inc., found on the web at <http://www.blackhawkgeo.com>, and <http://www.geosphereinc.com>.

3-16 Match to the Corps 9—Civil Works Business Practice Areas. Match to the Corps business practice areas presupposes that everything about remote sensing for a particular ground or water parameter is known or works. However, this is not the case. Mapping for the amount of visible detail for a particular business area can be and has been readily listed in the National Imagery Interpretability Rating Scale (NIIRS). An approximate match between NIIRS level and GSD is given in the following.

a. *Navigation Needs*—lock and dam modification and construction, harbor facilities construction, channel dredging.

(1) How can remote sensing help in the maintenance, dredging, and planning for new construction?

(2) Remote sensing match:

- Hydrographic surveys creating maps of underwater depth and obstructions.
- Maps of original land and water area to be converted.
- Elevation profiles of the areas.
- Maps of the surrounding area to meet requirement of no net loss of wetlands.
- See Paragraph 3-3.

b. *Flood Damage Reduction Needs*—levee, dam, jetty, and seawall construction and beach sand re-nourishment projects, installation of flood warning systems.

(1) How can remote sensing help in planning for construction, for beach sand re-nourishment projects, and for the installation of flood warning systems?

(2) Remote sensing match:

- Maps of construction and surrounding areas.
- Elevation profiles of the areas.
- Beach maps and elevation profiles and near shore bathymetry.
- Levee top elevations for flood warning systems.
- See Paragraph 3-3.

c. *Environmental Mission Needs*—ecosystem restorations, protection of forest and wildlife habitat, water quality monitoring, wetland creation, radioactive and abandoned mine lands (AML) cleanup.

(1) How can remote sensing help in planning for ecosystem restorations, monitoring forest and wildlife habitat and water quality, and for wetland creation and AML cleanup?

(2) Remote sensing match:

- Maps of current ecosystem, wetlands, rivers, streams, aquifers, natural vegetation.
- Maps of forest types and vegetation communities.
- Map chlorophyll and sediments in lakes and reservoirs.
- Map mine sites, polluted drainage and stream and watershed areas.
- See “Sensor Data Considerations (programmatic and technical).”

d. Wetlands and Waterways Needs—authority over dumping, dredging, and filling in Waters of the US, delineate wetlands, monitor water quality of water supplies, planning conservation of water in the arid southwest.

(1) How can remote sensing help in delineating wetlands and issuing permits for dumping, dredging, and filling, monitoring water quality of water supplies, and in management of water in arid and agricultural regions of the west and southwest?

(2) Remote sensing match:

- Maps delineating wetlands.
- Maps of water quality and sedimentation of water supplies.
- Maps of snow/ water equivalency and reservoir capacity and agriculture demand.
- See Paragraph 3-3.

e. Real Estate Needs—locations and types.

(1) How can remote sensing help in planning real estate location and type?

(2) Remote sensing match:

- Mapping urban, suburban and city locations for entry into a GIS.
- see “Sensor Data Considerations (programmatic and technical).”

f. Recreation—maintain 2500 recreation areas.

(1) How can remote sensing help in maintenance and operation of recreation areas?

(2) Remote sensing match:

- Mapping and classification of forests and habitat in parks and monitoring water quality of lakes and reservoirs.
- See Paragraph 3-3.

g. Emergency Response—response to hurricanes and natural disasters.

(1) How can remote sensing help in response to natural disasters?

(2) Remote sensing match:

- Immediate mapping of disaster area.
- High resolution mapping to determine extent of personal damage (houses) and temporary roofing capability (FEMA regulated at 50 % roof rafters still in place).
- See Paragraph 3-3.

h. Research and Development—Seven research laboratories and support to the Nation's civil works sector.

(1) How can remote sensing help in the work carried out by the seven research laboratories and support the nation's civil works sector?

(2) Remote sensing match:

- Mapping and classification in mission areas and specific projects.
- Development of new methods and techniques of remote sensing and processing.
- See Paragraph 3-3.

i. Support to Others—other state and Federal agencies, foreign countries, and reimbursable work done.

(1) How can remote sensing help in work done for other state and federal agencies, foreign countries and in reimbursable work done?

(2) Remote sensing match:

- Mapping, remote sensing and GIS training, and classification in ongoing projects
- See Paragraph 3-3.

Chapter 4 Data Acquisition and Archives

4-1 Introduction.

a. *USACE Image Acquisition Standard Operating Procedure.* Image data should be acquired following the established protocol developed by ERDC's TEC Imaging Office (TIO)*. The protocol allows for efficient monitoring of image acquisition and archival practice. There are numerous advantages in using TIO's image procedure. The most significant advantage in using TIO's protocol is cost savings. This savings is the result of on-going contracts between satellite data vendors and the federal government. In addition to a reduced cost, TIO is able to broaden the image-share licensing allowing USACE full access to previously purchased data. The image-share licensing agreement is funded by NIMA who in turn allows all DoD and Title 50 Intelligence members full use of imagery data. In other words, once a USACE researcher has acquired imagery all other USACE districts can legally access these data at no charge. These data are also available to contractors working under a USACE contract.

b. *SOP.* The standard operating procedure (SOP) for acquiring new data is defined by the EM 1110-1-2909 (Appendix I), which states that no imagery shall be purchased from a commercial vendor without first coordinating with TIO (Appendix G). TIO has streamlined image data purchases and provides quick and efficient turn-around. The only exception to this SOP is in the case of acquiring free imagery downloaded from the Internet. A handful of governmental and commercial agencies (such as NASA and SpaceImaging) have made select satellite images available at no cost. These sites may require a login and can provide software for viewing data free of charge.

Ordering Commercial Satellite Imagery

"No imagery shall be purchased from a commercial vendor without first coordinating with the TIO. Any U.S. Army organization with commercial satellite imagery requirements must forward their commercial satellite imagery requirements to TEC for research, acquisition, and distribution of the data."

Contact TEC's Imagery Office, using one of the following methods:

Web Site: WWW.tec.army.mil/tio/index.htm

Email: TIO@tec.army.mil

ERDC (Engineer Research and Development Center) includes the seven Corps of Engineers research laboratories.

TEC (Topographic Engineering Center) serves the Corps of Engineers and the Department of Defense. TIO (TEC Imaging Office) monitors and coordinates all USACE image requirements with commercial vendors and public data libraries.

c. Placing Image Orders. Commercial imagery and aerial photo requests can be placed via email, memorandum, fax, or phone. The following image requirements should be determined prior to contacting TIO.

1. Geographic area of interest in latitude/longitude coordinates in degrees and minutes (or path/row if known).
2. Acceptable date range for data coverage; cloud cover and quality restrictions.
3. Satellite system/sensor.
4. Desired end product (digital or hard copy and preferred media).
5. Mailing and electronic address and phone number.

Consider the timing requirements for the project. For projects not involving emergencies or hazards satellite data may be delivered by regular mail. TIO can also deliver data by FEDEX and FTP. The TIO performs an image data search through the CSIL (Commercial Satellite Image Library). When data is available in the CSIL, the TIO receives a CD of the data, and copies the data for the customer.

DO

Verify your geo-coordinates.

Review imagery for accuracy and quality make sure the imagery covers your area of interest.

You may call a commercial satellite vendor to discuss technical problems encountered after you receive the imagery from the TEC Imagery Office (i.e.: accuracy and quality problems).

DO NOT

Contact the vendors on your own without first communicating with the TIO.

During the acquisition stage, do not consult the vendor's technical staff to have additional work done that is not stated in the written proposal.

d. Points of Contact (as of September 2003).

- Army Commercial Imagery Acquisition Program Manager—Mary Pat Santoro, 703-428-6903
- TIO Team Leader—Mary Brenke, 703-428-6909
- TIO Team Member—Alana Hubbard, 703-428-6717

4-2 Specifications for Image Acquisition. The TEC Imagery Office (TIO) is the first stop for obtaining imagery for the USACE, contact Mary Brenke (703-428-6909) or Alana Hubbard (703-428-6717). But, before contacting them, some basic information about what is wanted should be put together. A list follows:

- Geographic coordinates—upper left and lower right corner latitude–longitude coordinates or, if known, the path/row of a Landsat scene, the K/J of a SPOT scene; the orbit and frame number for a SAR image from ERS, Radarsat, JERS, or Envisat.
- Acceptable coverage dates.
- Acceptable percentage of cloud cover, image quality, and off nadir angle limit.
- Satellite sensor or sensors.
- Image format—digital tape, CDROM, projection wanted, projection parameters, tar (*tape archive retrieval* is a compression file format), satellite format, compression or uncompressed.
- Your name, phone, FAX, e-mail, mailing address.
- Payment—TIO will determine the correct cost for the imagery, which will be purchased for you by the USGS Eros Data Center (EDC). You will have to do a Military Interdepartmental Purchase Request (MIPR) of the money to EDC, EDC will send the imagery to the TIO for duplication and archiving in CSIL at NIMA, the original image will be forwarded to you.

4-3 Satellite Image Licensing. The license for satellite imagery is extended to a no cost duplication of the data for any DOD agencies and their contractors when the imagery is bought through the TEC-TIO contract with NIMA and the USGS EROS Data Center. Beyond that, the license specifically states that no other duplication of the unprocessed data is allowed.

4-4 Image Archive Search and Cost. The following is a compilation of archive search sources, along with web site addresses and the approximate cost of imagery. Data costs reflect new purchases and archive data rates at the time of the release of this manual.

<i>a. USGS EROS Data Center.</i>		http://earthexplorer.usgs.gov
LANDSAT (MSS, TM4 & 5)		\$ 425 - 2700.00
LANDSAT7 (ETM)		\$ 600
DOQQ		First Image \$ 45.00 Additional images: \$ 7.50 – Pan \$ 15.00 - Color
Full Orbit AVHRR		\$ 50
DEMs and DLGs		no cost
ALI (Landsat mimic 37km by 42km)	\$ 500 – 2800	http://eo1.usgs.gov/
Hyperion (hyperspectral 7.7km by 42km)	\$ 500 - 2800	

- | | |
|--|---|
| <p><i>b. Space Imaging Corp.</i></p> <p>IRS
IKONOS</p> | <p>http://www.spaceimaging.com</p> <p>\$ 2700.00
\$ 18 - 200.00 per sq km</p> |
| <p><i>c. SPOT Image Corp.</i></p> <p>SPOT Pan and Multi-spectral
RADARSAT and ERS</p> | <p>http://www.spot.com</p> <p>\$ 750.00 - 2500.00
\$ 1500.00 - 4500.00</p> |
| <p><i>d. RADARSAT INC.</i></p> | <p>http://www.rsi.ca</p> <p>\$ 1500.00 - 3,000.0</p> |
| <p><i>e. NOAA—Satellite Active Archive.</i></p> <p>AVHRR full swath limited Mbyte size</p> | <p>http://www.saa.noaa.gov</p> <p>no cost</p> |
| <p><i>f. Earth Satellite Corporation.</i></p> <p>Landsat scenes & mosaics</p> | <p>http://www.geocover.com</p> <p>\$ 250 - see price list</p> |
| <p><i>g. Digital Chart of the World.</i></p> <p>Penn State University Library
GIS themes including DEMs</p> | <p>http://www.maproom.psu.edu/dcw/</p> <p>no cost</p> |
| <p><i>h. AVIRIS Home Page.</i></p> <p>Archived or new AVIRIS scenes</p> | <p>http://makalu.jpl.nasa.gov</p> <p>\$500.00 or \$ 30k to 60k new data</p> |
| <p><i>i. Eurimage Home Page.</i></p> <p>Europe Landsat TM 4, 5,7,
IKONOS, Quickbird, ERS, IRS
Radarsat, Envisat, Resurs-01</p> | <p>http://www.eurimage.com</p> <p>see price list</p> |
| <p><i>j. AIGLLC home page.</i></p> <p>HyMap hyperspectral (2.3km x 20km)</p> | <p>http://www.aigllc.com</p> <p>\$ 5000</p> |
| <p><i>k. ESA Home Page.</i></p> <p>Mideast Envisat, ERS, IRS, Landsat,
AVHRR SeaWiFs, MODIS</p> | <p>http://earthnet.esrin.esa.it</p> <p>see price list</p> |

<i>l. ALOS Home Page.</i>	http://www.alos.nasda.go.jp
PRISM, AVNIR-2, PALSAR	see price list
<i>m. DigitalGlobe home page.</i>	http://www.digitalglobe.com
Quickbird	\$6,000 - see price list
<i>n. EOS DAAC.</i>	http://edcdaac.usgs.gov
MODIS, ASTER, Landsat 7	free - \$600 - see price list
<i>o. Geostationary Satellite Server.</i>	http://www.goes.noaa.gov
GOES, Meteosat weather satellite data	free
<i>p. Espatial Home Page.</i>	http://www.espatialweb.com
Emerge electronic camera	\$11k for 50 sq mi mission
<i>q. Positive Systems Home Page.</i>	http://www.possys.com
ADAR digital camera	quote on request
<i>r. Flight Landata Inc.</i>	http://www.flidata.com
DMSV, variable filter hyperspectral	quote on request
<i>s. Earth Search Sciences Inc (ESSI).</i>	http://www.earthsearch.com
Probe-1 hyperspectral	quote on request
<i>t. EarthData.</i>	http://www.earthdata.com
LIDAR elevation data	quote on request
<i>u. University of Florida.</i>	http://www.alsm.ufl.edu
LIDAR elevation & airphoto data (25km by 1km elev. and air photo)	quote on request \$ 75k
<i>v. SHOALS Home Page.</i>	http://shoals.sam.usace.army.mil
LIDAR bathymetry	quote on request

w. *Intermap.*

<http://www.intermaptechnologies.com>

IFSAR elevation quote on request
Archive tile (7.5min x 7.5min x 5m posting) \$2000

x. *Aeromap U.S.*

<http://www.aeromap.com>

Orthophotography, imagery, DEMs quote on request

y. *TerraSystems Inc.*

<http://www.terrasys.com>

TS-1 DMSV & TS-3 electronic quote on request

z. *DLR (German aerospace center).*

<http://www.dfd.dlr.de>

MOS ocean color data & others see price list

aa. *NASA Goddard DAAC.*

<http://daac.gsfc.nasa.gov>

CZCS, MODIS, OCTS, SeaWiFs
Ocean color sensors & others see price list

bb. *ENVISAT home page.*

<http://envisat.esa.int>

MERIS ocean color data & others see price list
DESCW swath planner free

cc. *Alaska SAR Facility.*

<http://www.asf.alaska.edu>

Radarsat mosaic of Antarctica free
Alaska High Altitude Air Photo Program (AHAP)

dd. *ITRES Research Limited.*

<http://www.itres.com>

CASI (hyperspectral) quote on request

4-5 Specifications for Airborne Acquisition. Maps must be provided to the contractor of the image acquisition area. They must be in the projection and datum required, for example Geographic and WGS84. The collection flight lines should be drawn on the maps with starting and ending coordinates for each straight-line segment. If an area is to be imaged, then the overlap between flight lines must be specified, usually 20%. If the collection technique is that of overlapping frames, then both the sidelap and endlap must be specified, between 20 and 30%.

4-6 Airborne Image Licensing. Licenses for data collected by aircraft vary. The contractor must read and agree to the terms. Some state that there are no conditions, some state that the data can be passed or resold to others after a certain period of time, some state the contractor is the sole owner of the data and that they can never be passed without their written permission.

4-7 St. Louis District Air-Photo Contracting. The St. Louis District has an extensive Geodesy, Cartography, and Photogrammetry (GC&P) Section. Photogrammetrists as certified by the American Society of Photogrammetry and Remote Sensing (ASPRS) have many years of experience in aerial photography, surveying, mapping and in the A-E Contracting of these services. The GC&P section is currently responsible for the technical management of all aerial photography and mapping projects within the St. Louis District. They provide contracting services for all photogrammetric mapping projects for other government agencies, as well as other Corps of Engineers Districts.

a. Their experts in photogrammetry can provide assistance in developing contracts, scopes of work, government estimates or negotiation assistance. Technical guidance is provided in the development, acquisition, accuracy, and utilization of base topographic and planimetric mapping. They also provide advice on remote sensing data, environmental data sets, and engineering data to be incorporated into Geographic Information Systems (GIS) to assist engineers and scientists in Corps of Engineers project work.

b. The Point of Contact at the St. Louis District is Dennis Morgan (314)-331-8373. Appendices H and I include example contracts of a Statement of Work (SOW) and a Memorandum of Understanding (MOU).

Chapter 5

Processing Digital Imagery

5-1 Introduction. Image processing in the context of remote sensing refers to the management of digital images, usually satellite or digital aerial photographs. Image processing includes the display, analysis, and manipulation of digital image computer files. The derived product is typically an enhanced image or a map with accompanying statistics and metadata. An image analyst relies on knowledge in the physical and natural sciences for aerial view interpretation combined with the knowledge of the nature of the digital data (see Chapter 2). This chapter will explore the basic methods employed in image processing. Many of these processes rely on concepts included in the fields of geography, physical sciences, and analytical statistics.

5-2 Image Processing Software.

a. Imaging software facilitates the processing of digital images and allows for the manipulation of vast amounts of data in the file. There are numerous software programs available for image processing and image correction (atmospheric and geometric corrections). A few programs are available as share-ware and can be downloaded from the internet. Other programs are available through commercial vendors who may provide a free trial of the software. Some vendors also provide a tutorial package for testing the software.

b. The various programs available have many similar processing functions. There may be minor differences in the program interface, terminology, metadata files (see below), and types of files it can read (indicated by the file extension). There can be a broad range in cost. Be aware of the hardware requirements and limitations needed for running such programs. An on-line search for remote sensing software is recommended to acquire pertinent information concerning the individual programs.

5-3 Metadata.

a. Metadata is simply ancillary information about the characteristics of the data; in other words, it is data about the data. It describes important elements concerning the acquisition of the data as well as any post-processing that may have been performed on the data. Metadata is typically a digital file that accompanies the image file or it can be a hardcopy of information about the image. Metadata files document the source (i.e., Landsat, SPOT, etc.), date and time, projection, precision, accuracy, and resolution. It is the responsibility of the vendor and the user to document any changes that have been applied to the data. Without this information the data could be rendered useless.

b. Depending on the information needed for a project, the metadata can be an invaluable source of information about the scene. For example, if a project centers on change detection, it will be critical to know the dates in which the image data were collected. Numerous agencies have worked toward standardizing the documentation of metadata in an effort to simplify the process for both vendors and users. The Army Corps of Engineers follows the Federal Geographic Data Committee (FGDC) standards for metadata

(go to <http://geology.usgs.gov/tools/metadata/standard/metadata.html>). The importance of metadata cannot be overemphasized.

5-4 Viewing the Image. Image files are typically displayed as either a gray scale or a color composite (see Chapter 2). When loading a gray scale image, the user must choose one band for display. Color composites allow three bands of wavelengths to be displayed at one time. Depending on the software, users may be able to set a default band/color composite or designate the band/color combination during image loading.

5-5 Band/Color Composite. A useful initial composite (as seen in Figure 5-1a) for a Landsat TM image is Bands 3, 2, 1 (RGB). This will place band 3 in the red plane, band 2 in the green plane, and band 1 in the blue plane. The resultant image is termed a true-color composite and it will resemble the colors one would observe in a color photograph. Another useful composite is Bands 4, 3, 2 (R, G, B), known as a false-color composite (Figure 5-1b). Similar to a false-color infrared photograph, this composite displays features with color and contrast that differ from those observed in nature. For instance, healthy vegetation will be highlighted by band 4 and will therefore appear red. Water and roads may appear nearly black.



a. True-color Landsat TM composite 3, 2, 1 (RGB respectively).

b. False color composite 4, 3, 2.

Figure 5-1. Figure 5-1a is scene in which water, sediment, and land surfaces appear bright. Figure 5-1b is a composite that highlights healthy vegetation (shown in red); water with little sediment appears black. Images developed for USACE Prospect #196 (2002).

5-6 Information About the Image. Once the image is displayed it is a good idea to become familiar with the characteristics of the data file. This information may be found in a separate metadata file or as a header file embedded with the image file. Be sure to note the pixel size, the sensor type, data, the projection, and the datum.

5-7 Datum.

a. A geographic datum is a spherical or ellipsoidal model used to reference a coordinate system. Datums approximate the shape and topography of the Earth. Numerous

datums have evolved, each developed by the measurement of different aspects of the Earth's surface. Models are occasionally updated with the use of new technologies. For example, in 1984 satellites carrying GPS (global position systems) refined the World Geodetic System 1927 (WGS-27); the updated datum is referred to as WGS-84 (World Geodetic System-1984). Satellite data collected prior to 1984 may have coordinates linked to the WGS-27 datum. Georeferencing coordinates to the wrong datum may result in large positional errors. When working with multiple images, it is therefore important to match the datum for each image.

b. Image processing software provide different datums and will allow users to convert from one datum to another. To learn more about geodetic datums go to http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/geo4lay.pdf.

5-8 Image Projections.

a. Many projects require precise location information from an image as well as geocoding. To achieve these, the data must be georeferenced, or projected into a standard coordinate system such as Universal Transverse Mercator (UTM), Albers Conical Equal Area, or a State Plane system. There are a number of possible projections to choose from, and a majority of the projections are available through image processing software. Most software can project data from one map projection to another, as well as unprojected data. The latter is known as rectification. Rectification is the process of fitting the grid of pixels displayed in an image to the map coordinate system grid (see Paragraph 5-14).

b. The familiar latitude and longitude (Lat/Long) is a coordinate system that is applied to the globe (Figure 5-2). These lines are measured in degrees, minutes, and seconds (designated by °, ', and " respectively). The value of one degree is given as 60 minutes; one minute is equivalent to 60 seconds ($1^{\circ} = 60'$; $1' = 60''$). It is customary to present the latitude value before the longitude value.

5-9 Latitude. Latitude lines, also known as the parallels or parallel lines, are perpendicular to the longitude lines and encircle the girth of the globe. They are parallel to one another, and therefore never intersect. The largest circular cross-section of the globe is at the equator. For this reason the origin of latitude is at the equator. Latitude values increase north and south away from the equator. The north or south direction must be reported when sighting a coordinate, i.e., 45°N. Latitude values range from 0 to 90°, therefore the maximum value for latitude is 90°. The geographic North Pole is at 90°N while the geographic South Pole is at 90°S

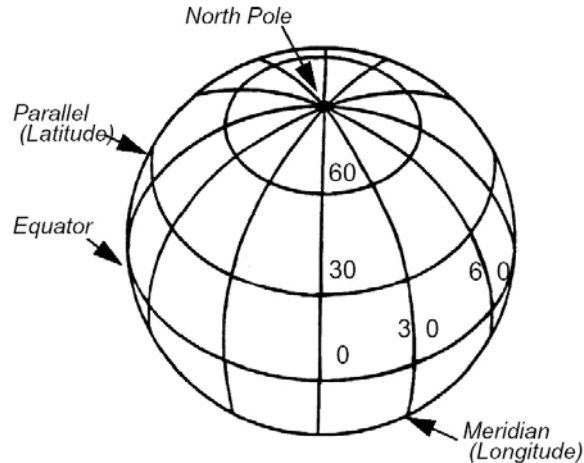


Figure 5-2. Geographic projection.

5-10 Longitude. The lines of longitude pass through the poles, originating at Greenwich, England (0° longitude) and terminating in the Pacific (180°). Because the Earth's spheroidal shape approximates a circle, its degree measurement can be given as 360° . Therefore, to travel half way around the world one must move 180° . The degrees of longitude increase to the east and west, away from the origin. The coordinate value for longitude is given by the degree number and the direction from the origin, i.e., 80°W or 130°E . **Note:** 180°W and 180°E share the same line of longitude.

5-11 Latitude/Longitude Computer Entry. Software cannot interpret the north/south or east/west terms used in any coordinate system. Negative numbers must be used when designating latitude coordinates south of the Equator or longitude values west of Greenwich. This means that for any location in North America the latitude coordinate will be positive and the longitude coordinate will be given as a negative number. Coordinates north of the equator and east of Greenwich will be positive. It is usually not necessary to add the positive sign (+) as the default values in most software are positive numbers. The coordinates for Niagara Fall, New York are $43^\circ 6' \text{N}$, $79^\circ 57' \text{W}$; these values would be recorded as decimal degrees in the computer as 43.1° , -79.95° . Notice that the negative sign replaces the "W" and minutes were converted to decimal degrees (see example problem below). **Important Note:** Coordinates west of Greenwich England are entered into the computer as a negative value.

5-12 Transferring Latitude/Longitude to a Map. Satellite images and aerial photographs have inherent distortions owing to the projection of the Earth's three-dimensional surface onto two-dimensional plane (paper or computer monitor). When the Latitude/Longitude coordinate system is projected onto a paper plane, there are tremendous distortions. These distortions lead to problems with area, scale, distance, and direction. To alleviate this problem cartographers have developed alternative map projections.

Problem: The Golden Gate Bridge is located at latitude $37^{\circ} 49' 11''$ N, and longitude $122^{\circ} 28' 40''$ W. Convert degrees, minutes, and seconds (known as sexagesimal system) to decimal degrees and format the value for computer entry.

Solution: The whole units of degrees will remain the same (i.e., the value will begin with 37). Minutes and seconds must be converted to degrees and added to the whole number of degrees.

Calculation: Latitude: $37^{\circ} = 37^{\circ}$
 $49' = 49'(1^{\circ}/60') = 0.82^{\circ}$
 $11'' = 11''(1'/60'')(1^{\circ}/60') = 0.003^{\circ}$
 $37^{\circ} + 0.82^{\circ} + 0.003^{\circ} = 37.82^{\circ}$
 $37^{\circ} 49' 11'' \text{ N} = 37.82^{\circ}$

Longitude: $122^{\circ} = 122^{\circ}$
 $28' = 28'(1^{\circ}/60') = 0.47^{\circ}$
 $40'' = 40''(1'/60'')(1^{\circ}/60') = 0.01^{\circ}$
 $122^{\circ} + 0.47^{\circ} + 0.01^{\circ} = 122.48^{\circ}$
 $122^{\circ} 28' 40'' \text{ W} = 122.48^{\circ}$

Answer: $37.82^{\circ}, -122.48^{\circ}$

5-13 Map Projections.

a. Map projections are attempts to render the three-dimensional surface of the earth onto a planar surface. Projections are designed to minimize distortion while preserving the accuracy of the image elements important to the user. Categories of projections are constructed from cylindrical, conic, and azimuthal planes, as well as a variety of other techniques. Each type of projection preserves and distorts different properties of a map projection. The most commonly used projections are Geographical (Lat/Lon), Universal Transverse Mercator (UTM), and individual State Plane systems. Geographic (Lat/Lon) is the projection of latitude and longitude with the use of a cylindrical plane tangent to the equator. This type of projection creates great amounts of distortion away from the poles (this explains why Greenland will appear larger than the US on some maps).

b. The best projection and datum to use will depend on the projection of accompanying data files, location of the origin of the data set, and limitations on acceptable projection distortion.

5-14 Rectification.

a. Image data commonly need to be rectified to a standard projection and datum. Rectification is a procedure that distorts the grid of image pixels onto a known projection and datum. The goal in rectification is to create a faithful representation of the scene in terms of position and radiance. Rectification is performed when the data are unprojected, needs to be reprojected, or when geometric corrections are necessary. If the analysis does not require the data to be compared or overlain onto other data, corrections and projections may not be necessary. See Figure 5-3 for an example of a rectified image.

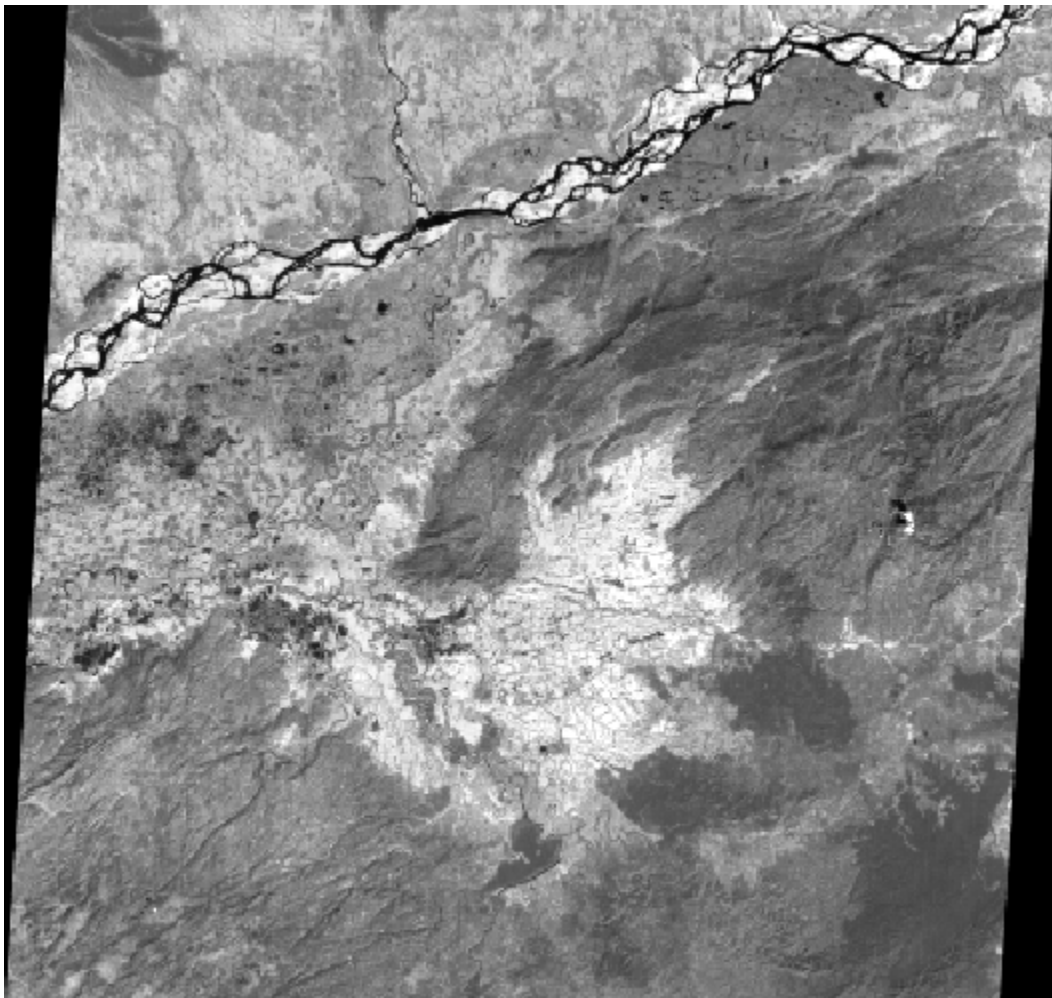


Figure 5-3. A rectified image typically will appear skewed. The rectification correction has rubber-sheeted the pixels to their geographically correct position. This geometric correction seemingly tilts the image leaving black margins where there are no data.

b. There are two commonly used rectification methods for projecting data. Image data can be rectified by registering the data to another image that has been projected or by assigning coordinates to the unprojected image from a paper or digital map. The following sections detail these methods. A third method uses newly collected GIS reference points or in-house GIS data such as road, river, or other Civil Works GIS information.

5-15 Image to Map Rectification. Unprojected images can be warped into projections by creating a mathematical relationship between select features on an image and the same feature on a map (a USGS map for instance). The mathematical relationship is then applied to all remaining pixels, which warps the image into a projection.

5-16 Ground Control Points (GCPs). The procedure requires the use of prominent features that exist on both the map and the image. These features are commonly referred to as ground control points or GCPs. GCPs are well-defined features such as sharp bends in a river or intersections in roads or airports. Figure 5-4 illustrates the selection of GCPs in the image-to-image rectification process; this process is similar to that used in image to map rectification. The minimum number of GCPs necessary to calculate the transformation depends upon the order of the transformation. The order of transformation can be set within the software as 1st, 2nd, or 3rd order polynomial transformation. The following equation (5-1) identifies the number of GCPs required to calculate the transformation. If the minimum number is not met, an error message should inform the user to select additional points. Using more than the minimum number of GCPs is recommended.

$$\frac{(t+1)(t+2)}{2} = \text{minimum number of GCPs} \quad 5-1$$

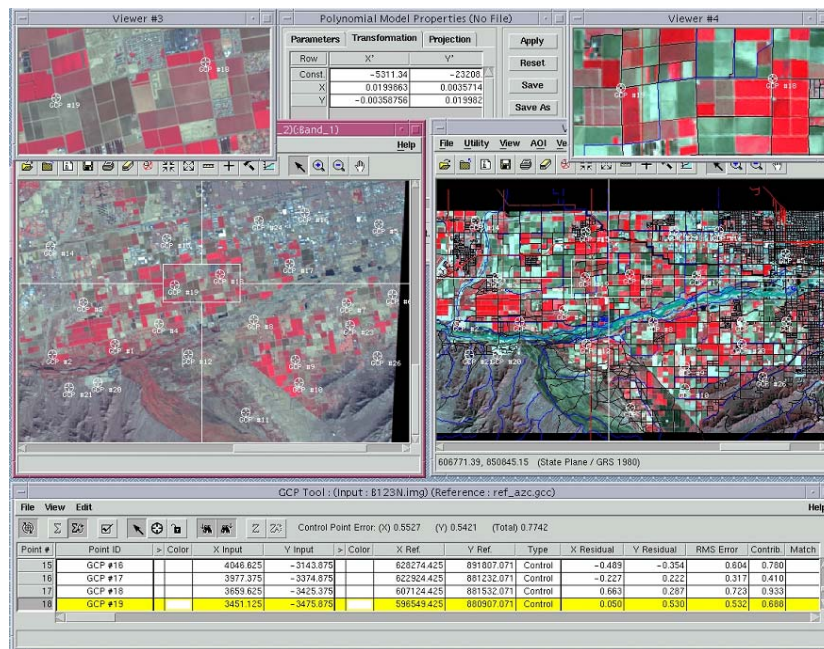
where t = order of transformation (1st, 2nd, or 3rd).

a. To begin the procedure, locate and record the coordinate position of 10 to 12 features found on the map and in the image. Bringing a digital map into the software program will simplify coordinate determination with the use of a coordinate value tool. When using a paper map, measure feature positions as accurately as possible, and note the map coordinate system used. The type of coordinate system used must be entered into the software; this will be the projection that will be applied to the image. Once projected, the image can be easily projected into a different map projection.

b. After locating a sufficient number of features (and GCPs) on the map, find the same feature on the image and assign the coordinate value to that pixel. Zooming in to choose the precise location (pixel) will lower the error. When selecting GCPs, it is best to choose points from across the image, balancing the distribution as much as possible; this will increase the positional accuracy. Once the GCP pixels have been selected and given a coordinate value, the software will interpolate and transform the remaining pixels into position.

5-17 Positional Error. The program generates a least squares or “Root Mean Square” (RMS) estimation of the positional accuracy of the mathematical transforma-

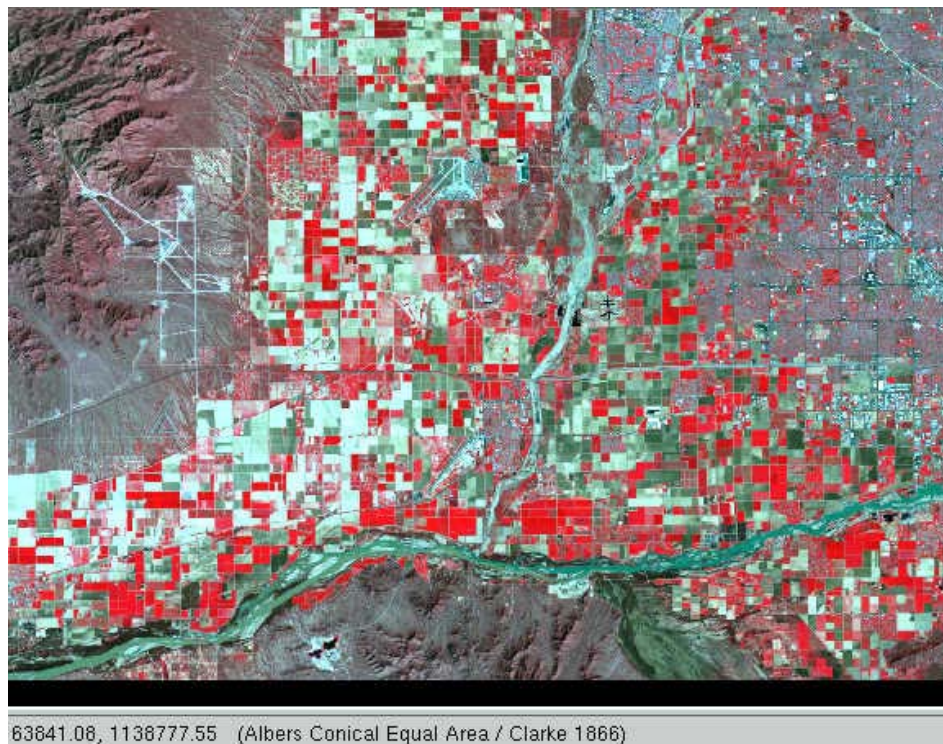
tion. The root mean square estimates the level of error in the transformation. The estimate will not be calculated until three or four GCPs have been entered. Initial estimates will be high, and should decrease as more GCPs are added to the image. A root mean square below 1.0 is a reasonable level of accuracy. If the RMS is higher than 1.0, simply reposition GCPs with high individual errors or delete them and reselect new GCPs. With an error less than 1.0 the image is ready to be warped to the projection and saved.



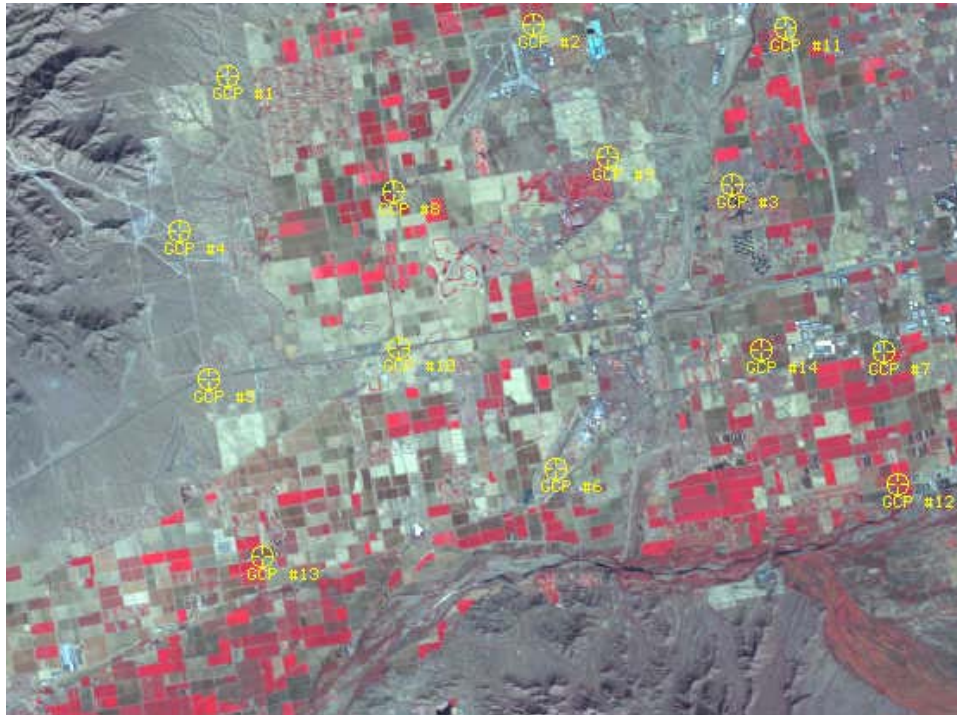
a. The scene appearance of the GCP selection module may look similar to this scene capture. Each segment of the function is presented individually below.



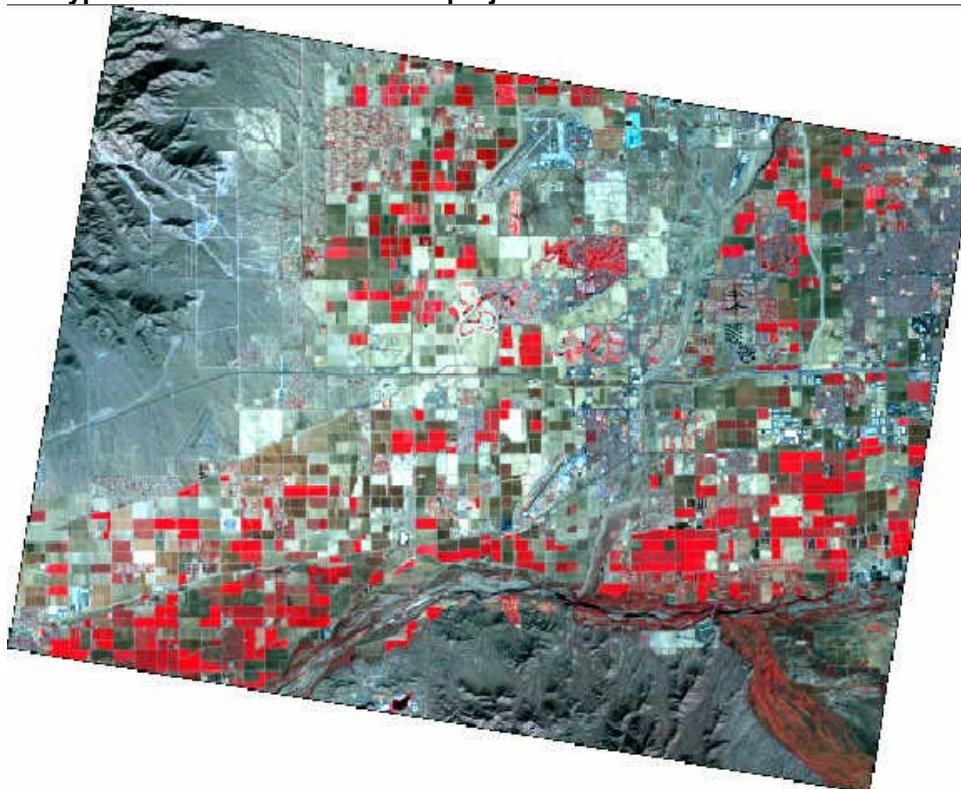
b. This scene represents the original, unprojected data file



c. This geo-registered image is used to match sites within the unprojected data file. Projected images such as this are often available on-line.



d. GCPs are located by matching image features between the projected and unprojected image. Notice the balanced spatial distribution of the GCPs; this type of distribution lowers the projection error.



e. Unprojected data are then warped to the GCP positions. This results in a skewed image. The image is now projected onto a coordinate system and is now ready for GIS processing.

Point #	Point ID	> Color	X Input	Y Input	> Color	X Ref.	Y Ref.	Type	X Residual	Y Residual	RMS Error
1	GCP #1	>	1975.622	-2753.911	>	49213.866	1161299.942	Control	1.234	1.972	2.326
2	GCP #2	>	2655.250	-2637.750	>	59543.625	1161310.875	Control	1.379	0.956	1.678
3	GCP #3	>	3098.250	-2996.250	>	65186.625	1154926.875	Control	-0.774	0.961	1.234
4	GCP #4	>	1868.859	-3098.903	>	46798.702	1156464.425	Control	1.623	1.324	2.094
5	GCP #5	>	1931.464	-3429.864	>	46894.946	1151387.293	Control	0.571	-1.450	1.558
6	GCP #6	>	2703.750	-3629.250	>	57822.011	1146542.026	Control	0.187	-0.572	0.602
7	GCP #7	>	3435.150	-3369.297	>	69283.500	1148578.500	Control	1.021	0.736	1.258
8	GCP #8	>	2343.645	-3013.072	>	53967.095	1156542.926	Control	-2.201	0.076	2.203
9	GCP #9	>	2820.656	-2935.227	>	61218.435	1156484.175	Control	-1.299	-1.320	1.852
10	GCP #10	>	2355.239	-3363.377	>	53271.130	1151353.348	Control	-3.162	0.435	3.192
11	GCP #11	>	3216.509	-2647.033	>	67765.742	1159693.500	Control	-1.119	-5.344	5.460
12	GCP #12	>	3465.588	-3666.561	>	68978.790	1144097.756	Control	-0.742	-0.866	1.140
13	GCP #13	>	2052.654	-3828.383	>	47701.592	1145192.371	Control	-0.153	-2.550	2.554
14	GCP #14	>	3163.098	-3364.161	>	65321.952	1149396.204	Control	3.435	5.641	6.605
15	GCP #15	>			>			Control			

f. RMS error for each GCP is recorded in a matrix spreadsheet. A total RMS error of 0.7742 is provided in the upper margin of Figure 5-4a.

Figure 5-4. GCP selection display modules.

5-18 Project Image and Save. The last procedure in rectification involves re-sampling the image using a “nearest neighbor” re-sampling technique. The software easily performs this process. Nearest neighbor re-sampling uses the value of the nearest pixel and extracts the value to the output, or re-sampled pixel. This re-sampling method preserves the digital number value (spectral value) of the original data. Additional re-sampling methods are bilinear interpolation and cubic convolution, which recalculate the spectral data. The image is projected subsequent to re-sampling, and the file is ready to be saved with a new name.

Recommendation: Naming altered data files and documenting procedures

Manipulating the data alters the original data file. It is therefore a good idea to save data files with different names after performing major alterations to the data. This practice creates reliable data backup files.

Because of the number of data files an analysis can create, it is best to clearly name the altered image files with the procedure name performed on the image (i.e., “TmSept01warped” indicates Thematic Mapper data collected September 2001, warped by user). Be sure to document your procedures and parameters used in a journal or a text file. Include the name of the altered file, changes applied to the data, the date, and other useful information.

5-19 Image to Image Rectification.

a. Images can also be rectified to a second projected digital image. The procedure is similar to that performed in image to map rectification. Simply locate common, identifiable features in both images, match the locations, and assign GCPs. Adjust GCPs until RMS error is less than 1.0. Enter the coordinate system that will be used and designate a re-sampling method (Figure 5-4).

b. Rectified images can easily be converted from one coordinate system to another. Projected images can readily be superimposed onto other projected data and used for georeferencing image features.

5-20 Image Enhancement. The major advantage of remote sensing data lies in the ability to visually evaluate the data for overall interpretation. An accurate visual interpretation may require modification of the output brightness of a pixel in an effort to improve image quality. Here are a number of methods used in image enhancement. This paragraph examines the operations of 1) contrast enhancement, 2) band ratio, 3) spatial filtering, and 4) principle components. The type of enhancement performed will depend on the appearance of the original scene and the goal of the interpretation.

a. Image Enhancement #1: Contrast Enhancement.

(1) *Raw Image Data.* Raw satellite data are stored as multiple levels of brightness known as the digital number (DN). Paragraph 2-7*a* explained the relationship between the number of brightness levels and the size of the data storage. Data stored in an 8-bit data format maintain 256 levels of brightness. This means that the range in brightness will be 0 to 255; zero is assigned the lowest brightness level (black in gray- and color-scale images), while 255 is assigned the highest brightness value (white in gray scale or 100% of the pigment in a color scale). The list below summarizes the brightness ranges in a gray scale image.

0	=	black
50	=	dark gray
150	=	medium gray
200	=	light gray
255	=	white

(*a*) When a satellite image is projected, the direct one-to-one assignment of gray scale brightness to digital number values in the data set may not provide the best visual display (Figures 5-5 and 5-6). This will happen when a number of pixel values are clustered together. For instance, if 80% of the pixels displayed DNs ranging from 50–95, the image would appear dark with little contrast.

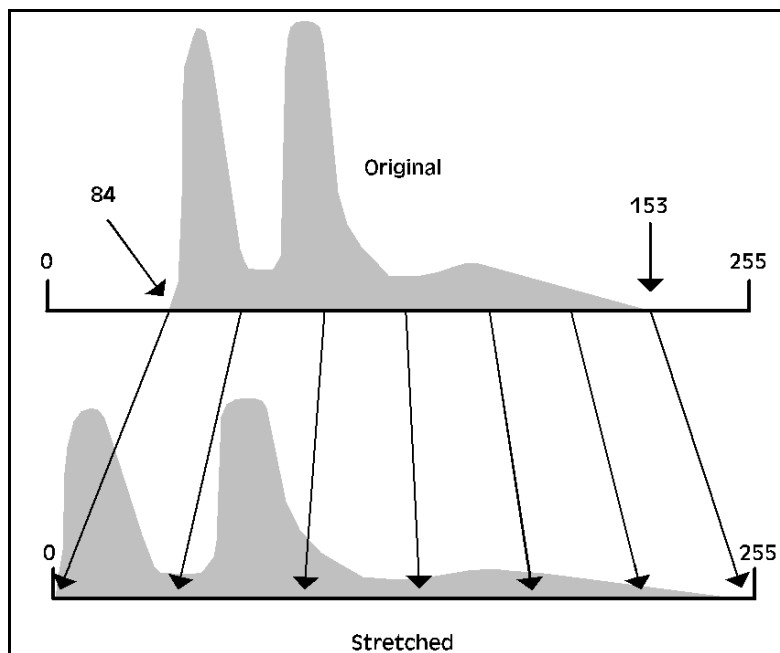


Figure 5-5. A linear stretch involves identifying the minimum and maximum brightness values in the image histogram and applying a transformation to stretch this range to fill the full range across 0 to 255.



Figure 5-6. Contrast in an image before (left) and after (right) a linear contrast stretch. Taken from http://rst.gsfc.nasa.gov/Sect1/Sect1_12a.html.

(b) The raw data can be reassigned in a number of ways to improve the contrast needed to visually interpret the data. The technique of reassigning the pixel DN value is known as the image enhancement process. Image enhancement adds contrast to the data by stretching clustered DNs across the 0–255 range. If only a small part of the DN range is of interest, image enhancement can stretch those values and compress the end values to suppress their contrast. If a number of DNs are clustered on the 255 end of the range,

it is possible that a number of the pixels have DN's greater than 256. An image enhancement will decompress these values, thereby increasing their contrast.

Data Analysis

Histograms

Image processing software can chart the distribution of digital number values within a scene. The distribution of the brightness values is displayed as a histogram chart. The horizontal axis shows the spread of the digital numbers from 0 to the maximum DN value in the data set. The vertical axis shows the frequency or how many pixels in the scene each value has (Figure 5-7). The histogram allows an analyst to quickly access the type of distribution maintained by the data. Types of distribution may be normal, bimodal, or skewed (Figure 5-7). Histograms are particularly useful when images are enhanced.

Lookup Tables

A lookup table (LUT) graphs the intensity of the input pixel value relative to the output brightness observed on the screen. The curve does not provide information about the frequency of brightness, instead it provides information regarding the range associated with the brightness levels. An image enhancement can be modeled on a lookup table to better evaluate the relationship between the unaltered raw data and the adjusted display data.

Scatter plots

The correlation between bands can be seen in scatter plots generated by the software. The scatter plots graph the digital number value of one band relative to another (Figure 5-8). Bands that are highly correlated will produce plots with a linear relationship and little deviation from the line. Bands that are not well correlated will lack a linear relationship. Digital number values will cluster or span the chart randomly. Scatter plots allow for a quick assessment of the usefulness of particular band combinations.

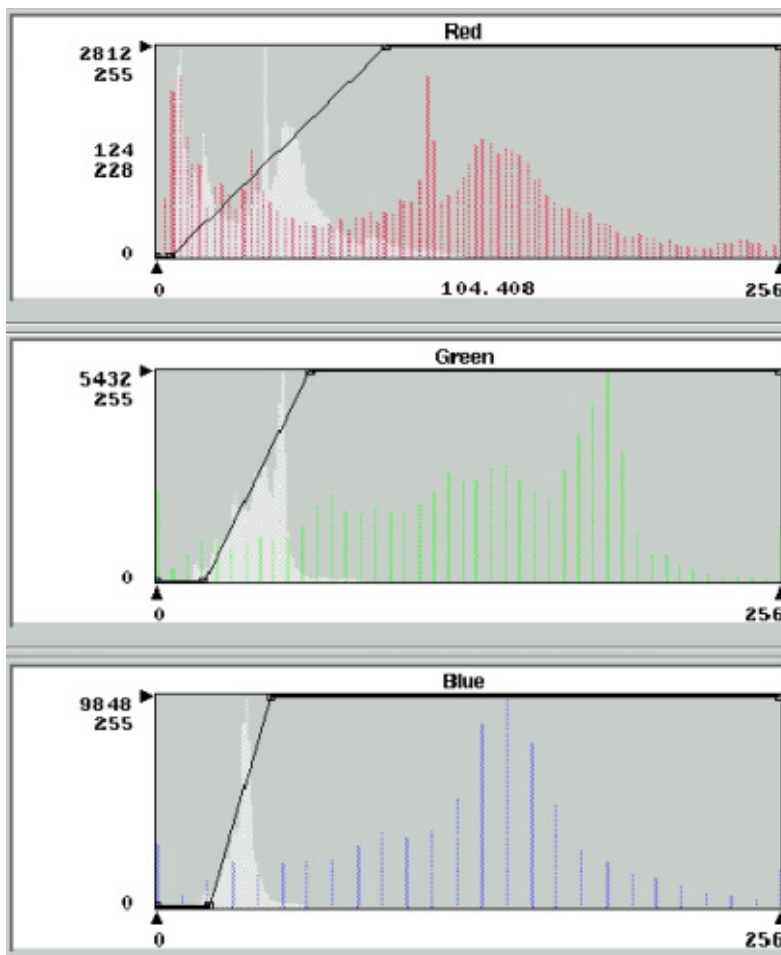


Figure 5-7. Pixel population and distribution across the 0 to 255 digital number range. All three plots show the pixel distribution before and after a linear stretch function (white denotes pre-stretch distribution and colored elements denote stretched pixel distribution). The stretched histogram shows gaps between the single values due to the discrete number of pixel values in the data set. The top histogram (red) has a bimodal distribution. The middle (green) maintains a skewed distribution, while the last histogram (blue) reveals a normal distribution. The solid black line superimposed in each image indicates the maximum and minimum DN value that is stretched across the entire range. Notice the straight lines that join the linear segment. Image taken from Prospect (2002 and 2003).

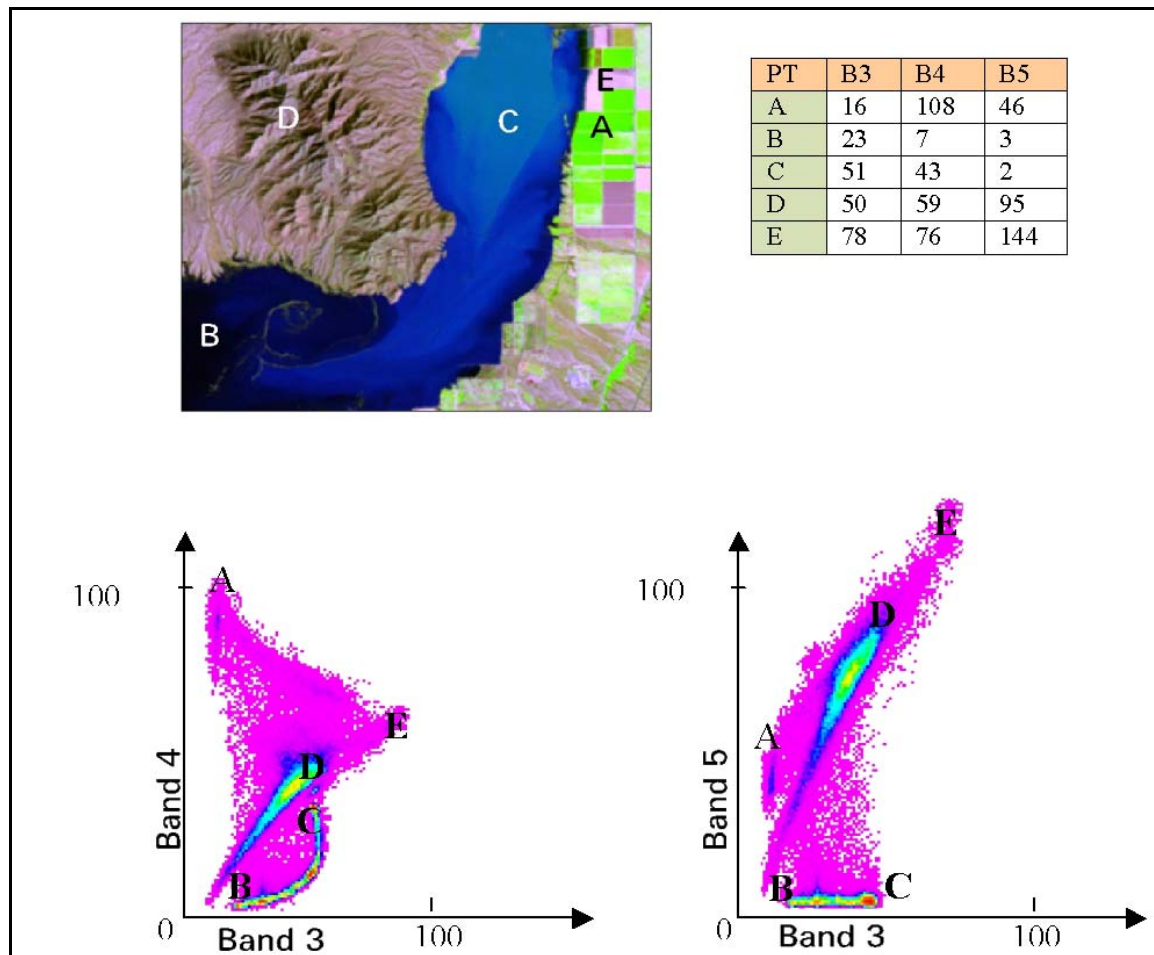


Figure 5-8. Landsat TM band 345 RGB color composite with accompanying image scatter plots. The scatter plots map band 3 relative to bands 4 and 5 onto a feature space graph. The data points in the plot are color coded to display pixel population. The table provides the pixel count for five image features in band 3, 4, and 5. A is agricultural land, B is deep (partially clear) water, C is sediment laden water, D is undeveloped land, E fallow fields. Image developed for Prospect (2002 and 2003).

(2) *Enhancing Pixel Digital Number Values.* Images can enhance or stretch the visual display of an image by setting up a different relationship between the DN and the brightness level. The enhancement relationship created will depend on the distribution of pixel DN values and which features need enhancement. The enhancement can be applied to both gray- and color-scale images.

(3) *Contrast Enhancement Techniques.* The histogram chart and lookup table are useful tools in image enhancement. Enhancement stretching involves a variety of techniques, including contrast stretching, histogram equalization, logarithmic enhancement, and manual enhancement. These methods assume the image has a full range of intensity (from 0–255 in 8-bit data) to display the maximum contrast.

(4) *Linear Contrast Stretching.* Contrast stretching takes an image with clustered intensity values and stretches its values linearly over the 0–255 range. Pixels in a very

bright scene will have a histogram with high intensity values, while a dark scene will have low intensity values (Figure 5-9). The low contrast that results from this type of DN distribution can be adjusted with contrast stretching, a linear enhancement function performed by image processing software. The method can be monitored with the use of a histogram display generated by the program.

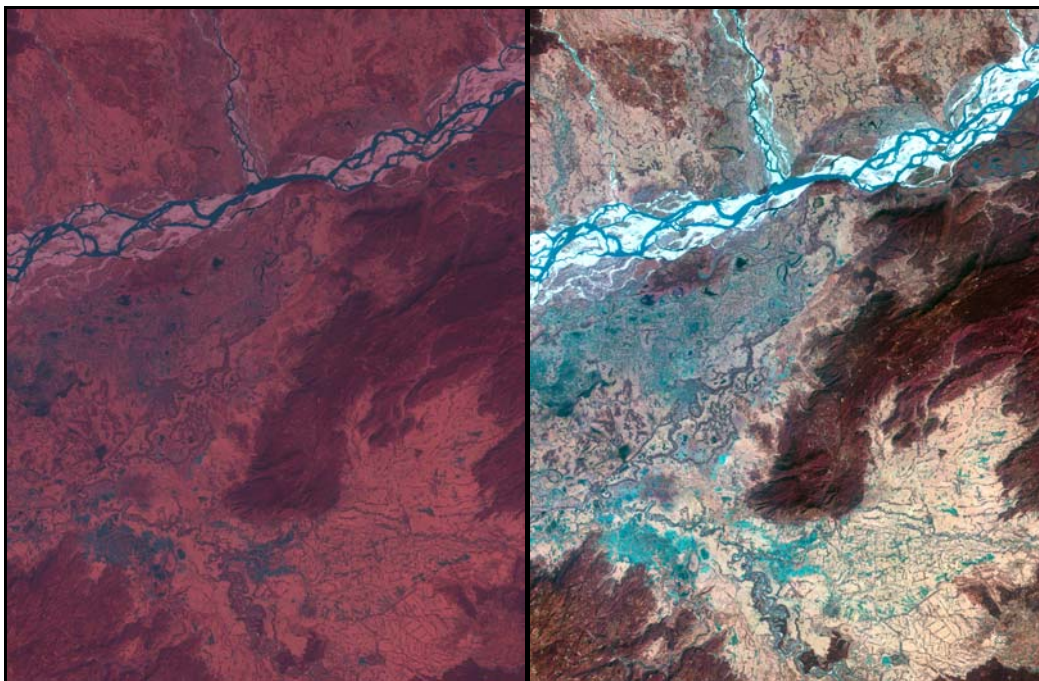


Figure 5-9. Unenhanced satellite data on left. After a default stretch, image contrast is increased as the digital number values are distributed over the 0–255 color range. The resulting scene (shown on the right) has a higher contrast.

(a) Contrast stretching allocates the minimum and maximum input values to 0 and 255, respectively. The process assigns a gray level 0 to a selected low DN value, chosen by the user. All DNs smaller than this value are assigned 0 as well, grouping the low input values together. Gray level 255 is similarly assigned to a selected high DN value and all higher DN values. Intermediate gray levels are assigned to intermediate DN values proportionally. The resulting graph looks like a straight line (shown in Figure 5-7 as the black solid-line plot superimposed onto the three DN histograms), while the corresponding histogram will distribute values across the range, leaving an increase to the image contrast (Figure 5-9). The stretched histogram shows gaps between the single values due to the discrete number of pixel values in the data set (Figure 5-7). The proportional brightness gives a more accurate appearance to the image data, and will better accommodate visual interpretation.

(b) The linear enhancement can be greatly affected by a random error that is particularly high or low in brightness values. For this reason, a non-linear stretch is sometimes preferred. In non-linear stretches, such as histogram equalization and logarithmic enhancement, brightness values are reassigned using an algorithm that exaggerates contrast in the range of brightness values most common in that image.

(5) *Histogram Equalization*. Low contrast can also occur when values are spread across the entire range. The low contrast is a result of tight clustering of pixels in one area (Figure 5-10a). Because some pixel values span the intensity range it is not possible to apply the contrast linear stretch. In Figure 5-10a, the high peak on the low intensity end of the histogram indicates that a narrow range of DN values is used by a large number of pixels. This explains why the image appears dark despite the span of values across the full 0–255 range.

(a) Histogram equalization evenly distributes the pixel values over the entire intensity range (see steps below). The pixels in a scene are numerically arranged according to their DN values and divided into 255 equal-sized groups. The lowest level is assigned a gray level of zero, the next group is assigned DN 1, ..., the highest group is assigned gray level 255. If a single DN value has more pixels than a group, gray levels will be skipped. This produces gaps in the histogram distribution. The resultant shape of the graph will depend on the frequency of the scene.

(b) This method generally reduces the peaks in the histogram, resulting in a flatter or lower curve (Figure 5-10b). The histogram equalization method tends to enhance distinctions within the darkest and brightest pixels, sacrificing distinctions in mid-gray. This process will result in an overall increase in image contrast (Figure 5-10b).

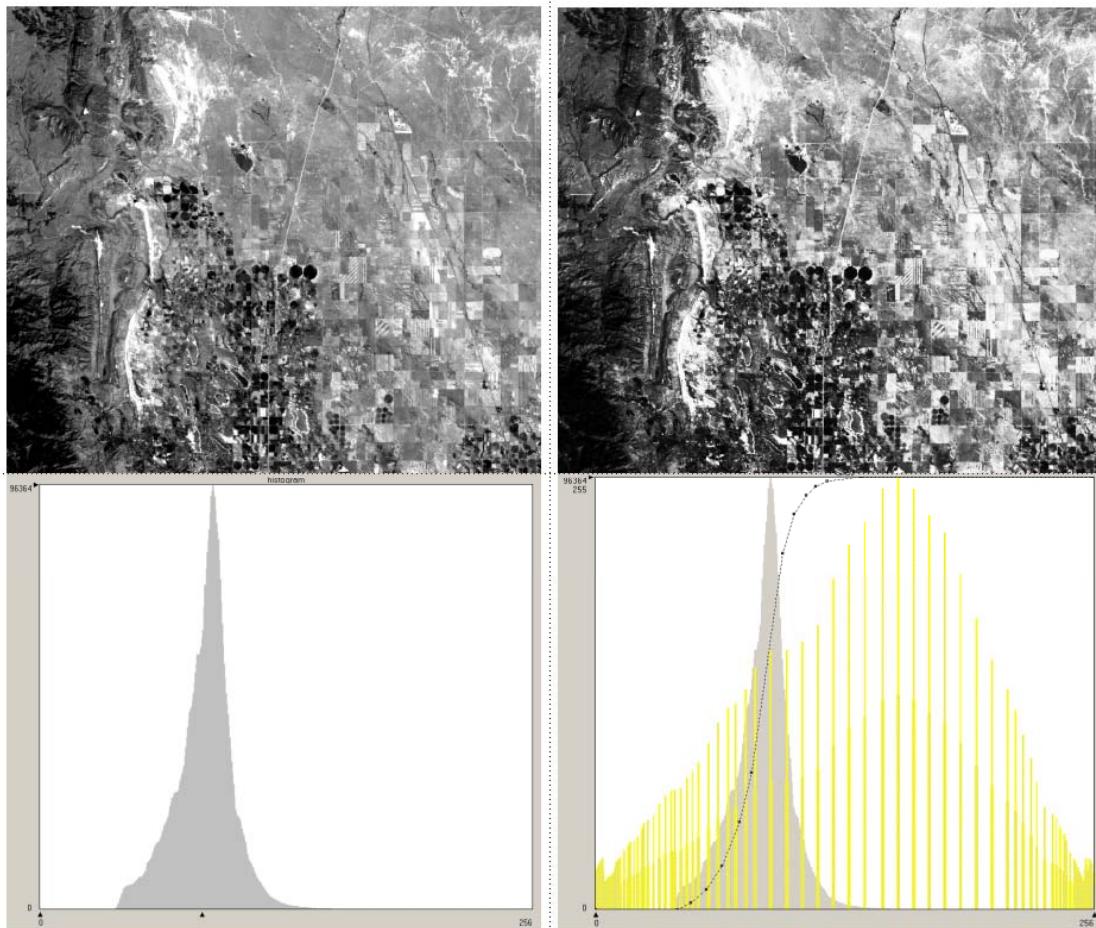
(6) *Logarithmic Enhancement*. Another type of enhancement stretch uses a logarithmic algorithm. This type of enhancement distinguishes lower DN values. The high intensity values are grouped together, which sacrifices the distinction of pixels with higher DN.

(7) *Manual Enhancement*. Some software packages will allow users to define an arbitrary enhancement. This can be done graphically or numerically. Manually adjusting the enhancement allows the user to reduce the signal noise in addition to reducing the contrast in unimportant pixels. **Note:** The processes described above do not alter the spectral radiance of the pixel raw data. Instead, the output display of the radiance is modified by a computed algorithm to improve image quality.

b. Image Enhancement #2: Band Arithmetic

(1) *Band Arithmetic*. Spectral band data values can be combined using arithmetic to create a new “band.” The digital number values can be summed, subtracted, multiplied, and divided (see equations 5-1 and 5-2). Image software easily performs these operations. This section will review only those arithmetic processes that involve the division or ratio of digital band data.

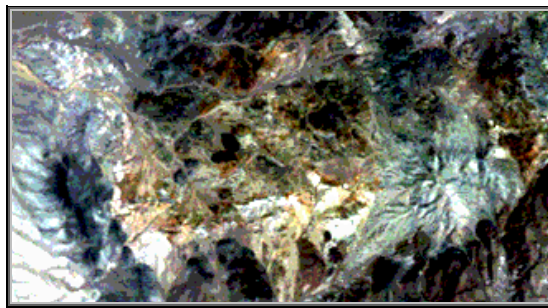
(2) *Band Ratio*. Band ratio is a commonly used band arithmetic method in which one spectral band is proportioned with another spectral band. This simple method reduces the effects of shadowing caused by topography, highlights particular image elements, and accentuates temporal differences (Figure 5-11).



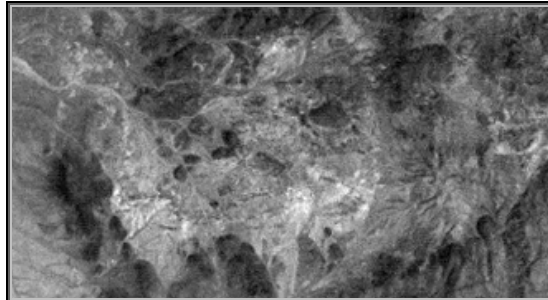
a. Image and its corresponding DN histogram show that the majority of pixels are clustered together (centering approximately on DN value of 100).

b. After histogram equalization stretch the pixels are reassigned new values and spread out across the entire value range. The data maximum is subdued while the histogram leading and trailing edges are amplified, the resulting image has an overall increase in contrast.

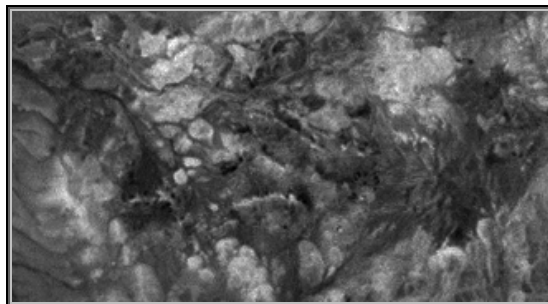
Figure 5-10. Landsat image of Denver area.



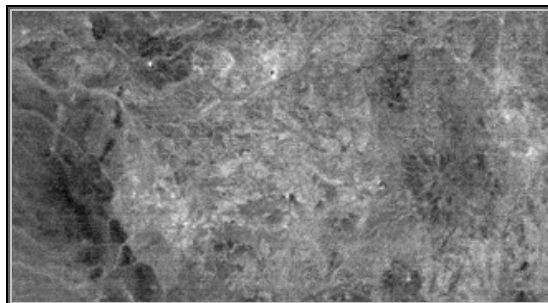
Landsat bands 3, 2, 1



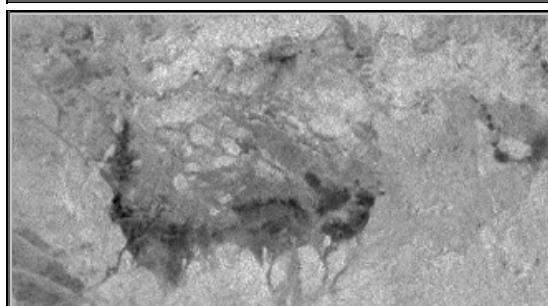
Band ratio 3/1 highlights hematite



Band ratio 1/7 highlights aluminum ore



Band ratio 7/5 highlights clays



Band ratio 4/2 highlights biomass

Figure 5-11. NASA Landsat images from top to bottom: Color composite bands 3, 2, 1, band ratio 3/1 highlights iron oxide minerals, band ratios 7/5 and 1/7 reveals the presence of water in minerals—appropriate for mapping clay minerals or aluminum ore, and band ratio 4/2 allows for biomass determination.

(3) *Shadow Removal from Data.* The effect of shadowing is typically caused by a combination of sun angle and large topographic features (i.e., shadows of mountains). Table 5-1 lists the pixel digital number values for radiance measured from two different objects for two bands (arbitrarily chosen) under differing lighting conditions. Pixel data representing the radiance reflecting off deciduous trees (trees that lose their leaves annually) is consistently higher for non-shadowed objects. This holds true as shadowing effectively lowers the pixel radiance. When the ratio of the two bands is taken (or divided by one another) the resultant ratio value is not influenced by the effects of shadowing (see Table 5-1). The band ratio therefore creates a more reliable data set.

Table 5-1
Effects of shadowing

Tree type	Light conditions	Band A (DN)	Band B (DN)	Band A/B (ratio) (DN)
Deciduous Trees	In sunlight	48	50	0.96
	In shadow	18	19	0.95
Coniferous Trees	In sunlight	31	45	0.69
	In shadow	11	16	0.69

(4) *Emphasize Image Elements.* A number of ratios have been empirically developed and can highlight many aspects of a scene. Listed below are only a few common band ratios and their uses. When choosing bands for this method, it is best to consider bands that are poorly correlated. A greater amount of information can be extracted from ratios with bands that are covariant.

- B3/B1 – iron oxide
- B3/B4 – vegetation
- B4/B2 – vegetation biomass
- B4/B3 – known as the RVI (Ratio Vegetation Index)
- B5/B2 – separates land from water
- B7/B5 – hydrous minerals
- B1/B7 – aluminum hydroxides
- B5/B3 – clay minerals

(5) *Temporal Differences.* Band ratio can also be used to detect temporal changes in a scene. For instance, if a project requires the monitoring of vegetation change in a scene, a ratio of band 3 from image data collected at different times can be used. The newly created band file may have a name such as “Band3’Oct.98/Ban3’Oct.02.” When the new band is loaded, the resulting ratio will highlight areas of change; these pixels will appear brighter. For areas with no change, the resulting pixel values will be low and the resulting pixel will appear gray.

(a) One advantage of the ratio function lies in its ability to not only filter out the effects of shadowing but also the effects attributable to differences in sun angle. The sun angle may change from image to image for a particular scene. The sun angle is controlled by the time of day the data were collected as well as the time of year (seasonal effects). Processing images collected under different sun angle conditions may be un-

avoidable. Again, a ratio of the bands of interest will limit shadowing and sun angle effects. It is therefore possible to perform a temporal analysis on data collected at different times of the day or even at different seasons.

(b) A disadvantage of using band ratio is the emphasis that is placed on noise in the image. This can be reduced, however, by applying a spatial filter before employing the ratio function; this will reduce the signal noise. See Paragraph 5-20c.

(6) *Create a New Band with the Ratio Data.* Most software permits the user to perform a band ratio function. The band ratio function converts the ratio value to a meaningful digital number (using the 256 levels of brightness for 8-bit data). The ratio can then be saved as a new band and loaded onto a gray scale image or as a single band in a color composite.

(7) *Other Types of Ratios and Band Arithmetic.* There are a handful of ratios that highlight vegetation in a scene. The NDVI (Normalized Difference Vegetation Index; equations 5-1 and 5-2) is known as the “vegetation index”; its values range from -1 to 1.

$$\text{NDVI} = \frac{\text{NIR} - \text{red}}{\text{NIR} + \text{red}} \quad (5-1)$$

where NDVI is the normalized difference vegetation index, NIR is the near infrared, and red is the band of wavelengths coinciding with the red region of the visible portion of the spectrum. For Landsat TM data this equation is equivalent to:

$$\text{NDVI} = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}} \quad (5-2)$$

In addition to the NDVI, there is also IPVI (Infrared Percentage Vegetation Index), DVI (Difference Vegetation Index), and PVI (Perpendicular Vegetation Index) just to name a few. Variation in vegetation indices stem from the need for faster computations and the isolation of particular features. Figure 5-12 illustrates the NDVI.



Figure 5-12. Top: True color CAMIS image. Bottom: NDVI mask isolating vegetated pixels. This mask will be useful during the classification process, which will subsequently classify only the vegetation in the scene while disregarding water and urban features. Taken from Campbell (2003).

c. *Image Enhancement #3: Spatial Filters.* It is occasionally advantageous to reduce the detail or exaggerate particular features in an image. This can be done by a convolution method creating an altered or “filtered” output image data file. Numerous spatial filters have been developed and can be automated within software programs. A user can also develop his or her own spatial filter to control the output data set. Presented below is a short introduction to the method of convolution and a few commonly used spatial filters.

(1) *Spatial Frequency.* Spatial frequency describes the pattern of digital values observed across an image. Images with little contrast (very bright or very dark) have zero spatial frequency. Images with a gradational change from bright to dark pixel values have low spatial frequency; while those with large contrast (black and white) are said to have high spatial frequency. Images can be altered from a high to low spatial frequency with the use of convolution methods.

(2) *Convolution.*

(a) Convolution is a mathematical operation used to change the spatial frequency of digital data in the image. It is used to suppress noise in the data or to exaggerate features of interest. The operation is performed with the use of a spatial kernel. A kernel is an array of digital number values that form a matrix with odd numbered rows and columns (Table 5-2). The kernel values, or coefficients, are used to average each pixel relative to its neighbor across the image. The output data set will represent the averaging effect of the kernel coefficients. As a spatial filter, convolution can smooth or blur images, thereby reducing image noise. In feature detection, such as an edge enhancement, convolution works to exaggerate the spatial frequency in the image. Kernels can be reapplied to an image to further smooth or exaggerate spatial frequency.

(b) Low pass filters apply a small gain to the input data (Table 5-2a). The resulting output data will decrease the spatial frequency by de-emphasizing relatively bright pixels. Two types of low pass filters are the simple mean and center-weighted mean methods (Table 5-2a and b). The resultant image will appear blurred. Alternatively, high pass frequency filters (Table 5-2c) increase image spatial frequency. These types of filters exaggerate edges without reducing image details (an advantage over the Laplacian filter discussed below).

(2) *Laplacian or Edge Detection Filter.*

(a) The Laplacian filter detects discrete changes in spectral frequency and is used for highlighting edge features in images. This type of filter works well for delineating linear features, such as geologic strata or urban structures. The Laplacian is calculated by an edge enhancement kernel (Table 5-2d and e); the middle number in the matrix is much higher or lower than the adjacent coefficients. This type of kernel is sensitive to noise and the resulting output data will exaggerate the pixel noise. A smoothing convolution filter can be applied to the image in advance to reduce the edge filter's sensitivity to data noise.

The Convolution Method

Convolution is carried out by overlaying a kernel onto the pixel image and centering its middle value over the pixel of interest. The kernel is first placed above the pixel located at the top left corner of the image and moved from top to bottom, left to right. Each kernel position will create an output pixel value, which is calculated by multiplying each input pixel value with the kernel coefficient above it. The product of the input data and kernel is then averaged over the array (sum of the product divided by the number of pixels evaluated); the output value is assigned this average. The kernel then moves to the next pixel, always using the original input data set for calculating averages. Go to <http://www.cla.sc.edu/geog/rslab/Rsc/rsc-frames.html> for an in-depth description and examples of the convolution method.

The pixels at the edges create a problem owing to the absence of neighboring pixels. This problem can be solved by inventing input data values. A simpler solution for this problem is to clip the bottom row and right column of pixels at the margin.

(b) The Laplacian filter measures the changes in spectral frequency or pixel intensity. In areas of the image where the pixel intensity is constant, the filter assigns a digital number value of 0. Where there are changes in intensity, the filter assigns a positive or negative value to designate an increase or decrease in the intensity change. The resulting image will appear black and white, with white pixels defining the areas of changes in intensity.

Table 5-2

Variety in 9-Matrix Kernel Filters Used in a Convolution Enhancement. Each graphic shows a kernel, an example of raw DN data array, and the resultant enhanced data array. See <http://www.cee.hw.ac.uk/hipr/html/filtops.html> for further information on kernels and the filtering methods.

a. Low Pass: simple mean kernel.

1	1	1
1	1	1
1	1	1

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	10	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Raw data

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	2	2	2	1	1
1	1	2	2	2	1	1
1	1	2	2	2	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Output data

b. Low Pass: center weighted mean kernel.

1	1	1
1	2	1
1	1	1

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	10	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Raw data

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	2	2	2	1	1
1	1	2	3	2	1	1
1	1	2	2	2	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Output data

c. High Pass kernel.

-1	-1	-1
-1	8	-1
-1	-1	-1

10	10	10	10	10	10	10
10	10	10	10	10	10	10
10	10	10	10	10	10	10
10	10	10	15	10	10	10
10	10	10	10	10	10	10
10	10	10	10	10	10	10
10	10	10	10	10	10	10

Raw data

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	-5	-5	-5	0	0
0	0	-5	40	-5	0	0
0	0	-5	-5	-5	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Output data

d. Direction Filter: north-south component kernel.

-1	2	-1
-2	1	-2
-1	2	-1

1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1

Raw data

0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0

Output data

e. Direction Filter: East-west component kernel.

-1	-2	-1
2	4	2
-1	-2	-1

1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1

Raw data

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Output data

d. *Image Enhancement #4: Principle Components.* The principle component analysis (PCA) is a technique that transforms the pixel brightness values. This transformation compresses the data by drawing out maximum covariance and removes correlated elements. The resulting data will contain new, uncorrelated data that can be later used in classification techniques.

(1) *Band Correlation.* Spectral bands display a range of correlation from one band to another. This correlation is easily viewed by bringing up a scatter plot of the digital data and plotting, for instance, band 1 vs. band 2. Many bands share elements of information, particularly bands that are spectrally close to one another, such as band 1 and 2. For bands that are highly correlated, it is possible to predict the brightness outcome of one band with the data of the other (Figure 5-13). Therefore, bands that are well correlated may not be of use when attempting to isolate spectrally similar objects.

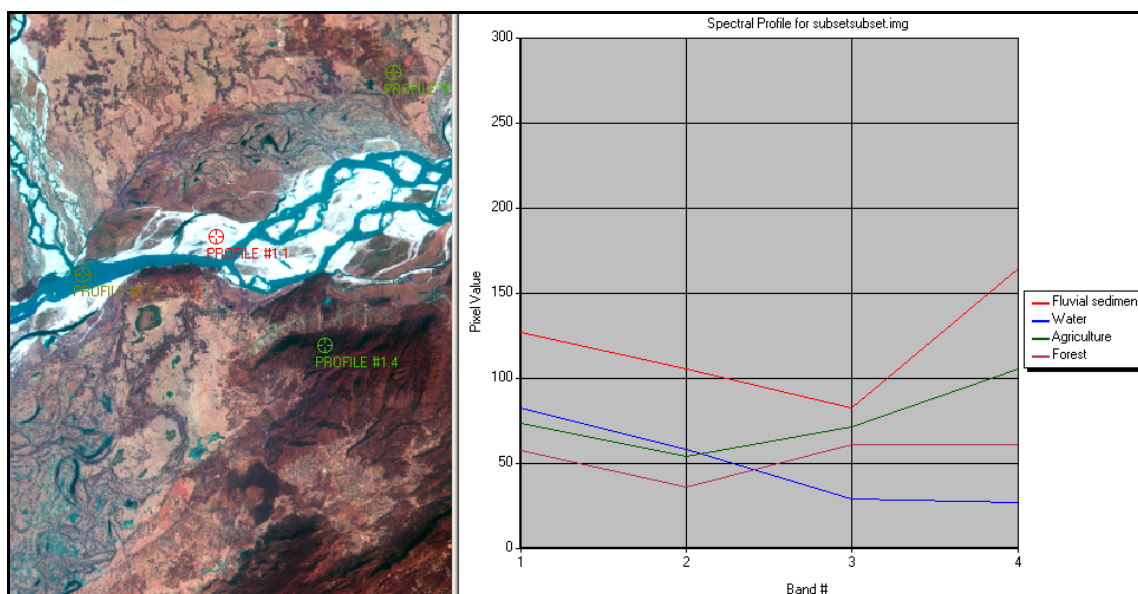


Figure 5-13. Indian IRS-1D image and accompanying spectral plot. Representative pixel points for four image elements (fluvial sediment in a braided channel, water, agriculture, and forest) are plotted for each band. Plot illustrates the ease by which each element can be spectrally separated. For example, water is easily distinguishable from the other elements in band 2.

(2) *Principle Component Transformation.* The principle component method extracts the small amount of variance that may exist between two highly correlated bands and effectively removes redundancy in the data. This is done by “transforming” the major vertical and horizontal axes. The transformation is accomplished by rotating the horizontal axis so that it is parallel to a least squares regression line that estimates the data. This transformed axis is known as PC_1 , or Principle Component 1. A second axis, PC_2 , is drawn perpendicular to PC_1 , and its origin is placed at the center of the PC_1 range (Figure 5-14). The digital number values are then re-plotted on the newly transformed axes. This transformation will result in data with a broader range of values. The data can be saved as a separate file and loaded as an image for analysis.

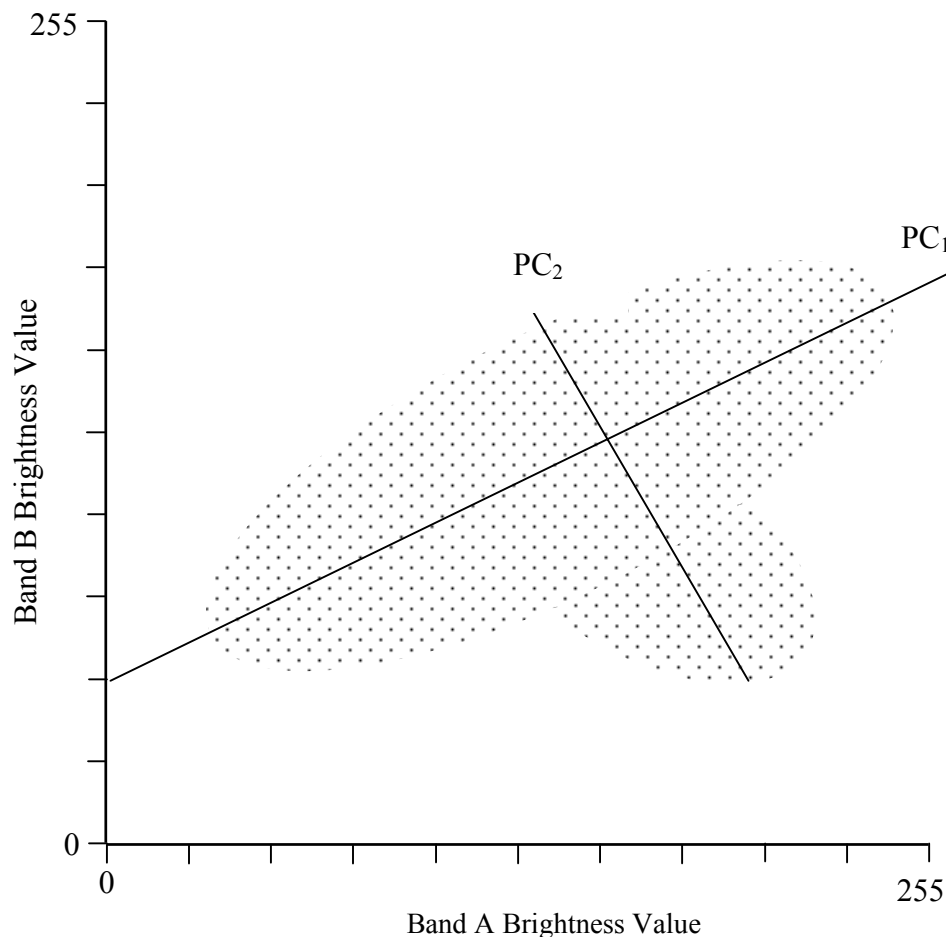


Figure 5-14. Plot illustrates the spectral variance between two bands, A and B. PC_1 is the line that captures the mean of the data set. PC_2 is orthogonal to PC_1 . PC_1 and PC_2 become the new horizontal and vertical axis; brightness values are redrawn onto the PC_1 and PC_2 scale.

c. Transformation Series (PC_1 , PC_2 , PC_3 , PC_4 , PC_5 , etc.). The process of transforming the axis to fit the maximum variance in the data can be performed in succession on the same data set. Each successive axis rotation creates a new principal component axis; a series of transformations can then be saved as individual files. Band correlation is greatly reduced in the first PC transformation, 90% of the variance between the bands will be isolated by PC_1 . Each principle component transformation extracts less and less variance, PC_2 , for instance, isolates 5% of the variance, and PC_3 will extract 3% of the variance, and so on (Figure 5-15). Once PC_1 and PC_2 have been processed, approximately 95% of the variance within the bands will be extracted. In many cases, it is not useful to extract the variance beyond the third principle component. Because the principle component function reduces the size of the original data file, it functions as a pre-processing tool and better prepares the data for image classification. The de-correlation of band data in the principle component analysis is mathematically complex. It linearly

transforms the data using a form of factor analysis (eigen value and eigen vector matrix). For a complete discussion of the technique see Jensen (1996).

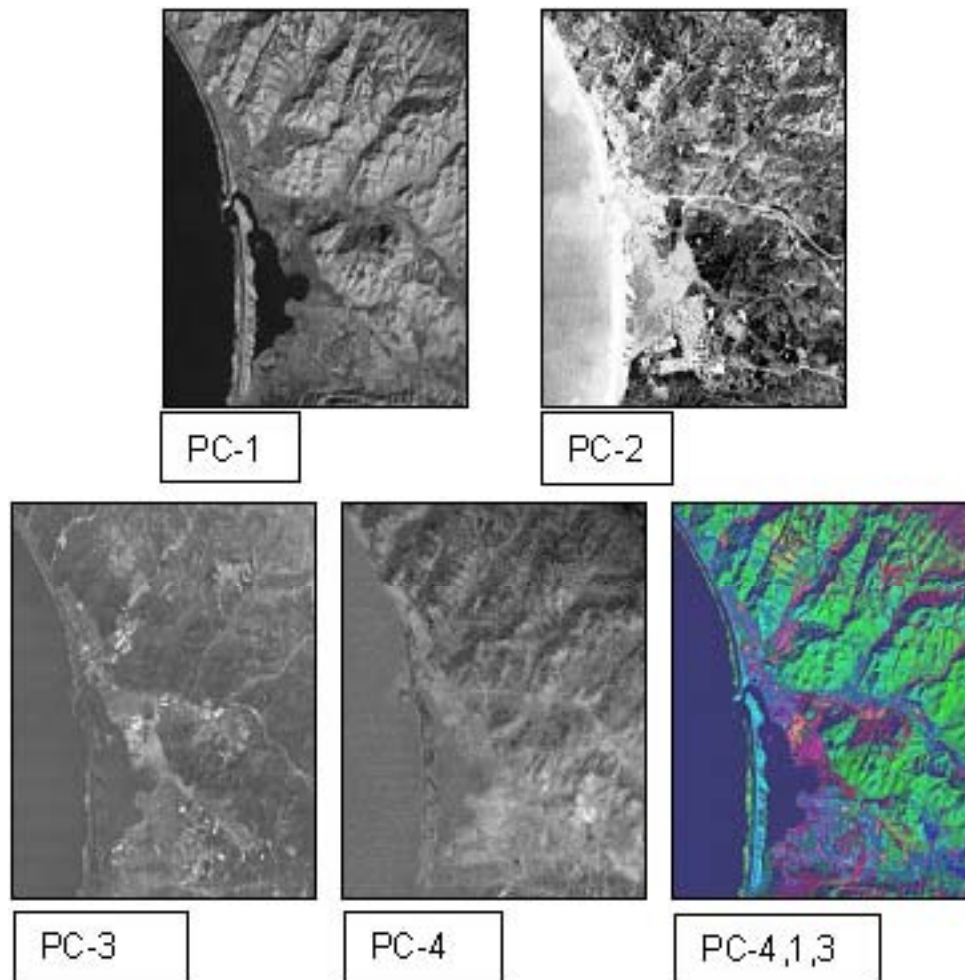


Figure 5-15. PC-1 contains most of the variance in the data. Each successive PC-transformation isolates less and less variation in the data. Taken from <http://rst.gsfc.nasa.gov/start.html>.

d. Image Classification. Raw digital data can be sorted and categorized into thematic maps. Thematic maps allow the analyst to simplify the image view by assigning pixels into classes with similar spectral values (Figure 5-16). The process of categorizing pixels into broader groups is known as image classification. The advantage of classification is it allows for cost-effective mapping of the spatial distribution of similar objects (i.e., tree types in forest scenes); a subsequent statistical analysis can then follow. Thematic maps are developed by two types of classifications, supervised and unsupervised. Both types of classification rely on two primary methods, training and classifying. Training is the designation of representative pixels that define the spectral signature of the object class. Training site or training class is the term given to a group of training pixels. Classifying procedures use the training class to classify the remaining pixels in the image.

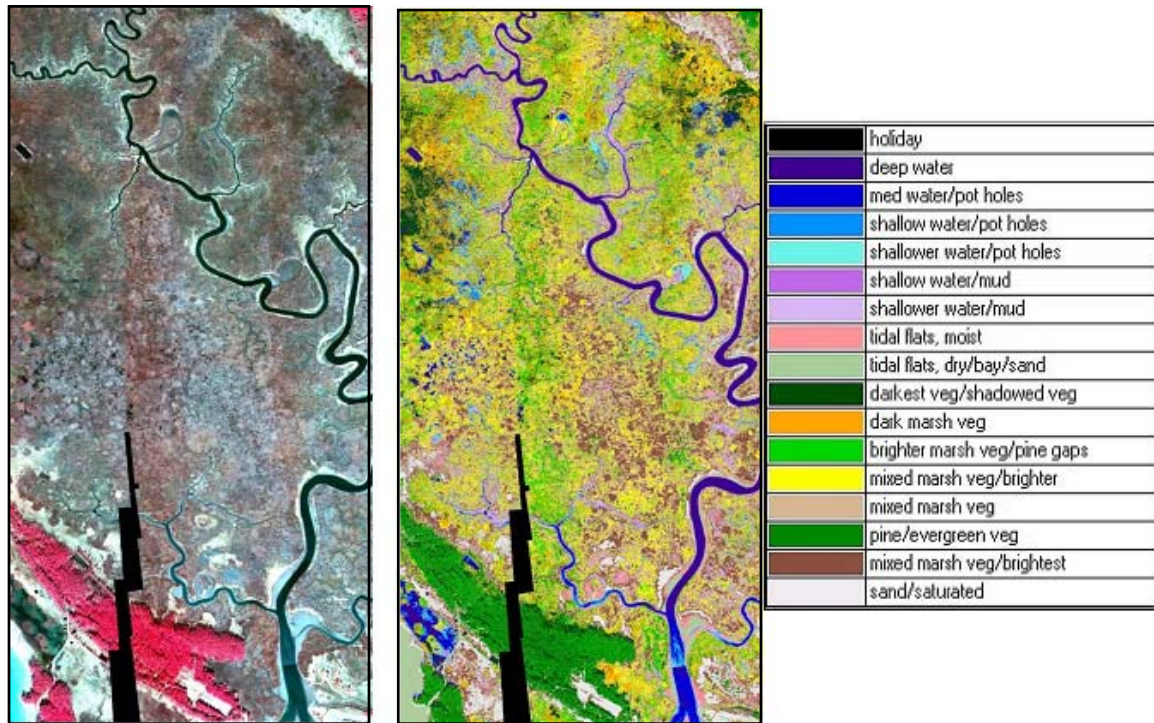


Figure 5-16. Landsat image (left) and its corresponding thematic map (right) with 17 thematic classes. The black zigzag at bottom of image is the result of shortened flight line over-lap. (Campbell, 2003).

(1) *Supervised Classification.* Supervised classification requires some knowledge about the scene, such as specific vegetative species. Ground truth (field data), or data from aerial photographs or maps can all be used to identify objects in the scene.

(2) *Steps Required for Supervised Classification.*

(a) Firstly, acquire satellite data and accompanying metadata. Look for information regarding platform, projection, resolution, coverage, and, importantly, meteorological conditions before and during data acquisition.

(b) Secondly, chose the surface types to be mapped. Collect ground truth data with positional accuracy (GPS). These data are used to develop the training classes for the discriminant analysis. Ideally, it is best to time the ground truth data collection to coincide with the satellite passing overhead.

(c) Thirdly, begin the classification by performing image post-processing techniques (corrections, image mosaics, and enhancements). Select pixels in the image that are representative (and homogeneous) of the object. If GPS field data were collected, geo-register the GPS field plots onto the imagery and define the image training sites by outlining the GPS polygons. A training class contains the sum of points (pixels) or polygons (clusters of pixels) (see Figures 5-17 and 5-18). View the spectral histogram to inspect the homogeneity of the training classes for each spectral band. Assign a color to represent each class and save the training site as a separate file. Lastly, extract the re-

maining image pixels into the designated classes by using a discriminate analysis routine (discussed below).

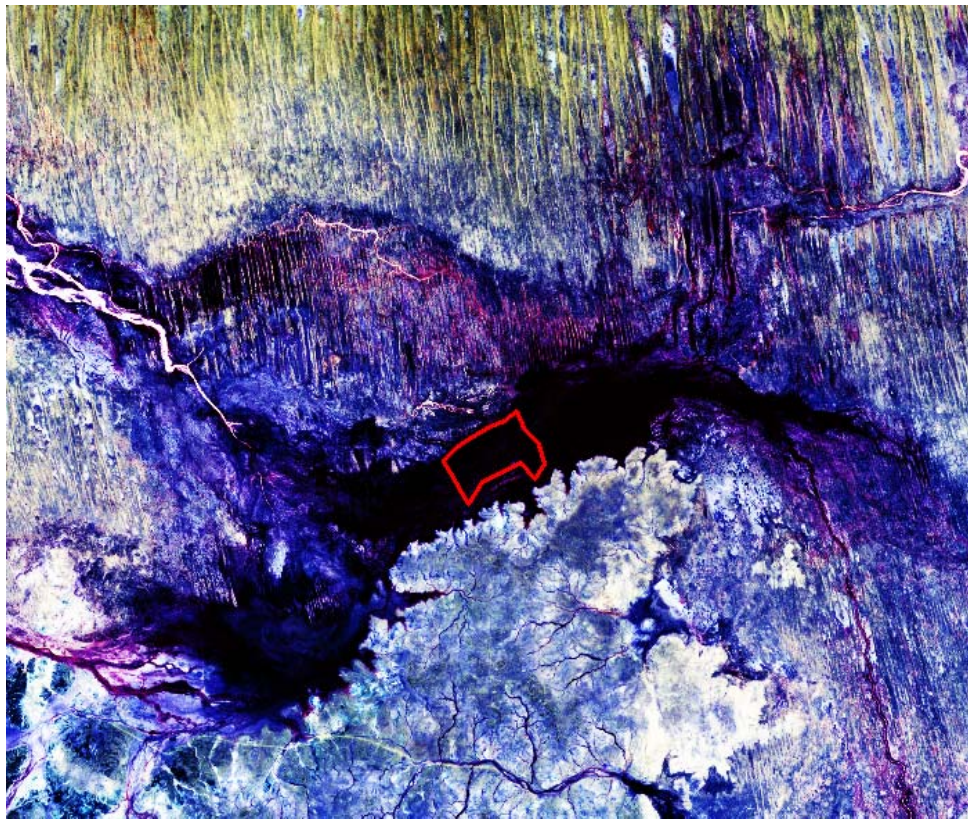


Figure 5-17. Landsat 7 ETM image of central Australia (4, 3, 2 RGB). Linear features in the upper portion of the scene are sand dunes. Training data are selected with a selection tool (note the red enclosure). A similar process was performed on data from Figure 5-16 (the DN values for figure 5-16 are presented in Figure 5-18).

SORT #	CLASS NAME	COLOR	TRAINING	CLASSIFIED	% TOTAL	% DATA
1	Unclassified			25,207,732	68.86%	
2	ROAD	Red1	77	0	0.00%	0.00
3	AG	Green1	1642	0	0.00%	0.00
4	LP	Red1	4148	2,164,089	5.91%	19.53
5	LPO	Blue1	5627	1,562,180	4.27%	14.10
6	LPH	Maroon1	4495	2,170,395	5.93%	19.58
7	MHW-low	Aquamarine	888	329,360	0.90%	2.97
8	CUT	Chartreuse	1219	1,055,063	2.88%	9.52
9	MHW-high	Sienna1	3952	1,566,698	4.28%	14.14
10	MORT	Green3	1703	4,651	0.01%	0.04
12	juncus-low-density	Red1	52	37,808	0.10%	0.34
13	juncus-high-density	Blue1	65	102,174	0.28%	0.92
13	juncus-panicum-mix	Cyan1	53	0	0.00%	0.00
14	juncus-mixed-clumps-field	Magenta1	29	3	0.00%	0.00
16	g1=hd-scol+background+w	Green1	32	610,283	1.67%	5.51
17	g2=md-scol+background	Yellow1	29	952	0.00%	0.01
18	g4=md-scol+spartina+mud	Maroon1	36	0	0.00%	0.00
19	g3=md-scol+spartina+background	Purple1	50	0	0.00%	0.00
20	g5=ld-scol+mud	Aquamarine	56	617	0.00%	0.01
21	g1=md-spal+w	Red1	66	4,789	0.01%	0.04
22	g2=hd-spal+w	Green1	52	141,060	0.39%	1.27
23	g3=hd-spal+w+sppa	Cyan1	29	803,145	2.19%	7.25
24	g4=md-spal+w+sppa	Magenta1	44	0	0.00%	0.00
25	g5=hd-spal+mud	Red1	25	25	0.00%	0.00
26	g6=mixed-spal	Chartreuse	28	6,555	0.02%	0.06
26	g7=md-spal+lit+mud	Thistle1	36	6	0.00%	0.00
28	g8=md-mixed-spal	Blue4	85	0	0.00%	0.00
29	g1=hd-sppa+mix	Red1	37	74	0.00%	0.00
30	g2=hd-sppa+mud	Blue1	40	0	0.00%	0.00
31	g3=mhd-sppa+spal+background	Cyan1	32	939	0.00%	0.01
32	g4=lmd-sppa+mix+background	Magenta1	160	0	0.00%	0.00
33	g9=ld-sppa+spal+mud	Blue4	28	520,290	1.42%	4.69
34	g10=ld-sppa+mix+background	Cyan3	45	0	0.00%	0.00
35	g11=ld-sppa+w+mix	Green2	32	1,255	0.00%	0.01
37				11082411.00		

Figure 5-18. Classification training data of 35 landscape classification features. “Training” provides the pixel count after training selection; classification provides the image pixel count after a classification algorithm is performed. This data set accompanies Figure 5-16, the classified image. (Campbell, 2003).

(3) *Classification Algorithms.* Image pixels are extracted into the designated classes by a computed discriminant analysis. The three types of discriminant analysis algorithms are: minimum mean distance, maximum likelihood, and parallelepiped. All use brightness plots to establish the relationship between individual pixels and the training class (or training site).

(a) *Minimum Mean Distance.* Minimum distance to the mean is a simple computation that classifies pixels based on their distance from the mean of the training class.

It is determined by plotting the pixel brightness and calculating its Euclidean distance (using the Pythagorean theorem) to the unassigned pixel. Pixels are assigned to the training class for which it has a minimum distance. The user designates a minimum distance threshold for an acceptable distance; pixels with distance values above the designated threshold will be classified as unknown.

(b) *Parallelepiped*. In a parallelepiped computation, unassigned pixels are grouped into a class when their brightness values fall within a range of the training mean. An acceptable digital number range is established by setting the maximum and minimum class range to plus and minus the standard deviation from the training mean. The pixel brightness value simply needs to fall within the class range, and is not based on its Euclidean distance. It is possible for a pixel to have a brightness value close to a class and not fall within its acceptable range. Likewise, a pixel may be far from a class mean, but fall within the range and therefore be grouped with that class. This type of classification can create training site overlap, causing some pixels to be misclassified.

(c) *Maximum Likelihood*. Maximum Likelihood is computationally complex. It establishes the variance and covariance about the mean of the training classes. This algorithm then statistically calculates the probability of an unassigned pixel belonging to each class. The pixel is then assigned to the class for which it has the highest probability. Figure 5-19 visually illustrates the differences between these supervised classification methods.

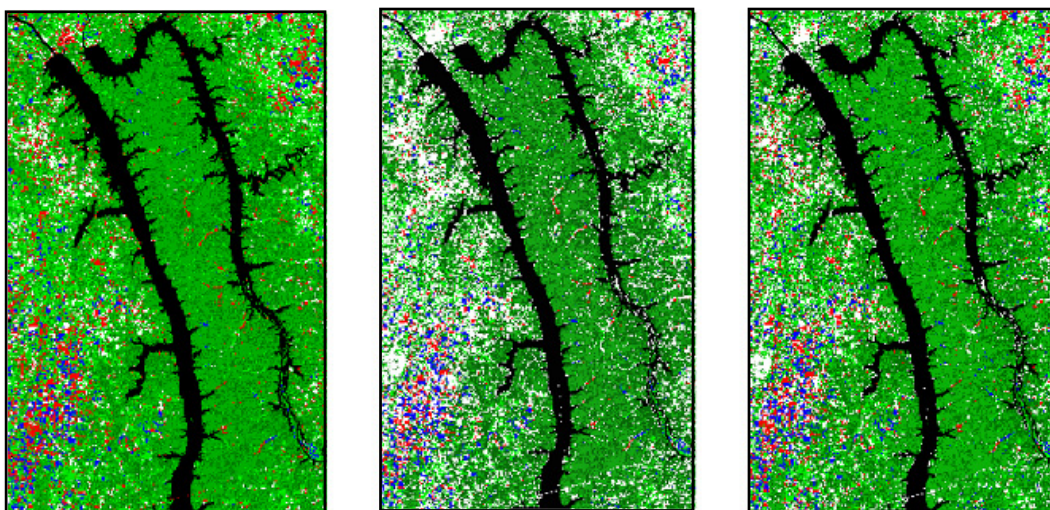


Figure 5-19. From left to right, minimum mean distance, parallelepiped, and maximum likelihood. Courtesy of the Department of Geosciences at Murray State University.

(4) *Assessing Error*. Accuracy can be qualitatively determined by an error matrix (Table 5-3). The matrix establishes the level of errors due to omission (exclusion error), commission (inclusion error), and can tabulate an overall total accuracy. The error matrix lists the number of pixels found within a given class. The rows in Table 5-2 list the pixels classified by the image software. The columns list the number of pixels in the reference data (or reported from field data). Omission error calculates the probability of

a pixel being accurately classified; it is a comparison to a reference. Commission determines the probability that a pixel represents the class for which it has been assigned. The total accuracy is measured by calculating the proportion correctly classified pixel relative to the total tested number of pixels (Total = total correct/total tested).

Table 5-3
Omission and Commission Accuracy Assessment Matrix. Taken from Jensen (1996).

Reference Data						
Classification	Residential	Commercial	Wetland	Forest	Water	Raw Total
Residential	70	5	0	13	0	88
Commercial	3	55	0	0	0	58
Wetland	0	0	99	0	0	99
Forest	0	0	4	37	0	41
Water	0	0	0	0	121	121
Column Total	73	60	103	50	121	407
Overall Accuracy = 382/407=93.86%						

Producer's Accuracy (measure of omission error)

Residential= $70/73 = 96-4\%$ omission error
Commercial= $55/60 = 92-8\%$ omission error
Wetland= $99/103 = 96-4\%$ omission error
Forest= $37/50 = 74-26\%$ omission error
Water= $121/121 = 100-0\%$ omission error

User's Accuracy (measure of commission error)

Residential= $70/88 = 80-20\%$ omission error
Commercial= $55/58 = 95-5\%$ omission error
Wetland= $99/99 = 100-0\%$ omission error
Forest= $37/41 = 90-10\%$ omission error
Water= $121/121 = 100-0\%$ omission error

Example error matrix taken from Jensen (1986). Data are the result of an accuracy assessment of Landsat TM data.

Classification method summary

Image classification uses the brightness values in one or more spectral bands, and classifies each pixel based on its spectral information

The goal in classification is to assign remaining pixels in the image to a designated class such as water, forest, agriculture, urban, etc.

The resulting **classified** image is composed of a collection of pixels, color-coded to represent a particular theme. The overall process then leads to the creation of a thematic map to be used to visually and statistically assess the scene.

(5) *Unsupervised Classification.* Unsupervised classification does not require prior knowledge. This type of classification relies on a computed algorithm that clusters pixels based on their inherent spectral similarities.

(a) *Steps Required for Unsupervised Classification.* The user designates 1) the number of classes, 2) the maximum number of iterations, 3) the maximum number of times a pixel can be moved from one cluster to another with each iteration, 4) the minimum distance from the mean, and 5) the maximum standard deviation allowable. The program will iterate and recalculate the cluster data until it reaches the iteration threshold designated by the user. Each cluster is chosen by the algorithm and will be evenly distributed across the spectral range maintained by the pixels in the scene. The resulting classification image (Figure 5-20) will approximate that which would be produced with the use of a minimum mean distance classifier (see above, “classification algorithm”). When the iteration threshold has been reached the program may require you to rename and save the data clusters as a new file. The display will automatically assign a color to each class; it is possible to alter the color assignments to match an existing color scheme (i.e., blue = water, green = vegetation, red = urban) after the file has been saved. In the unsupervised classification process, one class of pixels may be mixed and assigned the color black. These pixels represent values that did not meet the requirements set by the user. This may be attributable to spectral “mixing” represented by the pixel.

(b) *Advantages of Using Unsupervised Classification.* Unsupervised classification is useful for evaluating areas where you have little or no knowledge of the site. It can be used as an initial tool to assess the scene prior to a supervised classification. Unlike supervised classification, which requires the user to hand select the training sites, the unsupervised classification is unbiased in its geographical assessment of pixels.

(c) *Disadvantages of Using Unsupervised Classification.* The lack of information about a scene can make the necessary algorithm decisions difficult. For instance, without knowledge of a scene, a user may have to experiment with the number of spectral clusters to assign. Each iteration is time consuming and the final image may be difficult to interpret (particularly if there is a large number of unidentified pixels such as those in Figure 5-19). The unsupervised classification is not sensitive to covariation and variations in the spectral signature to objects. The algorithm may mistakenly separate pixels with slightly different spectral values and assign them to a unique cluster when they, in fact, represent a spectral continuum of a group of similar objects.

(6) *Evaluating Pixel Classes.* The advantages of both the supervised and unsupervised classification lie in the ease with which programs can perform statistical analysis. Once pixel classes have been assigned, it is possible to list the exact number of pixels in each representative class (Figure 5-17, classified column). As the size of each pixel is known from the metadata, the metric area of each class can be quickly calculated. For example, you can very quickly deter-

mine the percentage of fallow field area versus productive field area in an agricultural scene.

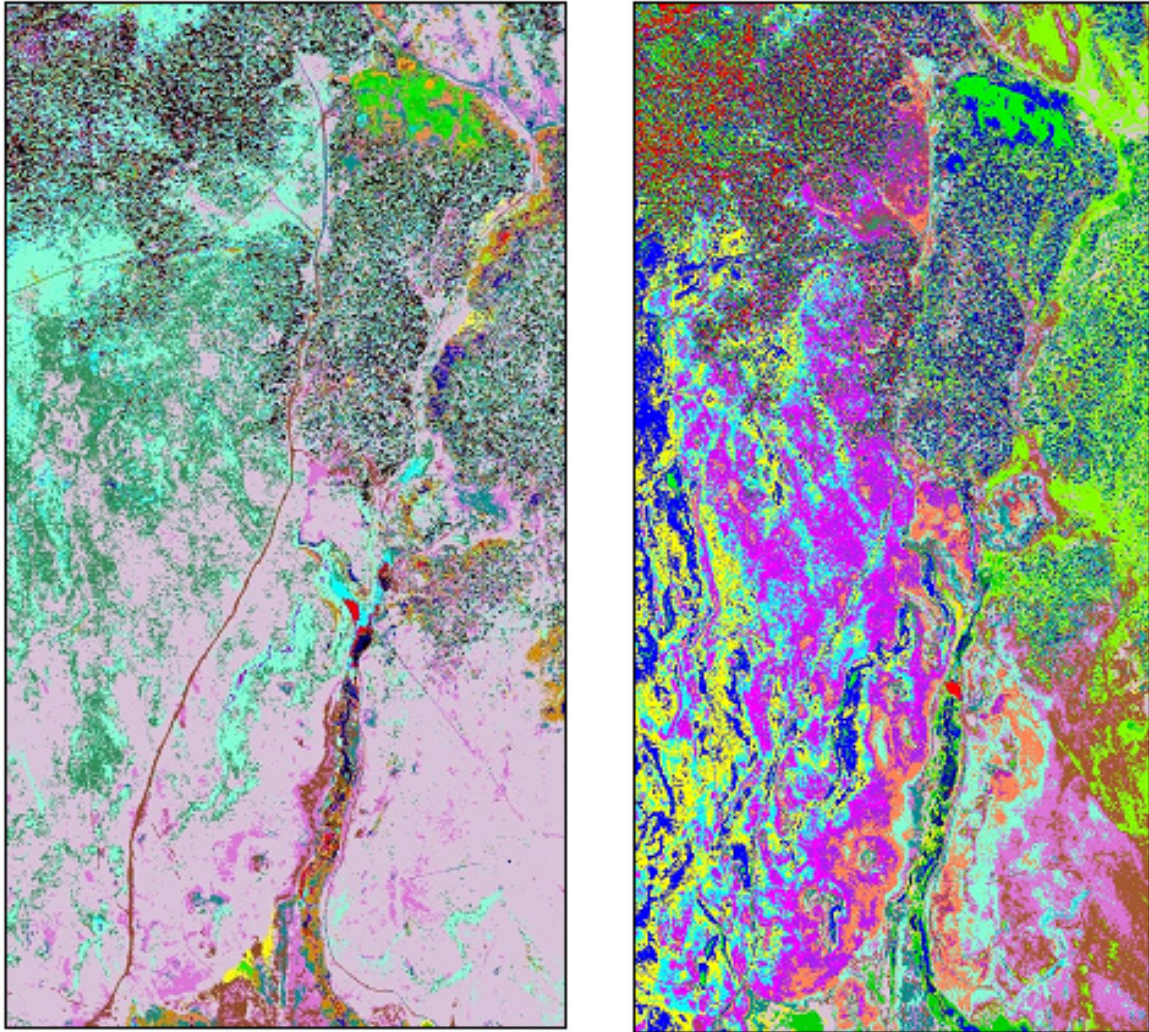


Figure 5-20. Unsupervised and supervised classification of a clay-mine (upper center, bright green pixels) imaged with HyMap hyperspectral data. Images courtesy of Dr. Brigitte Martini at the Earth Sciences Department, University of California, Santa Cruz, CA. Go to <http://www.es.ucsc.edu/~hyperwww/chevron/whatisrs5.html> for details on the image.

e. Image Mosaics, Image subsets, and Multiple Image Analysis.

(1) *Image Mosaics.* It is not uncommon for a study area to include areas beyond the range of an individual scene. In such a case, it will be necessary to collect adjacent scenes and mosaic or piece them together (Figures 5-21–5-23). It is preferable to choose scenes with data collected during the same season or general time frame and under similar weather conditions. Images can only be properly pieced together if their data are registered in the same projection and datum. It will be important to assess the registration of all images before attaching the scenes together. If any of the images are misregistered, this will lead to gaps in the image or it will create pixel overlay.

(2) *Image Mosaic and Image Subset*. The mosaic process is a common feature in image processing programs. It is best to perform image enhancements prior to piecing separate scenes together. Once the images are pieced together, the resulting image may be large and include areas outside the study region. It is good practice to take a subset of this larger scene to reduce the size of the image file. This will make subsequent image processing faster. To do this, use the clip or subset function in a software program. The clip function will need to know the corner coordinates of the subset (usually the upper left and lower right). Some software may require this procedure to be repeated for each individual band of data. The subset should be named and saved as a separate file or files. **Note:** An image subset may also be required if the margins of a newly registered scene are skewed, or if the study only requires a small portion of one scene. Reduction of the spatial dimensions of a scene reduces the image file size, simplifies image classification, and prepares the image for map production.

Example: Calculate the percentage of land cover types for a classification performed on a Landsat TM image with a spatial resolution of 30 m using a supervised maximum likelihood classification with a 3.0 standard deviation.

Solution: Calculate the percentage based on the total

Percent Calculation

Class	Number of class pixels	Percentage
Water	16,903	$(16,903/413,469) \times 100 = 4.1\%$
Forest:	368,641	$(368,641/413,469) \times 100 = 89.1\%$
Wetlands	6,736	$(6,736/413,469) \times 100 = 1.6\%$
Agriculture	13,853	$(13,853/413,469) \times 100 = 3.4\%$
Urban	6,255	$(6,255/413,469) \times 100 = 1.5\%$
Unknown	1081	$(1081/413,469) \times 100 = 0.3\%$
Total	413,469	$(413,469/413,469) \times 100 = 100\%$

Maximum likelihood is a superior classifier and training classes are well defined. This is evident in the low number of pixels in the unknown class.

Area can be calculated using the number of pixels in a class and multiplying it by the ground dimensions of the pixel. For example the number of square meters and hectares in the wetland class of this example is:

Wetlands	$6,736 \times (30\text{m})^2 = 6.1 \times 10^6 \text{ m}^2$	606.24 ha
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This last step is often not necessary as many software programs automatically calculate the hectares for each class.

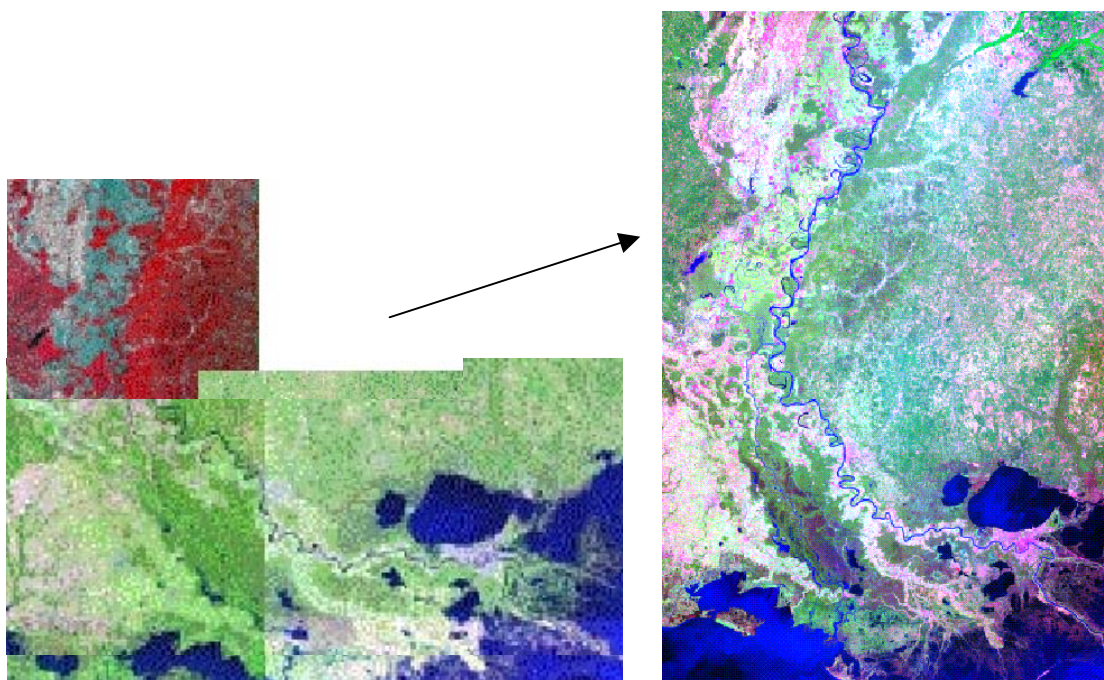


Figure 5-21. Multiple Landsat TM images, shown on the left (some sub-scenes are not shown here) were pieced together to create the larger mosaic image on the right. The seams within the mosaic image (right) are virtually invisible, an indication of the accuracy of the projection. Taken from Prospect (2002 and 2003).

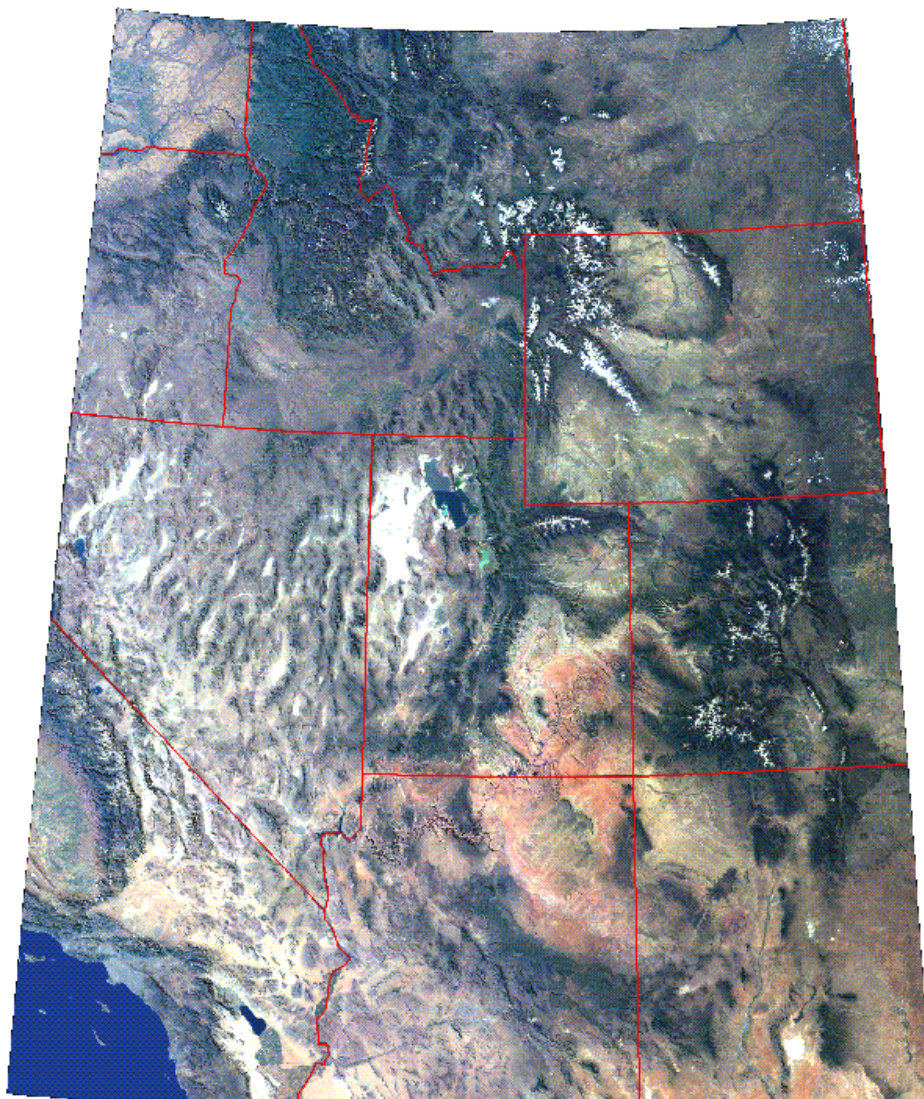


Figure 5-22. Multi-image mosaic of Western United States centered on the state of Utah. Mosaic seams are invisible in this scene, an indication of good radiometric and geometric corrections. The skewed and curved margins are an artifact of the rectification and mosaic process. Taken from http://www.jpl.nasa.gov/images/earth/usa/misr_020602_2.html.



Figure 5-23. Landsat 7 Image of the Boston, Massachusetts area. Image on the right shows red box outlining the boundaries of the subset scene on the left. Taken from <http://landsat.gsfc.nasa.gov/education/l7downloads/index.html>.

(3) *Multiple-image Temporal Analysis.* It is possible to combine bands from different images or data sets. This allows a user to perform a change detection analysis. The process of “layering” multi-temporal data involves loading a composite of bands from different images of the same scene. For example, a study assessing urban development in a forested area would benefit from examining a band combination that included band 3 data in the red plane, and band 3 data of a later image in the green plane. If the spectral signature of the scene has changed and is detectable within the resolution of the data, then changes in the scene will be highlighted. This image can then be classified and the areas of change can be statistically assessed. To perform this task accurately, it is important that both images are registered properly. Misregistration will lead to an offset in the image, which leaves brightly colored lines of pixels. Be sure to choose images whose data were collected under similar conditions, such as the same season, time of day, and prevailing weather, i.e., minimum cloud cover.

f. Remote Sensing and Geospatial Information. Remote sensing data are easily integrated with other digital data, such as vector data used in a GIS (Geographical Information System). Vector data can be incorporated into a raster satellite image by overlaying the data onto an image scene. Conversely, a raster image can be saved as a .jpeg or .tiff file and exported to a vector software processing program. Remote sensing data files can provide land cover and use information as well as digital elevation models (DEMs), and a number of geo-physical and biophysical parameters. Satellite images coupled with GIS data can be used to create original maps. The use of remote sensing in this type of application can drastically cut costs of GIS database development. It also provides data for inaccessible areas.

(1) *Digital Orthoquadrangle (DOQs).* A digital orthoquadrangle (DOQ) is a digital image of an aerial photograph that has had ground relief removed and is

geometrically corrected. The removal of ground relief adds to the accuracy measurement of distances on the ground. DOQs are available over the internet through the USGS or state level natural resources and environmental agencies. They come in black and white and color infrared. These digital aerial photographs come in a variety of scales and resolutions (often 1-m GSD). Due to the ortho-correction process, DOQs are typically in UTM, Geographic, or State Plane Projection. The images typically have 50 to 300 m overlap. This overlap simplifies the mosaic process. DOQs work well in combination with GIS data and may aid in the identification of objects in a satellite scene. It is possible to link a DOQ with a satellite image and a one-to-one comparison can be made between a pixel on the satellite image and the same geographic point on the DOQ.

(2) *Digital Elevation Models (DEM)*. A Digital Elevation Model (DEM) is a digital display of cartographic elements, particularly topographic features. DEMs utilize two primary types of data, DTM (digital terrain model) or DSM (digital surface model). The DTM represents elevation points of the ground, while DSM is the elevation of points at the surface, which includes the top of buildings and trees, in addition to terrain. The DEM incorporates the elevation data and projects it relative to a coordinate reference point. (See <http://www.ipf.tuwien.ac.at/fr/buildings/diss/node27.html> for more information on DEM, DTM, and DSMs.

(3) *DEM Generation*. Elevation measurements are sampled at regular intervals to form an array of elevation points within the DEM. The elevation data are then converted to brightness values and can be displayed as a gray scale image (Figure 5-24). The model can be viewed in image processing software and superimposed onto satellite image data. The resulting image will appear as a “three-dimensional” view of the image data.

(a) DEMs come in a variety of scales and resolutions. Be sure to check the date and accuracy of the DEM file. DEMs produced before 2001 have as much as 30 m of horizontal error. As with other files, the DEM must be well registered and in the same projection and datum as other files in the scene. Check the metadata accompanying the data to verify the projection.

(b) The primary source of DEM data is digital USGS topographic maps and not satellite data. Spaceborne elevation data will be more readily available with the processing and public release of the Shuttle Radar Topography Mission (SRTM) data. Some of this data is currently available through the Jet Propulsion Laboratory (<http://www.jpl.nasa.gov/srtm/>) and USGS EROS Data Center (<http://srtm.usgs.gov/index.html>).



Figure 5-24. Digital elevation model (DEM). The brightness values in this image represent elevation data. Dark pixels correspond to low elevations while the brightest pixels represent higher elevations. Taken from the NASA tutorial at http://rst.gsfc.nasa.gov/Sect11/Sect11_5.html.

(c) DEMs can be created for a study site with the use of a high resolution raster topographic map. The method involved in creating a DEM is fairly advanced; see <http://spatialnews.geocomm.com/features/childs3/> for information on getting starting in DEM production.

(4) *Advanced Methods in Image Processing.* Remote sensing software facilitates a number of advanced image processing methods. These advanced methods include the processing of hyperspectral data, thermal data, radar data, spectral library development, and inter-software programming.

(a) *Hyperspectral Data.* Hyperspectral image processing techniques manage narrow, continuous bands of spectral data. Many hyperspectral systems maintain over 200 bands of spectral data. The narrow bands, also known as channels, provide a high level of detail and resolution. This high resolution facilitates the identification of specific objects, thereby improving classification (Figure 5-24). The advantage of hyperspectral imaging lies in its ability to distinguish individual objects that would be otherwise grouped in broadband multi-spectra imagery. Narrow bands are particularly useful for mapping resources such as crop and mineral types. The narrow, nearly continuous bands create large data sets, which require advance software and hardware to store and manipulate the data.

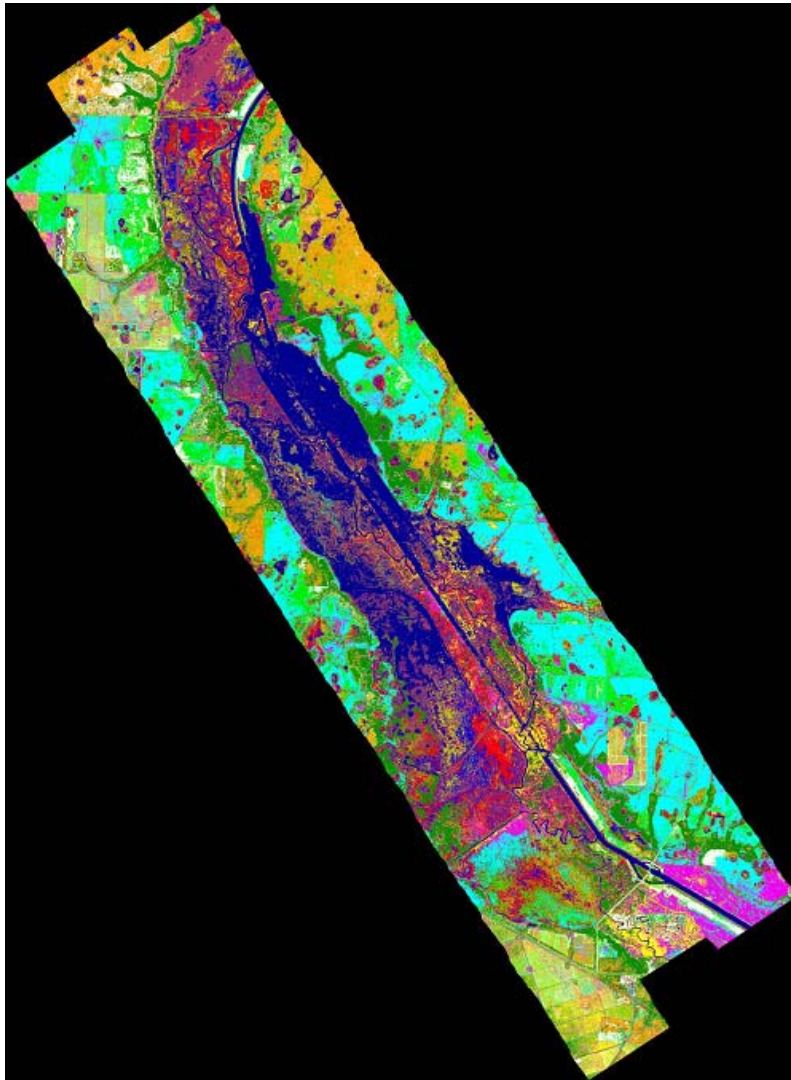


Figure 5-25. Hyperspectral classification image of the Kissimmee River in Florida (Image created by Lowe Engineers - LLC and SAIC, 2003). Classifications of 28 vegetation communities are based on a supervised classification.

(b) *Thermal Data.* Thermal image processing techniques are used to image objects by the analysis of their emitted energy (Figure 5-26). The thermal band wavelength ranges are primarily 8 to 14 μm and 3 to 5 μm . The analysis of thermal data is typically used in projects that evaluate surface temperatures, such as oceans and ice sheets, volcano studies, and the emission of heat from man-made objects (e.g., pipelines).

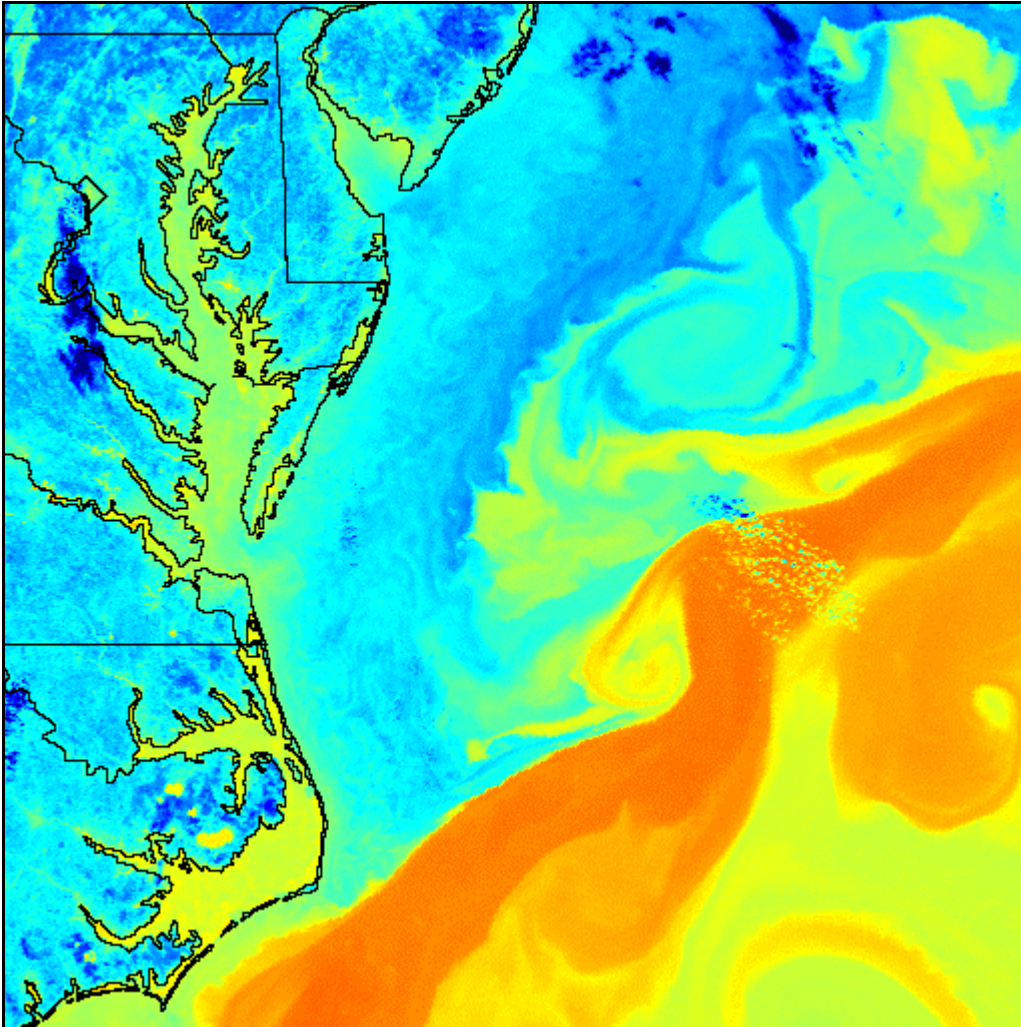


Figure 5-26. Close-up of the Atlantic Gulf Stream. Ocean temperature and current mapping was performed with AVHRR thermal data. The temperatures have been classified and color-coded. Yellow = water 23°C (73°F), green = 14°C (57°F), blue = 5°C (41°F). Taken from <http://www.osdpd.noaa.gov/PSB/EPS/EPS.html>.

(c) *Radar.* Radar (radio detection and ranging) systems are able to penetrate cloud cover in certain wavelengths. This technology is useful for imaging day or night surface features during periods of intense cloud cover, such as storms, smoke from fire, or sand and dust storms (Figure 5-27).



Figure 5-27. Radarsat image, pixel resolution equals 10 m. Image is centered over the Illinois River (upper left), Mississippi River (large channel in center), and the Missouri River (smaller channel in center. Chapter 6 case study 3 details the analysis of this scene. Taken from Tracy (2003).

g. Customized Spectral Library. Many software programs allow users to build and maintain a customized spectral library. This is done by importing spectra signatures from objects of interest and can be applied to identify unknown objects in an image.

h. Internal Programming.

(1) Image processing software allows users to develop computing techniques and unique image displays by programming from within the software package. Programming gives the user flexibility in image manipulation and information extraction. The users' manual and online help menus are the best resources for information on how to program within particular software.

(2) New applications in image processing and analysis are rapidly being developed and incorporated into the field of remote sensing. Other advanced uses in image processing include the modification of standard methods to meet individual project needs and improving calibration methods. Go to http://www.techexpo.com/WWW/opto-knowledge/IS_resources.html for more

information on advanced and specialized hardware and software and their applications.

i. *The Interpretation of Remotely Sensed Data.* There are four basic steps in processing a digital image: data acquisition, pre-processing, image display and enhancement, and information extraction. The first three steps have been introduced in this and previous chapters. This section focuses on information extraction and the techniques used by researchers to implement and successfully complete a remote sensing analysis. The successful completion of an analysis first begins with an assessment of the project needs. This initial assessment is critical and is discussed below.

(1) *Assessing Project Needs.* Initiating a remote sensing project will require a thorough understanding of the project goals and the limitations accompanying its resources. Projects should begin with an overview of the objectives, followed by plans for image processing and field data collection that best match the objectives.

(a) An understanding of the customer resources and needs will make all aspects of the project more efficient. Practicing good client communication throughout the project will be mutually beneficial. The customer may need to be educated on the subject of remote sensing to better understand how the analysis will meet their goals and to recognize how they can contribute to the project. This can prevent false expectations of the remotely sensed imagery while laying down the basis for decisions concerning contributions and responsibilities. Plan to discuss image processing, field data collection, assessment, and data delivery and support.

(b) The customer may already have the knowledge and resources needed for the project. Find out which organizations may be in partnership with the customer. Are there resources necessary for the project that can be provided by either? It is important to isolate the customer's ultimate objective and learn what his or her intermediate objectives may be. When assessing the objectives, keep in mind the image classification needed by the customer and the level of error they are willing to accept. Consider the following during the initial stages of a project:

- What are the objectives?
- Who is the customer and associated partners?
- Who are the end users?
- What is the final product?
- What classification system is needed?
- What are the resolution requirements?
- What is the source of image data?
- Does archive imagery exist?
- Is season important?
- What image processing software will be used? Is it adequate?
- What type of computer hardware is available? Is it adequate?
- Is there sufficient memory storage capacity for the new imagery?

- Are hardware and software upgrades needed? Who will finance upgrades?
- Are plotters/printers available for making hardcopy maps?
- Can the GIS import and process output map products?

(c) Field considerations:

- What are the ecosystem dynamics? What type of field data will be required?
- Will the field data be collected before, after, or during image acquisition?
- Who will be collecting the field data?
- What sampling methods will be employed?
- What field data analysis techniques will be required?
- Who will be responsible for GPS/survey control?
- Who will pay for the field data collection?
- Is the customer willing to help by providing new field data, existing field data, or local expertise?

(2) *Visualization Interpretation.*

(a) Remotely sensed images are interpreted by visual and statistical analyses. The goal in visualization is to identify image elements by recognizing the relationship between pixels and groups of pixels and placing them in a meaningful context within their surroundings. Few computer programs are able to mimic the adroit human skill of visual interpretation. The extraction of visual information by a human analyst relies on image elements such as pixel tone and color, as well as association. These elements (discussed in Chapter 2) are best performed by the analyst; however, computer programs are being developed to accomplish these tasks.

(b) Humans are proficient at using ancillary data and personal knowledge in the interpretation of image data. A scientist is capable of examining images in a variety of views (gray scale, color composites, multiple images, and various enhancements) and in different scales (image magnification and reduction). This evaluation can be coupled with additional information such as maps, photos, and personal experience. The researcher can then judge the nature and importance of an object in the context of his or her own knowledge or can look to interdisciplinary fields to evaluate a phenomena or scene.

(3) *Information Extraction.* Images from one area of the United States will appear vastly different from other regions owing to variations in geology and biomes across the continent. The correct identification of objects and groups of objects in a scene comes easily with experience. Below is a brief review of the spectral characteristics of objects that commonly appear in images.

(a) *Vegetation.* Vegetation is distinguished from inorganic objects by its absorption of the red and blue portions of the visible spectrum. It has high reflectance in the green range and strong reflectance in the near infrared. Slight variability in the reflectance is ascribable to differences in vegetation morphology,

such as leaf shape, overall plant structure, and moisture content. The spacing or vegetation density and the type of soil adjacent to the plant will also create variations in the radiance and will lead to “pixel mixing.” Vegetation density is well defined by the near infrared wavelengths. Mid-infrared (1.5 to 1.75 μm) can be used as an indication of turgidity (amount of water) in plants, while plant stress can be determined by an analysis using thermal radiation. Field observations (ground truth) and multi-temporal analysis will help in the interpretation of plant characteristics and distributions for forest, grassland, and agricultural fields. See Figures 5-28 and 5-29.

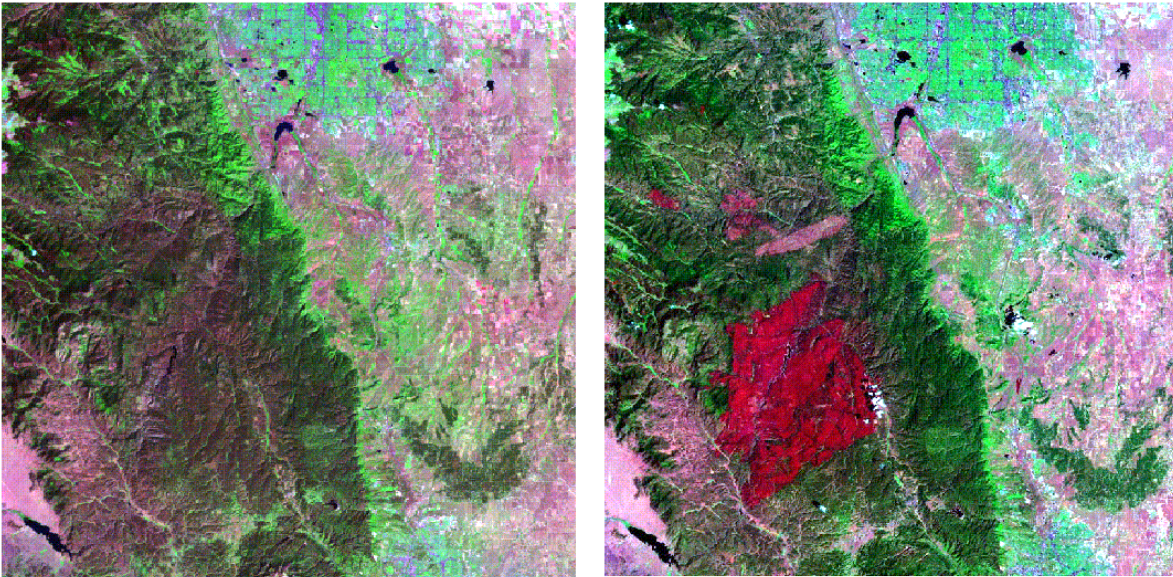


Figure 5-28. Forest fire assessment using Landsat imagery (Denver, Colorado). Image on the left, courtesy of NASA, was collected in 1990; image on the right was collected in 2002 (taken from <http://landsat7.usgs.gov/gallery/detail/178/>). Healthy vegetation such as forests, lawns, and agricultural areas are depicted in shades of green. Burn scars in the 2002 image appear scarlet. Together these images can assist forest managers in evaluating extent and nature of the burned areas.

(b) *Exposed Rock (Bedrock).* Ground material such as bedrock, regolith (unconsolidated rock material), and soil can be distinguished from one another and distinguished from other objects in the scene. Exposed rock, particularly hydrothermally altered rock, has a strong reflectance in the mid-infrared region spanning 2.08 to 2.35 μm . The red portion of the visible spectrum helps delineate geological boundaries, while the near infrared defines the land–water boundaries. Thermal infrared wavelengths are useful in hydrothermal studies. As discussed in earlier sections, band ratios such as band 7/band 5, band 5/band 3, and band 3/band 1 will highlight hydrous minerals, clay minerals, and minerals rich in ferrous iron respectively. See Figure 5-30.

(c) *Soil.* Soil is composed of loose, unconsolidated rock material combined with organic debris and living organisms, such as fungi, bacteria, plants, etc. Like exposed rock, the soil boundary is distinguished by high reflectance in

the red range of the spectrum. Near infrared wavelengths highlight differences between soil and crops. The thermal infrared region is helpful in determining moisture content in soil. See Figure 5-31.



Figure 5-29. Landsat scene bands 5, 4, 2 (RGB). This composite highlights healthy vegetation, which is indicated in the scene with bright red pixels. Taken from <http://imagers.gsfc.nasa.gov/ems/infrared.html>.



Figure 5-30. ASTER (SWIR) image of a copper mine site in Nevada. Red/pink = kaolinite, green = limestones, and blue-gray = unaltered volcanics. Courtesy of NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

(d) *Water (Water, Clouds, Snow, and Ice)*. As previously mentioned, the near infrared defines the land–water boundaries. The transmittance of radiation by clear water peaks in the blue region of the spectrum. A ratio of band 5/band 2 is useful in delineating water from land pixels. Mid-infrared wavelengths in the 1.5- to 1.75-mm range distinguishes clouds, ice, and snow. See Figure 5-32.

(e) *Urban Settings*. Objects in an urban setting include man-made features, such as buildings, roads, and parks. The variations in the materials and size of the structure will greatly affect the spectral data in an urban scene. These features are well depicted in the visible range of the spectrum. Near infrared is also useful in distinguishing urban park areas. Urban development is well defined in false-color and true color aerial photographs, and in high resolution hyperspectral data. The thermal infrared range (10.5 to 11.5 μm) is another useful range owing to the high emittance of energy. A principal components analysis may aid in highlighting particular urban features. See Figure 5-33.

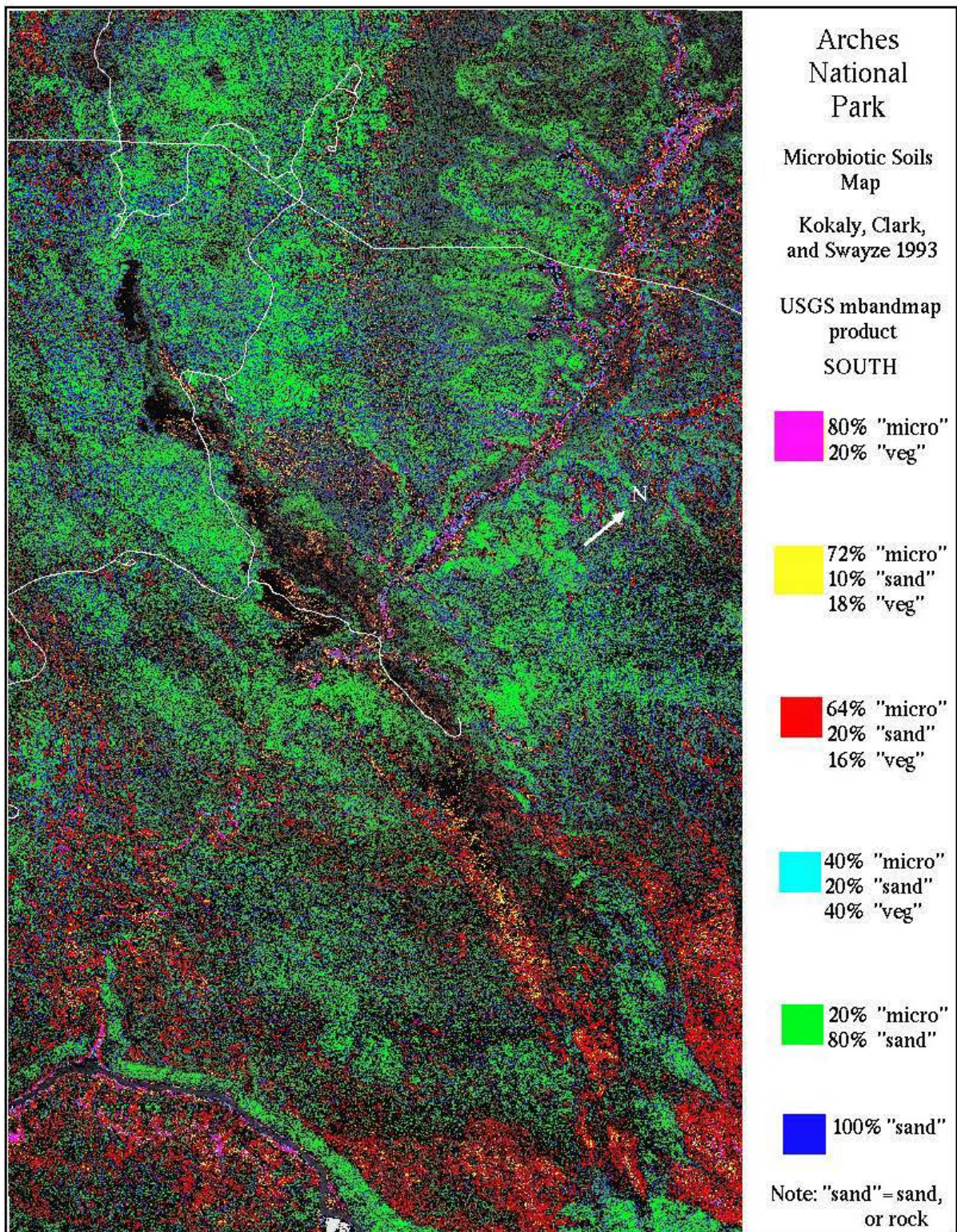


Figure 5-31. AVIRIS image, centered on Arches National Park, produced for the mapping of cryptogamic soil coverage in an arid environment. Taken from <http://speclab.cr.usgs.gov/PAPERS.arches.crypto.94/arches.crypto.dri.html>.

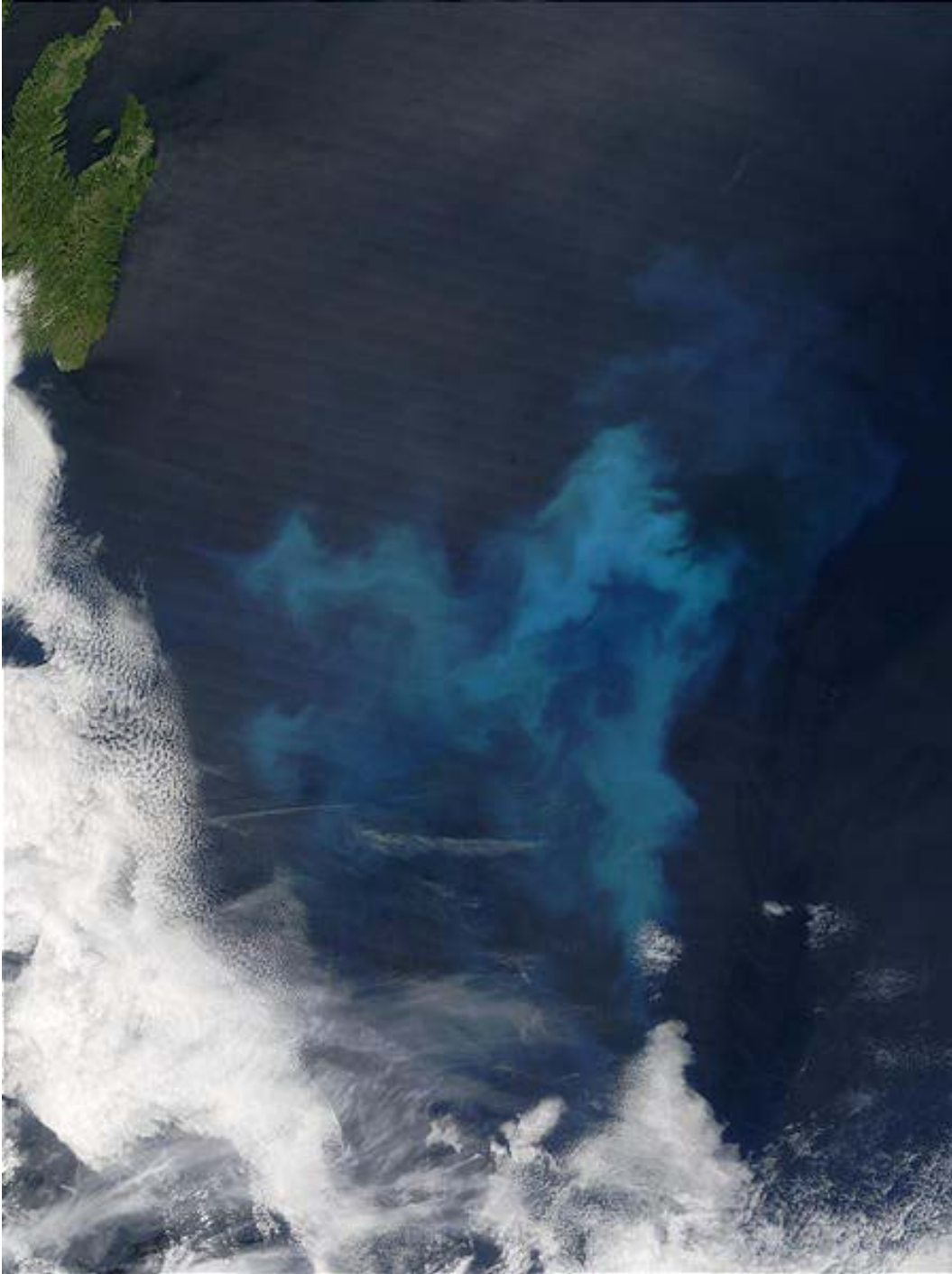


Figure 5-32. MODIS image of a plankton bloom in the Gulf of St. Lawrence near Newfoundland, Canada. Ground pixel size is 1 km. In this image, water and clouds are easily distinguishable from land (green pixels at top left of scene). Taken from <http://rapidfire.sci.gsfc.nasa.gov/gallery/?2003225-0813/Newfoundland.A2003225.1440.1km.jpg>.



Figure 5-33. Orlando, Florida, imaged in 2000 by Landsat 7 ETM+ bands 4, 3, 2 (RGB). The small circular water bodies in this image denote the location of karst features. Karst topography presents a challenge to development in the Orlando area. Taken from <http://edcwww.cr.usgs.gov/earthshots/slow/Orlando/Orlando>

(f) *Other Landscape Features.* A variety of unique landscape features are easily imaged with remote sensing. A few examples are illustrated below: Volcanic eruption (Figure 5-34), forest fires (Figure 5-35), abandoned ships (Figure 5-36), dust storm (Figure 5-37), oil fires (Figure 5-38), and flooding (Figure 5-39).

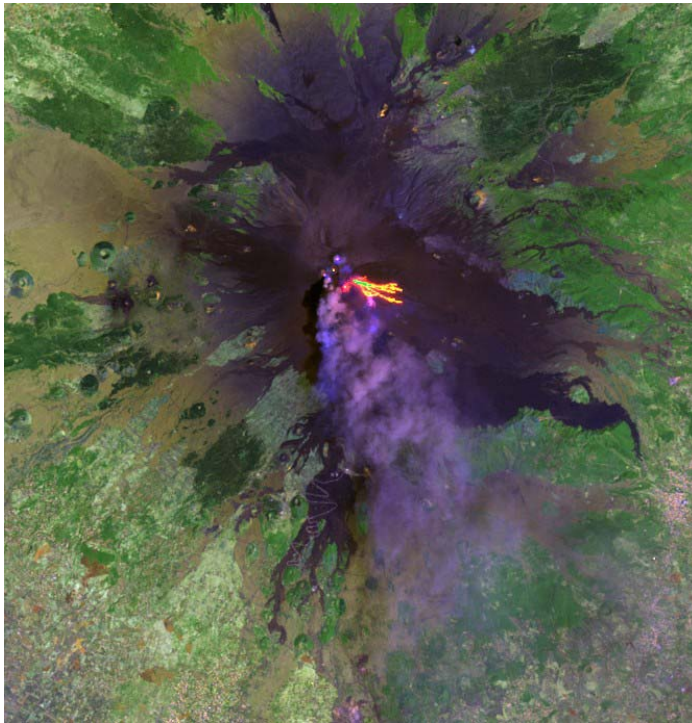


Figure 5-34. Landsat image of Mt. Etna eruption of July 2001. Bands 7, 5, 2 (RGB) reveal the lava flow (orange) and eruptive cloud (purple). Taken from <http://www.usgs.gov/volcanoes/etna/>.

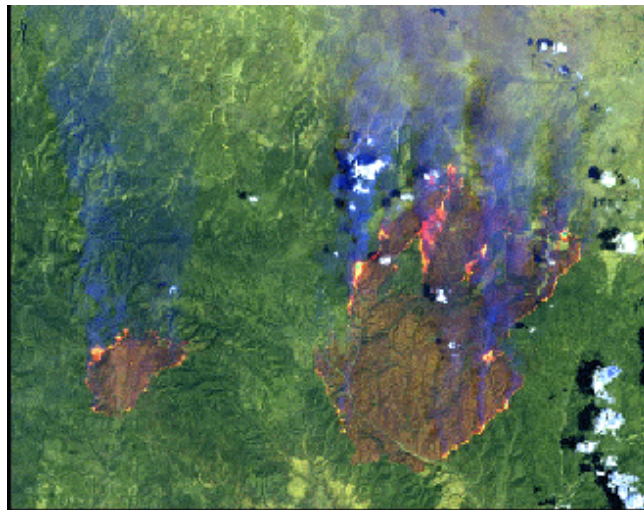


Figure 5-35. Forest Fires in Arizona may assist forest managers in fire-fighting strategies and prevention. Meteorologist also use such images to evaluate air quality. Image taken from <http://rst.gsfc.nasa.gov/Front/overview.html>.



Figure 5-36. Grounded barges at the delta of the Mississippi River are indicated by the yellow circle. Taken from http://www.esa.ssc.nasa.gov/rs_images_display.asp?name=prj_image_arcvip.5475.1999.101916538330.jpg&image_program=&image_type=&image_keywords=&offset=312&image_back=true.



Figure 5-37. July 2001 Saharan dust storm over the Mediterranean. Taken from <http://rapidfire.sci.gsfc.nasa.gov/gallery/>.



Figure 5-38. Oil trench fires and accompanying black smoke plumes over Baghdad, Iraq (2003). This image was acquired by Landsat 7 bands 3, 2, 1 (RGB). Urban areas are gray, while the agricultural areas appear green. Taken from <http://landsat7.usgs.gov/gallery/detail/220/>.

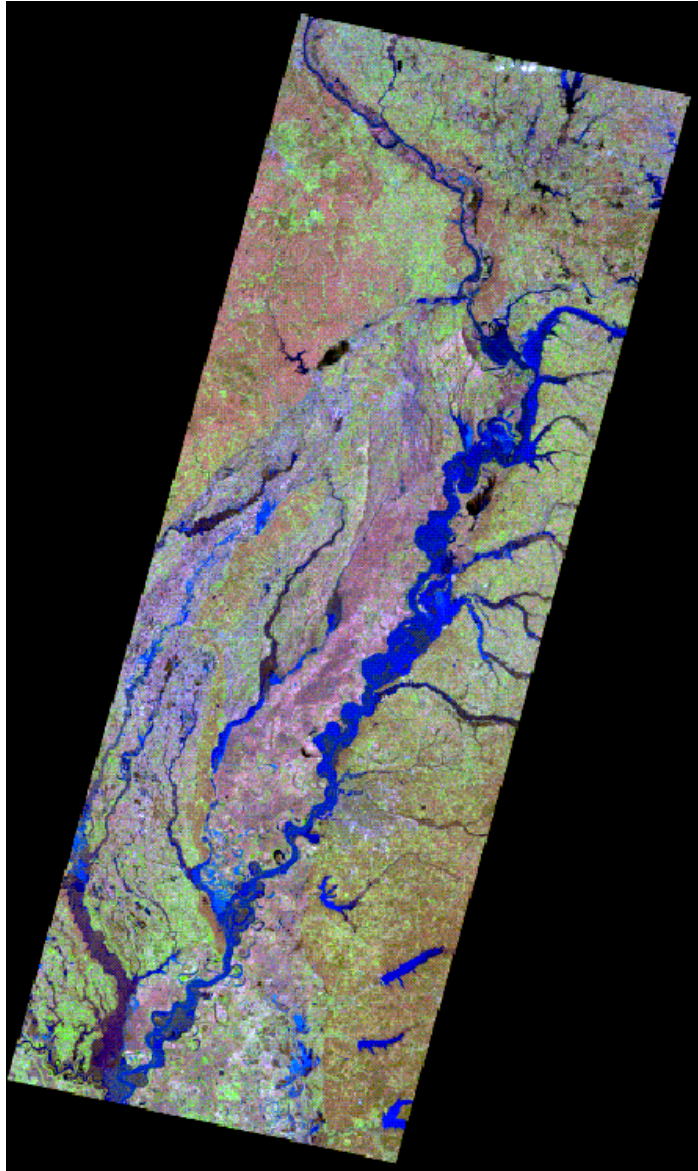


Figure 5-39. The mosaic of three Landsat images displays flooding along the Mississippi River, March 1997.

j. Statistical Analysis and Accuracy Assessment. Accuracy assessment means the correctness or reliability in the data. Error is inherent in all remote sensing data. It is important to establish an acceptable level of error and to work within the resolution of the image. Working within the means of the resolution of an image is important for maintaining the desired accuracy. Attempting to extract information from an image for which objects are not clearly resolvable will likely lead to incorrect assumptions. Error can be introduced during acquisition by the sensor and while performing geometric and radiometric correction and image enhancement processes. Another major source of error lies in the misidentification and misinterpretation of pixels and groups of pixels and their classification.

(1) *Resolution and RMS (Root Mean Squared)*. Some errors are simple to quantify. For instance, the image pixel in a TM image represents the average radiance from a 30- × 30-m area on the ground. So, measurements within a TM scene will only be accurate to within 30 m. Positional accuracy may be established by a comparison with a standard datum giving an absolute uncertainty value. The RMS (root mean squared) error is automatically calculated during image rectification. This error can be improved while designating GCPs (Ground Control Points; see Paragraph 5-17).

(2) *Overall Accuracy*. Overall accuracy can be established with “Ground truth.” Ground truth is site-specific and measures the accuracy by sampling a number of areas throughout a scene. Overall accuracy of an image is then calculated by modeling the difference between the observed pixel DN signature and known object on the ground.

(3) *Error Matrices*. Assessing classification error is more involved. Solving for this type of error requires a numerical statistical analysis. Some software incorporates accuracy assessment within the classification function. For instance, classification error assessment compares an image classification matrix with a reference matrix. See Paragraph 5-20d(4) for information on classification accuracy. In this type of assessment, the reference data are assumed correct. Pixels are assessed in terms of their mistaken inclusion or exclusion from an object class; this is known as commission and omission (see Congalton and Green, 1999). All known error should be noted and included in any assessment. Review Congalton and Green (1999) for further information on the practice of error assessment.

k. Presenting the Data. Once a visual and statistical evaluation has been performed, the analysis must be presented in a manner that best communicates the information needed. The information may be presented as a hardcopy printout of the image or presented as a map (Figure 5-40). The information may also be displayed as a statistical database, which includes data tables and graphs. Knowledge of GIS, cartography, and spatial analysis is helpful in choosing and executing the manner in which the data will be presented. For instance, a number of GIS software programs are capable of displaying the image in a map format with a linked data set. Be sure to keep in mind the final product needed by the client.

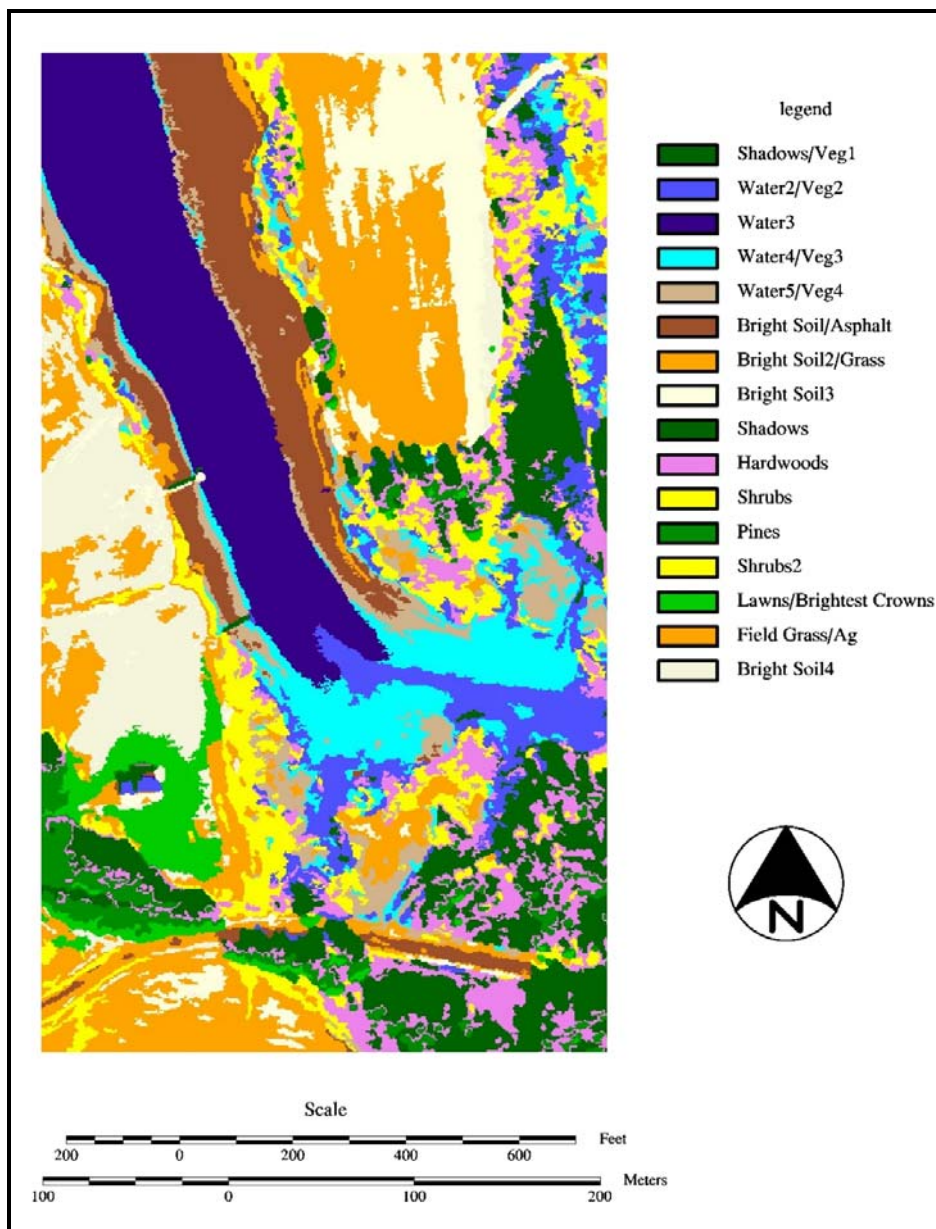


Figure 5-40. The final product may be displayed as a digital image or as a high quality hard copy. Taken from Campbell (2003).

Chapter 6.

Remote Sensing Applications in USACE

6-1 Introduction. Remote Sensing is currently used by Corps scientists and engineers at the seven research and development laboratories as well as at the Districts and Divisions. Remote sensing has proven to be a cost effective means of spatially analyzing the environment and is particularly useful in regions with limited field access. A vast amount of literature covering remote sensing applications in environmental and engineering projects has been published and much of it is available through the ERDC and USACE library system. This chapter only touches the surface of the material that describes the variety of applications and products in use. Some of the references listed in Appendix A also have internet web sites providing more in-depth information on the subject of remote sensing and current research.

6-2 Case Studies.

a. Each study presented below uses remote sensing tools and data. Special emphasis have been placed on Corps works and contracted work related to civil projects. Non-Corps projects, such as NASA works, are also presented in an effort to provide broader examples of the potential use of remote sensing and to aid in the implementation of remote sensing into existing and future US Army Corps of Engineers projects. This chapter 1) reviews the capabilities of sensors, 2) illustrates the value of remote sensing data analysis and integration into spatial data management systems, and 3) communicates recent studies to promote cooperation between Corps Districts, local government, and the general public.

b. The following topics are presented in this chapter:

- Water Quality.
- Wetland mitigation.
- Archeology.
- Engineering.
- Soil science—sediment transport.
- Forestry.
- Agriculture.
- Environmental projects.
- DEM generation.
- Applications in snow and ice.
- Emergency Management.

6-3 Case Study 1: Kissimmee River Restoration Remote Sensing Pilot Study Project Final Report

- *Subject Area:* Environmental Assessment.
- *Purpose:* To evaluate the vegetative response to the restoration of the Kissimmee River floodplain ecosystem using hyperspectral data.
- *Data Set:* Hyperspectral Airborne.

a. Introduction. Historically, the Kissimmee River meandered 103 miles (~166 km), connecting Lake Kissimmee to Lake Okeechobee. The river and its floodplain supported diverse wetland communities including aquatic and terrestrial plants and animals. The Kissimmee River was hydrologically unique owing to prolonged and extensive flood inundation. During the 1960s, the river and its 1- to 2-mile (1.6- to 3.2-km) wide floodplain was channelized and drained in an effort to control flooding. Canal excavation eliminated one-third of the channel, and drainage destroyed two-thirds the floodplain. This Corps of Engineers project led to a significant decrease in waterfowl, wading bird, and fish populations.

(1) An environmental restoration plan is underway in an attempt to restore the pre-1960 ecosystem in the Kissimmee River floodplain. The USACE Jacksonville District and the South Florida Water Management District are jointly responsible for this 3000- square mile (7770 km²) restoration project. The primary goal of the restoration project is to re-establish a significant portion of the natural hydrologic connectivity between Lake Kissimmee and Lake Okeechobee. With the natural hydrologic conditions in place, the objective of the project is to rebuild the wetland plant communities and restore the local biological diversity and functionality.

(2) The study reviewed here represents a pilot study conducted by SAIC (Science Applications International Corporation) to establish a baseline for environmental monitoring of the Kissimmee Restoration Project. Their study explored the utility of hyperspectral image data in aiding vegetative mapping and classification. The hyperspectral remote sensing data demonstrated themselves to be highly useful in delineating complex plant communities. Continued use of such a data set will easily aid in the management of the Kissimmee River Restoration Project.

b. Description of Methods. The test area within the restoration site was chosen by USACE. Preliminary field studies conducted in 1996, established approximately 70 plant communities, a handful of which were not present during the study of interest (conducted in 2002). It was determined that the rapid changes in hydrologic conditions had altered the plant community structure during the interim between studies; in places, some plant species and groups had entirely disappeared. Researchers monitoring the vegetation restoration at the Kissimmee site were concerned with the establishment of native versus non-native invasive and exotic plant species. The colonization by non-native plant species, such as Brazilian Pepper and Old World Climbing Fern, are of interest because of their potential affect on other revitalization efforts; those focusing on fauna restoration, for instance. The spectral analysis of heterogeneous plant species communities is difficult owing to the commonality of plant chemistry and morphology. The spectral difference between native and non-native plants is therefore narrow, and difficulties in distinguishing them are compounded by their mixing (or sharing of habitat). Additionally, the domination by one plant species in many places added to the problem of accurately classifying the plant communities. See below for vegetation classes established for this study.

(1) Examples of vegetation classes include:

- Aquatic vegetation.

- Broadleaf marsh.
- Miscellaneous wetland vegetation.
- Upland forest.
- Upland herbaceous.
- Upland shrub.
- Wetland forest.
- Wetland shrub.
- Wet prairie.
- Vines

(2) Geological constraints did not aid in the identification of the vegetation classes. Geologic constraints tend to be more useful in mapping plant communities in areas with a more mature ecosystem or where there is significant variation in the substrate or soil. Choosing a sensor capable of delineating healthy vegetation versus stressed vegetation was another consideration that needed to be addressed by the researchers. This would allow land use managers the opportunity to closely monitor the decline and rise of various species throughout the duration of the wetland restoration.

c. Field Work.

(1) Airborne hyperspectral data were collected in conjunction with 146 ground-truth data points (also known as training sites); this collection was made on-foot and by airboat. Fieldwork was done and data collected during a flood by a botanist and a GIS specialist. In the field, SAIC's hand held spectrometer was used to collect the spectral data associated with mixed plant communities from within the Kissimmee River floodplain. These ground-control points were then used to test the accuracy of the vegetation map developed from the hyperspectral data.

(2) Problems arose using the plant classes defined by the 1996 field study. Classes were subsequently altered to better suit the dechannelized ecology. A supervised classification was applied to the data and two vegetation maps were produced denoting 68 vegetation communities and 12 plant habitat types (Figure 5-25). The hyperspectral map was then compared to the existing vegetation map produced in 1996.

d. Hyperspectral Sensor Selection. Researchers on this project had the opportunity to choose between AVIRIS and HyMap. HyMap was eventually chosen for its accuracy, spectral capabilities, and reasonable expense. HyMap, a hyperspectral sensor (HSI), was placed on board a HyVista aircraft. HyMap maintains 126 bands across the 15- to 20-nm range. The error in HyMap data was found to be at ± 3 m, equivalent to the accuracy of the on board GPS unit. To learn more about HyMap and HyVista view <http://www.hyvista.com/main.html>.

(1) For this project, the hyperspectral (HSI) data maintained clear advantages over other sensor data. HSI's high spectral resolution allows for the distinction of spectrally similar vegetation and had the potential to monitor vegetation health status. The shortwave infrared (SWIR) wavelengths were found to be most sensitive to the non-photosynthetic

properties in the vegetation. This further helped to discriminate among the vegetation classes.

(2) HyVista pre-processed the digital data. Pre-processing included a smoothing algorithm to reduce the signal to noise ratio (SNR) across the scene, to an impressive >500:1. The data were geographically rectified using ground control points identified on a geo-registered USGS orthophoto. The geo-positional accuracy was determined to be within ± 3 pixels across 95% of the scene. This was established by comparing the image with a high-resolution orthophoto. A digital orthophoto was then overlaid on top of the digital hyper-spectral data to verify geo-positional accuracy.

e. Study Results. Analyst used KHAT (Congalton, 1991), a classification statistic used to test the results of supervised versus unsupervised classification (Equation 6-1). KHAT considers both omission and commission errors. Statistically it is “a measure of the difference between the actual agreement between reference data and the results of classification, and the chance agreement between the reference data and a random classifier” (see <http://www.geog.buffalo.edu/~lbian/rsoc17.html> to learn more on accuracy assessment). KHAT values usually range from 0 to 1. Zero indicates the classification is not better than a random assignment of pixels; one indicates that the classification maintains a 100% improvement from a random assignment. KHAT values equaled 0.69 in this study, well within the 0.6 to 0.8 range that describes the class designation to be “very good” (≥ 0.8 is “excellent”). For this study, KHAT indicated good vegetative mapping results with the supervised classification for distinguishing plant species and for mapping surface water vegetation. The KHAT also verified the potential value of image classification to map submerged aquatic vegetation using HIS data.

$$k = \frac{\text{observed accuracy} - \text{chance agreement}}{1 - \text{chance agreement}} \quad (6-1)$$

$$N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} \times x_{+i})$$

$$k = N2 - \sum_{i=1}^r (x_{i+} \times x_{+i})$$

where

- r = number of rows in the error matrix
- x_{ii} = number of observations in row i and column i (the diagonal)
- x_{i+} = total observations of row i
- x_{+i} = total observations of column i
- N = total of observations in the matrix .

The estimated time savings of the mapping project as compared with the manual analysis using color infrared was calculated to be a factor of 10 or better. Additional benefits include a digital baseline for change detection and managing restoration. The study did not establish under which conditions HSI did not work. HSI processing and analyses was shown to be a generally valuable tool in a large-scale riparian restoration.

f. Conclusions. HSI's advantages over aerial panchromatic and color infrared include its ability to automate data processing rapidly; this will be highly useful for change detection if the hyperspectral data are collected over time. This data can then be easily coupled with other useful GIS data when researchers attempt to combine hydrographic and wildlife data. Wetland hyperspectral imaging paired with advanced data processing and analysis capabilities were shown to be a valuable tool in supporting large-scale programs, such as the Comprehensive Everglades Restoration Program (CERP). For continued successful management of the Kissimmee Restoration Project, the Corps' Jacksonville District and the South Florida Water Management District will have to decide on a mapping method that provides the detail needed to monitor plant community evolution while balancing this need with budget constraints.

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6-4 Case Study 2: Evaluation of New Sensors for Emergency Management

- *Subject Area:* Emergency Management.
- *Purpose:* To test the resolvability of high-resolution imaging to evaluate roof condition.
- *Data Set:* Visible and infrared.

a. Introduction.

(1) Emergency response and management efforts are best facilitated with timely and accurate information. Typically, these data include an enormous amount of geo-spatial information detailing the extent and condition of damage, access to emergency areas or support services, and condition of urban infrastructure. Remotely sensed imagery has the capability of delivering this type of information, but it is best combined with geo-spatial data when they are rectified and pre-processed in a way that allows for easy visual and algorithm analysis. The amalgamation of geo-spatial data into one comprehensive map will aid emergency management organizations in their effort to coordinate and streamline their response.

(2) Understanding the utility and limitations of a sensor is highly valuable to emergency response workers. This study evaluated the effectiveness of Emerge, a new airborne sensor that collects visible and infrared radiation. Emerge was tested in relation to four primary requirements, listed below.

- Ground sampling distance (GSD).
- Capability for storing large volumes of digital data.
- Pre-processing and the vendors ability to orthorectify up to "500 single frames of imagery in 12 hours or less" and save these data onto a CD-ROM or ftp for fast delivery.
- Indexing system for all resolutions collected, allowing for easy determination of image location.

b. Description of Methods. Originally, this study intended to evaluate roof damage caused by an actual emergency. In the absence of such an emergency, alternate imagery was collected over a housing development under construction in Lakeland, Florida, located 30 miles (48 km) northeast of Tampa, Florida. The different phases of housing construction provided an analog to roof damage during an event such as strong winds or a hurricane. The different structural states of both residential and commercial roofs included exposed rafters, exposed plywood, and plywood covered by tarpaper or shingles.

c. Field Work. Initially, field reconnaissance established the appropriateness of using two neighboring test areas in Lakeland, Florida. Roof conditions at individual buildings were evaluated and geo-referenced. After the first flight, an assessment of the ground sampling distance (GSD) and sensor data determined that a finer resolution would be required to adequately examine roof condition. Two additional flights were then acquired, resulting in a collection of data gathered at resolutions of 3, 2, and 1 ft (91.4-, 61-, and 30.5- cm respectively), and 8-in (20.3 cm). Landscaping features, such as tree type and leaf on/off state, were also documented with digital photos. This information was later used to establish the feasibility in mapping vegetation using the Emerge system.

d. Sensor Data Acquisition. The two test sites, occupying 8 square miles ($\sim 21 \text{ km}^2$), were surveyed at several resolutions using Emerge imagery (see http://www.directionsmag.com/pressreleases.php?press_id=6936 for more details on the Emerge System). Multiple resolutions were collected over a 2-month period. As a result, a one-to-one comparison of the effect of resolution on image analysis was difficult, as house construction in some areas was completed during the 2-month interval. The volume of data collected was equivalent to that required for a 60 square mile ($\sim 155 \text{ km}^2$) area, with approximately 25% image overlap (at a single resolution). This volume of data totaled 5 gigabits.

e. Study Results. Evaluation of the imagery showed that roof rafters were best resolved at a 1-ft and 8-in. (30.5 and 20.3 cm) resolution. At this resolution, plywood can be distinguished from other construction materials and individual rafters can be observed. Tarpaper was not distinguishable from shingles owing to their spectral similarities.

(1) Despite the functionality of the 1-ft and 8-in (30.5 and 20.3 cm) resolutions, in places with bright spectral response, saturation on the high end of the intensity scale lowered the resolvability of rafters relative to the flooring material. This was the result of a high gain set for radiation detection within the sensor. Over-saturation lowers the contrast between rafters and the flooring, making it difficult to fully evaluate the condition of the roof. Lowering radiation saturation requires collecting data during low to medium sun angle. This may, however, delay data acquisition.

(2) Sun angle controls image contrast in two ways. First, a low sun angle may increase shadowing, leading to a loss in target radiation data. Secondly, a high sun angle may over-saturate the sensor. Both extremes were shown to lower contrast in this study, making roof analysis difficult.

(3) A scatter plot breakdown of band 1 relative to band 2 was performed to evaluate the possibility of automating an analysis that would delineate intact roofs and damaged

roofs. A preliminary analysis suggests that this is possible because of the strong covariance displayed by roofs shingled with monochromatic materials. Any automated process developed would need to address the limitations posed by non-monochromatic shingles (which would appear spectrally mixed and indistinguishable from damaged roofs).

(4) A vegetation analysis was also explored to test the resolution required to accurately describe tree type and condition. At the 1-ft (30.5 cm) resolution, researchers were able to determine leaf on/off conditions (data were collected in February). However, at this resolution it was not possible to delineate any details regarding leaf morphology. At the 8-in (20.3 cm). resolution, palms were distinguishable, although it was not possible to differentiate broad versus narrow leaves.

f. Conclusions. Evaluation of the Emerge sensor led to the development of a detection matrix. This matrix reviews the capabilities of the sensor at various spatial resolutions for all objects studied (see Table 6-1). This study determined that Emerge could adequately meet the requirements of emergency management systems. High-resolution data can be acquired within 4 hours of the plane's landing. This includes the time needed for pre-processing (orthorectification and the production of geo-TIFF files for CD-ROM and ftp). Shingles and tarpaper are not resolvable, though rafters and plywood are at the 2-ft (~61 cm) resolution. For high-resolution images, a medium sun angle increased roof detail. Palm trees and leaf on/off conditions can be visually identified at the 8-in (20.3 cm). resolution; however, broad-leafed trees cannot be distinguished from narrow-leafed trees. The only limitations placed on these data centered on over-saturation and sensor inability to distinguish tree types. The covariance displayed by band 1 relative to band 2 indicates the potential success for developing an automated algorithm to locate and count damaged roofs.

Table 6-1
Detection Matrix for Objects at Various GSDS

Objects/GSD	3-ft (91.4)	2-ft (61 cm)	1-ft (30.5 cm)	8-in. (20.3 cm)
Roof rafters	Not visible	Barely visible	Often visible	Visible
Shingles/tarpaper (other) vs. plywood	Can sometimes separate	Can often separate	Can determine wood vs. other cover	Can determine wood vs. other cover
Rafters in 3-band saturation	Causes rafter detail loss	Causes rafter detail loss	Causes rafter detail loss	Causes rafter detail loss
Broad-leaf vs. narrow-leaf	Cannot separate	Can determine leaf on/off	Can determine leaf on/off	Palms are always visible
All in cloud shadow	Degrades image	Some info recoverable	Some info recoverable	Some info recoverable
Roofs as a function of sun zenith angle	Best detail, near zero angle, overhead sun	Best detail, medium angle, shadow casting	Best detail, medium angle, shadow casting	Best detail, medium angle, shadow casting
All in 1, 2, 3 RGB, 2 Σ stretch	Enhances imagery	Enhances imagery	Enhances imagery	Enhances imagery

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6-5 Case Study 3: River Ice Delineation with RADARSAT SAR

- *Subject Area:* Ice monitoring
- *Purpose:* To evaluate the concentration and condition of river ice.
- *Data Set:* RADARSAT SAR

a. Introduction. Remote sensors operating in the microwave region of the spectrum have the advantage of seeing through clouds and atmospheric haze. RADARSAT SAR (synthetic aperture radar) collects spectral data in the microwave region and is capable of imaging ground targets during adverse weather conditions, such as storms. Additionally, RADARSAT SAR collects 10-m pixel sized data, a high spatial resolution well suited for studies examining ice in narrow river channels. The study reviewed here explored RADARSAT SAR's potential in delineating and monitoring ice and ice floes in rivers ranging in stream widths of 160 to 1500 m. A better estimate of ice conditions along large streams will allow for better navigation planning and will provide river dam regulators the information needed to plan and prepare for ice breakup and floes.

b. Description of Methods. Three rivers of varying widths were evaluated for ice cover over the course of two winters (2002 and 2003). The first winter was relatively mild with partial river ice development at the three sites. Winter 2003 possessed a number of below freezing days and was an ideal time for examining river ice in the northern mid-west. The rivers chosen for this study were the Mississippi River near St. Louis, Missouri, the Missouri River at Bismarck, North Dakota, and the Red Lake River in Grand Forks, North Dakota. Each site offered unique contributions to the study. The Mississippi River represented a stream with heavy navigation use, the Missouri River site included a hydropower dam, while the Red Lake River had extensive ice jam and flood records. Coordinated efforts among CRREL researchers, the local Corps Districts, and the RADARSAT International (RSI) aided in the acquisition and timing of satellite data collection.

(1) Stream channels were subset and isolated for river ice classification. To accomplish this, a band ratio was applied to Landsat TM data. They were then classified by an unsupervised process and extracted for mask overlay onto the radar data. This sufficiently outlined the land/water boundaries and isolated the stream in images with wide river channels. This process omitted vegetation and islands from the resultant image. The subsequent SAR subset did not include mixed pixels (land/water/ice).

(2) Images with narrow channels required hand-digitization and a textural analysis, followed by a supervised classification (to further eliminate land pixels). The hand-digitization proved less successful than the Landsat TM overlay and extraction method. Hand-digitization did not thoroughly omit pixels with mixed water, vegetation, and land (i.e., river islands).

(3) In the SAR images, only the channel reaches were analyzed for ice conditions using an unsupervised classification. The classification mapped brash ice (accumulated floating ice fragments), river channel sheet ice, shore ice, and open water.

c. Field Work. Direct field observations were not necessary as a web-camera mounted on a bridge provided the visual documentation of ice conditions in the river. At the Missouri River site, web-cameras have been strategically placed in a variety of locations in the US by ERDC/CRREL. To view the Missouri River images used in this study, as well as other river web-camera images, go to <http://webcam.crrel.usace.army.mil>. Study sites without a web-camera relied on District contacts for field information. At Red Lake River near Grand Forks, North Dakota, field reconnaissance ice surveys were conducted by the Corps St. Paul, Minnesota, District office.

d. Sensor Selection and Image Post-Processing.

(1) As stated above, RADARSAT SAR data was chosen for this study. Radar data have already proven their utility in sea ice mapping and monitoring (Carsey, 1989). Radar can aid in determining ice concentration, classification, ice motion monitoring, and ice feature changes. The study reviewed here adapted methods used to study large ice sheets to the evaluation of smaller more temporal river ice.

(2) The acquired radar images were visually analyzed and classified using an unsupervised classification to delineate open water, moving ice floes, and stationary ice covers. The delineation of river channels was undertaken by two methods, described above (hand-digitization and TM extraction and overlay).

e. Study Results. The following description summarizes the ice condition results stemming from each river surveyed:

“In the Mississippi River imagery near St. Louis, Missouri, the wide channel width (500–2000 meters) contributed to identifying river ice with RADARSAT imagery. In the 2002 image it was determined that 30% of the channel had ice in the flow, and in the 2003 image, it was determined that there was 100% ice cover. Additionally, this ice cover was separated into forms of ice; brash ice and border ice. In the 2003 image it is believed that the brash ice formed as a result of navigation ice-breaking activities.

(1) In the Missouri River imagery near Bismarck, North Dakota, the channel width (400–1000 m) was suitable, and river ice was determined from the RADARSAT imagery. The 2002 image showed that 77% of the channel had ice in the flow, and in the 2003 image, only 21% of the channel had ice. The 2003 imagery was acquired before full icing conditions, and a small amount of ice was interpreted to exist.

(2) In the Red Lake River imagery near the confluence with the Red River of the North at Grand Forks, North Dakota, the river channel is narrow (40–75 m). The narrowness of the channel limited the process of delineating the channel boundary on the imagery. As a result of the narrow channel width, river ice was not determined by this process. However, ice surveys were conducted by the US Army Corps of Engineers during the time of image acquisitions, and an ice cover was recorded in both 2002 and 2003.

f. Conclusions. RADARSAT SAR data were able to detect ice on rivers with widths ranging from 400 to 2000 m. Despite RADARSAT’s 10-m resolution, this data set was unable to detect the presence of ice on the narrower Red Lake River, with a width of 40–75 m. RADARSAT’s overall suitability for detecting river ice and ice conditions was shown to be

of potential use. The method presented here details an important tool that may aid in hazardous wintertime navigation and assist dam regulators on decisions regarding stream flow and reservoir levels.

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6-6 Case Study 4: Tree Canopy Characterization for EO-1 Reflective and Thermal Infrared Validation Studies in Rochester, New York

- *Subject Area:* Forestry and climate change
- *Purpose:* To collect forest canopy structure and temperature data.
- *Data Set:* Multispectral and hyperspectral

a. Introduction. Tree and forest structure respond strongly to environmental conditions and change. Subsequently, studies have successfully shown the utility of remote sensing in monitoring environmental conditions through the analysis of vegetation. The study reviewed here surveyed a mixed forest in northern New York State in an attempt to better understand the interaction between solar radiation and tree/forest structure. An additional objective of this study was to validate the Earth Observing satellite (EO-1, launched in 2000). The validation was performed by comparing the EO-1 satellite data with that of the Landsat-7 ETM+ data. The EO-1 satellite acquired data at the same orbit altitude as Landsat-7 while flying approximately 1 minute behind. EO-1 reflective bands were combined with the Landsat-7 ETM+ thermal infrared bands to estimate canopy temperature. The 1-minute delay in synchronization between the two sensors was evaluated to test the effects of separating the thermal and reflective measurements in time. Relating scene exitance (the radiative flux leaving a point on a surface, moving in all directions) and reflectance to the landscape provided insight to prevailing environmental characteristics for the region.

b. Description of Methods. Ground and tree canopy data were collected from mature healthy forest stands at a site in Durant-Eastman Park in Rochester, New York. Characterization of the forest included a stem and trunk survey, tree structure geometry measurements, regional meteorology, and leaf area index (LAI) measurements (see <http://www.uni-giessen.de/~gh1461/plapada/lai/lai.html> for more information on LAI). Two smaller field sites, Ballard Ridge and Smith Grove, were selected for detailed study from within the larger forested area. Tree heights for both sites averaged 20–30 m. Ballard Ridge consisted of a dense mature stand of maple, cottonwood, elm, and oak trees. The Smith Grove consisted of a dense mature stand of locust trees and cottonwood. Thermal and reflective spectral measurements were made on leaves, tree bark, leaf litter, soil, and grass.

c. Field Work. Leaf area index (LAI) was calculated in the field with the use of a non-imaging instrument, which measures vegetation radiation in the spectrum of 320–490 nm. Leaf area index is a ratio of the foliage area in a forest canopy relative to the ground surface area. It estimates the photosynthetic capability of a forest. The measured light intensity was used to calculate the average LAI for each location within the field site. High-resolution hemispherical photographs were collected at each site using a digital camera with a fisheye lens (148° field-of-view). The digital photographs were taken during the early morning and

late evening hours to reduce the effects of atmospheric haze. The digital hemispherical photographs were later analyzed using a specialized forestry software, which measures both LAI and canopy leaf structure. LAI calculations based on the computed hemispherical digital images compared favorably with the LAI measurements from the meter instrument.

d. Sensor System.

(1) Satellite data were collected with the use of Landsat MTI, Hyperion, and ALI (Advanced Land Imager) on 25 August 2001. The ALI sensor has nine spectral bandwidths plus a panchromatic band. Three bands were analyzed for this study 773.31 nm, 651.28 nm, and 508.91 nm. The forested areas appear bright red, urban areas are gray-blue, and the water is depicted by the dark blue regions.

(2) The sensor radiance was converted with the use of 6S, an atmospheric corrections model that converts sensor radiance to estimated surface reflectance. The differences and consistencies in the two sensors were then easily compared with the spectral data collected in the field. Then, a more detailed study of the forest site was made, using measured geometric and optical parameters as input to the SAIL multi-layer canopy reflectance model. The ETM+ and ALI data were then compared with the SAIL (Scattering by Arbitrarily Inclined Leaf) reflectance model and the high resolution Hyperion, a hyperspectral imaging instrument (see <http://eo1.usgs.gov/instru/hyperion.asp> for details).

e. Study Results. A comparison of the panchromatic ETM+ and ALI data show dramatic differences. The ALI data provided better definition of the marina and pier area as well as natural water features (urban and water targets). Relative to the ETM+ images the ALI data maintained a reduced DN value for all forest pixels, increasing the contrast in the forest region. The authors suggested the higher resolution and the narrow bandwidths accounted for the dramatic contrasts between the image data sets.

(1) Spectral plot comparisons of the multispectral bands for different ground targets (grass, water, urban features, and forest) illustrating the relationship between reflectance and wavelength indicated a close match between the two sensors. The spectral plots were created by the selection of training pixels for each target group. ALI spectral values were closer in value than those seen in the ETM+ data; again, this is a result of the narrow bandwidths and higher resolution. The only notable difference in the spectral response between the two sensors was evident in band 5 for grass and urban features. These targets had up to 20% variation in signal response between the sensors. Specifically, the ALI band 5 with a reflectance of 0.35 μm is ~20% higher than the ETM+ value of 0.29 μm .

(2) The combined spectral plot of data from ETM+, ALI, Hyperion, and the empirically derived SAIL show overall an excellent agreement. The three satellite data sets closely match one another, with slightly different values recorded in the SAIL model data. SAIL values best matched those of the sensors in the visible portion of the spectrum.

f. Conclusions. The authors of this study were able to establish a simple, multi-layer canopy reflectance model using measured parameters from the site to compare the ETM+ and ALI spectra. Hyperspectral data were also compared against the satellite and ground data. Additional work is needed to establish the relationship between leaf area index (LAI)

and satellite data. The potential use of ALI and hyperspectral Hyperion for studies of forests in remote locations and forests at risk may greatly enhance forest management and lower the costs associated with ecological monitoring. Accurate estimates of LAI based on satellite imagery have the potential to support forest biomass monitoring, and hence forest health and changes in canopy structure attributable to pollution and climate change. The ability to estimate LAI with remote sensing techniques is, therefore, a valuable tool in modeling the ecological processes occurring within a forest and in predicting ecosystem responses.

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6-7 Case Study 5: Blended Spectral Classification Techniques for Mapping Water Surface Transparency and Chlorophyll Concentration

- *Subject Area:* Water quality
- *Purpose:* To establish water clarity and algal growth in a dam reservoir
- *Data Set:* Landsat TM - Visible and infrared

a. Introduction.

(1) An accurate portrayal of water clarity and algal growth in dynamic water bodies can be difficult owing to the heterogeneity of water characteristics. Heterogeneity can stem from the spatial distribution of sediments delivered to a lake by a tributary. Water turbidity associated with tributary sediment load controls water clarity and subsequently will impact algae growth. Additionally, algal growth will influence water clarity by reducing water transparency during times of algal blooms. Both algal growth and sediment turbidity are controlled by such factors as water depth, flow rate, and season.

(2) To better monitor the water quality at dam reservoirs, a spatial estimate of both water clarity and algal chlorophyll over a broad area is required. To accurately capture these properties a large number of water samples must be taken, a task that may not be feasible for most studies. Remote sensing lends itself well to the assessment of water quality testing at a variety of spectral scales due to the response of suspended sediment in the visible and thermal spectrum. Chlorophyll, produced by algae, can also be detected by its visible and infrared emission. The study reviewed here developed a classification algorithm to predict water clarity and chlorophyll concentrations. The algorithm was based on a correlation between spectral data and the empirical field data. Previous studies attempting to classify water clarity and chlorophyll required field sampled training sites. The goal of this study was to develop an algorithm based on empirical data that would illuminate the need for such test training sites. Thus, researchers testing for water quality would then need only the Landsat TM data to monitor water quality at a fresh water lake.

b. Field Work. Secchi Disk measurements and water samples were collected at a dam reservoir in conjunction with a Landsat fly-over at West-Point Lake, Georgia. Water samples were frozen and stored in a dark room to preserve the algae populations. These samples were later analyzed for chlorophyll (C_a) concentrations. Water clarity was measured *in situ* with a Secchi Disk (S_d). This 20-cm disk estimates water clarity by measuring the depth to

which the disk is visible. Remote sensors generally detect water clarity to 20–50% of the S_d measurement. Sampling sites were chosen evenly across the reservoir and adjacent tributaries. A global positioning unit was used to locate 109 sample sites. Drift during sampling occurred but was compensated for with the use of a 3×3 kernel during image classification. Samples and data were collected during two periods—summer and fall of 1991.

c. Sensor System. Two Landsat TM data sets separated in time were used to develop a linear-logarithmic cluster analysis. Visible, near, and middle infrared radiation band ratio was employed with a stratified sampling technique. Using a variety of band ratio, the workers were able to accurately develop a blended classification scheme, which is detailed below.

d. Study Results. The authors adapted multivariate density estimation with the use of an algorithm k-NN density estimator. This was used to group spectrally similar pixels. The spectral classes and class structures (or groupings that separated the spectral classes) were developed using an unsupervised classification. Within each of the two scenes, 16 unique classes were determined. These classes were combined with the empirical data, leaving four logarithmic algorithms. Applying a 3×3 kernel to the data compensated for the drift that occurred during data collection. This placed the positional accuracy to within ± 30 m.

(1) The average spectral value was determined by a log estimation of the band ratio for the given pixel within the kernel (Equation 6-2). Combinations of band ratios were tested. A middle infrared ratio against the visible red showed the largest correlation with S_d and C_a . Visible green versus near infrared also provided a good separation of the spectral response for estimating S_d and C_a .

$$IR = \frac{1}{9} \sum_{x=1}^3 \sum_{y=1}^3 \ln \frac{(\text{mid IR})}{(\text{visible red})_{x,y}} \quad 6-2$$

(2) Observed versus predicted S_d and C_a were well correlated with the use of this log estimate. Focused sampling and spectral blending led to the development of an accurate unsupervised classification with a 95% confidence interval. Sampling positions near tributaries were overestimated at only five sampling sites (relative to 109 sampling sites).

e. Conclusions. A strong correlation was made between the Landsat TM middle IR and the empirical Secchi Disk and chlorophyll concentrations. Chlorophyll was shown to have increased from 12.64 to 17.03 mg/m³, contributing to a decline in water clarity. The application of this log estimate now eliminates the need to collect empirical water quality data, likely reducing the cost in a water quality survey.

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6-8 Case Study 6: A SPOT Survey of Wild Rice in Northern Minnesota

- *Subject Area:* Agriculture
- *Purpose:* To estimate the percentage of wild rice in a wetland environment
- *Data Set:* Visible and near infrared

a. Introduction.

(1) A vegetation survey of natural wild rice surrounding three neighboring lakes 200 miles (518 km) south of St. Paul, Minnesota, was conducted to provide a base map for pollutant and water level monitoring. The study presented here utilized standard supervised classification, based on ground-truth, of high-resolution SPOT data. Wild rice is a natural marsh grass that is sensitive to water level changes and to changes in phosphorous concentrations; increases in phosphorous and water levels can significantly destroy wild rice communities. This is of concern as this important grass is a staple in the Chippewa Indian diet and is consumed by migratory birds.

(2) The researchers in this study were tasked with mapping and estimating the acreage of wild rice surrounding three lakes in Minnesota. Three spectral classes were developed with the use of a supervised classification to delineate the grass and its varying substrate.

b. Description of Methods. Ground truth data were collected simultaneously with SPOT over flight. The ground truth data included information regarding vegetation and substrate type as well as the sites corresponding UTM (global position in the Universal Transverse Mercator coordinate system).

c. Field Work. In the field, 18 ground control points (GCPs) were collected for rectification of the SPOT image and an additional 132 ground truth points were collected for the supervised classification algorithm. This data collection coincided with the SPOT over flight.

d. Sensor System. SPOT was chosen for its optimal detection of vegetation in the presence of inorganic ground cover (i.e., water). Vegetation absorbs both red and blue radiation, while reflecting green and near infrared (NIR) because of chlorophyll production. This matched well with the spectrum data provided by SPOT (which maintains green, red, and NIR bands among others).

e. Study Results.

(1) Prior to the classification process, it had been predicted that the wild rice would dominate one spectral class, as wild rice is spectrally distinct from other vegetation. Openings in the grass canopy, however, contributed to the spectral mixing observed in the image scene. Three spectrally distinct populations were noted, likely because of the heterogeneity of the background reflectance, varying crop canopy, and varying water content in the substrate.

(2) A histogram plot of the digital number value assigned to each pixel in the scene clearly reveals three distinct spectral populations. These three classes were determined to be wild rice growing in the lake, wild rice in marsh, and wild rice in a saturated soil. Wild rice growing in shallow or marsh water produced pixels that overlapped with more than one class. The near-infrared (N-IR) band allowed for better spectral separation by eliminating the effect of varying amounts of water in the substrate.

f. Conclusions.

(1) An estimate of the acreage percent based on a supervised classification determined that 1% of the scene was dominated by wild rice. Habitat was shown to predominately exist along the lakeshore, at inlets, ponds, on banks, and in marsh areas. Wild rice was determined to grow in saturated soil, marsh, and in shallow lake waters. The author recommend 200 ground truth points be collected per class (100 for spectral determinations and 100 for classification designation). Application of the ground truth data to a SPOT scene collected 5 days after the ground truth data did not produce an accurate classification. This test reveals the limitations on the usefulness of SPOT data for surveying vegetation—ground truth must be collected at the time of data acquisition.

(2) A detailed map of the distribution of wild rice will allow land managers to better predict the impact of changes in water level and phosphorous input on the natural production of wild rice.

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6-9 Case Study 7: Duration and Frequency of Ponded Water on Arid Southwestern Playas

- *Subject Area:* Hydrology.
- *Purpose:* To delineate playa inundation frequency and duration.
- *Data Set:* Multispectral/thermal (Landsat 4, 5, and 7 and MTI – Multi-spectral Thermal Imager).

a. Introduction.

(1) Playas are ephemeral shallow lakes found in the arid southwest United States. Their hydrology is dominated by rainfall and runoff in the wet season and evaporation throughout most of the year. Surface hydrology, particularly frequency and duration, is poorly understood in the playa environment. US waters, including playa water, are Federally regulated under article 33 CFR 328.3 [a] of the *Clean Water Act*. Water bodies are delineated to their outermost extent termed their “Ordinary High Water” (OHW). OHW is defined by the presence of physical hydrological features representing the ordinary reaches of high water in its bed or basin.

(2) Playas exhibit tremendous temporal variation, as they may not pond at all during a particular year or may remain ponded for several years. The extent to which water remains

on the surface is influenced by the ambient climate, surface properties, evaporation rate, salinity, and infiltration or discharge of groundwater. Spatial and temporal factors such as inundation, evaporative rate, relocation of brine pools by winds, and desiccation of surface water hinder the ability to approximate the duration and frequency of ponding necessary to accurately model flood events or to determine whether certain Federal environmental regulations apply. This study attempted to model the frequency and duration of playa inundation in an effort to better delineate playas for regulations.

b. Description of Methods.

(1) For this study, three playa lakes on the Edwards Air Force Base were examined with the use of 20 years of historical Landsat and MTI imagery. These data were coupled with 59 years of precipitation records collected on the base. Rogers Lake (114 km²) and Rosamond Lake (53 km²) occupy the eastern and western region of the study area, respectively. Smaller playa lakes separate Rogers and Rosamond Lakes, including Buckland (5 km²). The playa lakes are located on a Pleistocene glacial lakebed; the Pleistocene features dwarf the present geologic structures. Chenopod vegetation and saltbush plant communities dominate the terrestrial plain surrounding the playa.

(2) The playas remain dry for most of the year; however, winter rainstorms and summer thunderstorms cause water to periodically inundate playas. The duration of flooding depends on the magnitude and location of precipitation and ambient prevailing climate. Significant flooding is also associated with El Niño events in the Pacific Ocean, which leads to above-normal precipitation in the Southwestern US. Precipitation records maintained at Edwards Air Force Base provided precipitation data for the years 1942 to 2001. The average annual precipitation was calculated to be 13 cm/year with an estimated 280cm/year evaporation rate.

c. Sensor System. The department of energy on collected visible and near infrared data with the use of a Multi-spectral Thermal Imager (MTI) from February through May of 2001. Two sequential daily MTI images were acquired at 16-day intervals. This was done to ensure the capture of water that may exist at any time throughout the course of 31 days. The acquisition of multiple scenes eliminated the lack of data due to cloud coverage. Seven years of data were analyzed for this inundation study.

d. Study Results.

(1) The visible bands were not useful in visually delineating ponded water. Ponded water was best defined by a band ratio technique of B5/B2, which evaluated the proportion of reflective energy to input energy. The ratio values for each pixel were consistently greater than 1.0 for non-water objects and less than 1.0 for water objects. This ratio method was then followed by a classification that grouped pixels with values less than 1.0. Workers then assigned a DN value of 0 for objects displaying a ratio value of less than 1.0, thereby coloring all water bodies black in the scene. This ratio technique aided the image analysis by eliminating the problems caused by sun angle, sun intensity, and seasons—problems intrinsic to multi-temporal image analysis.

(2) The average precipitation was calculated to be 8.28 cm/year. These data, coupled with the image data, established the inundation frequency to be 51% of the time. This suggests that the playas are inundated, on average, every other year.

e. Conclusions. Results indicate that ponding that persists 16 days or longer occurred approximately every other year. The average precipitation needed to initiate ponding is estimated at 8.29 cm. Duration of ponding was shown to range from 1 to 32 weeks, with a direct relationship between length of inundation and total seasonal rainfall. Playa inundation, duration, and frequency can be determined from precipitation data and satellite imagery. The authors suggest the addition of contributing factors such as soil type and geometry may lead to a more robust hydrologic model of the playa system. A thorough understanding of the playa hydrologic regime may one day lead to new land use regulations.

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6-10 Case Study 8: An Integrated Approach for Assessment of Levees in the Lower Rio Grande Valley

- *Subject Area:* Engineering.
- *Purpose:* To detect weak areas within levees prior to flood events.
- *Data Set:* LIDAR.

a. Introduction. A series of levees were constructed along the Lower Rio Grande in Texas and Mexico in the 1930s. Local farmers, working with the county government, constructed the levee system to prevent flood damage to crops in low-lying areas near the river. The levees were constructed of sediment and soil materials obtained locally. The Federal government later completed the levee system in the 1940s and continued expansion and repairs through the 1940s. The US Army Engineer Research and Development (ERDC), working recently with the International Boundary and Water Commission, developed a GIS database to catalog levee condition. Knowledge of levee conditions prior to a flood is helpful in determining where repair and rebuilding are necessary on these man-made structures. A visual display of the levee and detail on the location of potential structural failure could then be used to prioritize levee repair and reconstruction.

b. Description of Methods.

(1) This study maintained four primary objectives. The first was to survey the levee system of the Lower Rio Grande River. The information compiled during the course of this survey was organized into a GIS database. The second was to extensively evaluate levee condition. The third was to compare the results of the airborne survey with those obtained from ground-based surveys. This objective tested the validity of implementing a remote sensing survey. Fourth, ground-truth locations were selected based on LIDAR data, and at these locations soil and subsurface strata were mapped using a cone penetrometer.

(2) In the course of developing the GIS database, ERDC developed a 10-point criterion for evaluating the condition of the levee system. Traditional geophysical tools were

then merged with remote sensing methods to proceed with the levee assessment. Levee topology was assessed with the use of LIDAR, digital video, aerial photographs, soil maps, and geological maps. Topographic deviations of 6 in (15.2 cm) or more along the centerline of the levee were then targeted for detailed seismic field studies. In addition to targeting segments with an undulating topography, several stretches of the levee (on the US side) were seismically surveyed.

c. Field Work.

(1) Ground surveys were conducted at five sites ranging in length from 3000 to 5000 ft (0.91 to 1.5 km). Electrical resistivity, EM, and magnetic surveys were collected in conjunction with the airborne EM and magnetic survey. The ground-based geophysical sites were geo-referenced with the use of a global position unit.

(2) Much of the data acquired for the GIS database were collected from previous sources. Information was taken from state and Federal survey maps, and from new and old aerial photographs. Digital photography and aerial photographs were used to map Holocene and Pleistocene deposits and geomorphologic structures. In areas with recent urban development, older images dating to the 1930s were used to evaluate the underlying geology.

d. Sensor Data Acquisition. LIDAR was utilized to survey levee elevation to determine deviations from the original design. Deviations in height indicate segments with potential damage attributable to seepage or sediment voids. Floodwater overtopping, slope failure, and seepage all potentially compromise levee stability. Seepage can create void spaces in the sediment and soil, resulting in subsequent levee collapse.

e. Study Results.

(1) The levee was then mapped and tagged with a conditional assessment of good, marginal, acceptable, or high-risk zones. The assessment was based on a numerical measure of 10 features deemed important in determining levee stability. These 10 features were chosen by agreement among Corps experts specializing in levee construction and repair. Table 6-2 lists the 10 features ranked in order of importance.

(2) Low scores in any one of the 10 features could result in a poor rating for a given levee segment. The levee was divided into segments based on conductivity measurements (shown to be controlled by levee material make-up); each segment was then given a numerical value based on a weighted measure of the 10 features. Segment ratings were color coded and presented as a layer within the GIS database. The color-coded maps provided an easy to interpret assessment of levee condition.

Table 6-2
Factors Important in Levee Stability
Performance history (under flood stage)
Construction history (original or upgraded)
Visual inspection apparent condition (on-site observation)
Material type (sand [worst] transition to clay [best]; (from EM, borings, soil maps)
Topographic irregularity (swags, erosion) (from LIDAR)
Potential slope stability (material type, relation to flow)
Man-made intrusions (utilities, bridges, pump stations, etc.)
Geology (old stream beds, river deposits)
Proximity of borrow area (size, depth, distance, side of levee)
Anomalies (unexplained radical conductivity "spots")

List is modified from Dunbar et al. (2003)

f. Conclusions. LIDAR, accurate to within 2 to 3 in (5.1 to 7.6 cm), was beneficial in economically mapping the surface morphology of the Lower Rio Grande Valley levee system. The merged remote sensing and geophysical data onto a GIS database facilitated easy retrieval of information for individual segments and can continue to aid in the management of the levee system. The authors view this study as a success and acknowledge that the application of these techniques to other geographical regions, while potentially of benefit, may not hold true for levee projects in other regions.

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6-11 Case Study 9 : From Wright Flyers to Aerial Thermography—The 1910 Wright Brother's Hangar at Huffman Prairie

- *Subject Area:* Archeology
- *Purpose:* To review developing NASA products and detail their use in Corps works
- *Data Set:* Airborne CAMS

a. Introduction.

(1) The Huffman Prairie Flying Field, a National Historic Landmark located at Wright-Patterson Air Force Base, was surveyed using a variety of ground and airborne sensors in an effort to locate the forgotten Wright Brother's hangar. This hangar, in use from 1910 to 1916, was the training and testing site for the Wright Aeronautical Company activities. The hangar was demolished during the 1940's with no record of its precise location.

(2) In the early 1990s, CERL researchers investigated the Huffman Prairie Flying Field using traditional and common archeological methods, such as excavation, magnetic and electromagnetic surveys, and ground penetrating radar (GPR). NASA aided CERL's effort with the addition of thermal data collected from an airborne platform. The airborne

data isolated a rectangular footprint, which corresponded with the location of the Wright hangar. Later ground truth data collection and excavation works unearthed well-preserved wall posts constructed of wood. This project exemplifies the technological methods currently being adopted by archeologists. Geographic Information Systems (GIS) practices are now in wide use among archeologists, who take advantage of the utility of spatially related data.

b. Description of Methods. This study had two objectives; the first was to locate the precise position of the Wright hangar. In archeological terms, the site and the history centering on the Wright Brother's and their activities is well documented. The historical record contains many photographs and aerial photographs that trace the approximate location of the Wright buildings. In 1994 an architectural firm established the dimensions and structural details of the Wright hangar with the use of these photographs. They determined that the hangar was approximately 70 by 49 ft (21.3 by 14.9 m). Knowing the approximate dimensions and location of the building would seemingly make the archeological work a simple task. The second objective of the study was to determine if traditional and modern archeological work could add insightful information to the already well-documented site, and thereby further detail the history of early American aviation.

(1) The authors describe the general area surrounding the Huffman Prairie Wright Brothers field as being relatively undisturbed despite the growth and development of the Wright-Patterson Air Force Base neighboring the site. The prairie had been subject to burning, but not plowing. The task in locating the hangar included fieldwork, near surface geophysical work, and aerial remote sensing. The initial excavation made it apparent that identifying remains of the hangar would require either a significant amount of additional excavation or the use of technologically sophisticated, noninvasive methods. Further excavation was deemed too destructive for the site, leading to the decision to employ near-surface and aerial remote sensing.

(2) The geophysical work included magnetic, electromagnetic, and ground penetrating radar (GPR). Combining multiple geophysical techniques is a good practice, as one instrument may easily pick up features not identified by another. Geophysical survey methods typically involve data collection in a grid pattern across the study site. Anomalies in the sub-surface potentially indicate natural phenomena or anthropogenic disturbances in the strata. Some anomalies may then be excavated for ground-truth data collection. It is generally good practice to conduct some ground-truth to verify the geophysical interpretations.

c. Field Work.

(1) Fieldwork, prior to collecting the remote sensing, began in 1990. The researchers hoped to find underground building remnants or surface features, such as the hangar's footings or drip lines that paralleled the absent roofline. Long trenches were hand-excavated unearthing 60% industrial debris, 2% domestic articles; the remaining material consisted of wood debris and other uncategorized items. Excavation did not identify any intact architectural remains of the actual building, and did not locate the precise position of the hangar.

(2) Additional fieldwork verifying the geophysical results uncovered three features. Feature 1 was a well-preserved, intact wood post—possibly one of the hangar's major wall

posts. Features 2 and 3 were pits filled with artifacts and debris. Feature 2 fill included nails, a shell casing, and flat glass. The function of this pit was undetermined. Feature 3 contained wood, glass, nails, and roofing fragments. It was assumed that this was a posthole pit excavated in 1924 during the remodel and repair of the hanger. The posthole was subsequently back filled with reconstruction debris. These three features were not evenly spaced nor in a parallel or perpendicular orientation relative to the predicted location of the hanger. The authors did assert that possibly two of these features represented intact hangar posts.

d. Sensor Data Acquisition. The airborne remote sensing study conducted by NASA incorporated a calibrated airborne multispectral sensor (CAMS), which collects data in the visible, infrared, and thermal bands. A hand held inframetrics thermal scanner was also used.

e. Study Results.

(1) The geophysical survey results indicated that a rectangular area defined by the conductivity, magnetic, and GPR anomalies most likely encompassed the hangar location, which was initially indicated by the 1924 air photo. The airborne hand held inframetrics confirmed the shape and location of the hangar. An explanation for the distinct thermal response remains unclear. The authors suggested that soil compaction and heat retention related to spilled petroleum products may account for the unique thermal signature at the hangar site. The field research led to the collection of over 6000 individual samples; the majority of which were buried industrial artifacts. The authors stated that with “no historical records, it might have been very difficult to infer the primary function of the hangar building” from the collected fragments.

(2) All artifacts were georeferenced and a GIS map was generated to indicate the distribution of materials relative to the hangar and other building units. The majority of artifact categories are concentrated on the northern portion of the hangar as a result of demolition processes. The inframetrics was useful in locating the hangar footprint and delineated gullies adjacent to the road. The CAMS detected the actual roadbed.

f. Conclusions. This study demonstrates how remote sensing technologies can further traditional research efforts in the area of archeology and history. The amalgamation of GIS with airborne and ground remote sensing methods proved highly successful in providing additional information on the already well-documented site. The distribution mapping of artifacts indicated that the building had been demolished by a bulldozer, differing from the theory that the building had simply collapsed on its own accord. Even though the hangar may have been demolished using a bulldozer, its archaeological evidence maintained some integrity and was easily detected by the thermal sensor. Thermal sensors are thus likely to join the growing array of near surface geophysical and aerial remote sensing techniques that can enhance researchers ability to detect and study archaeological sites.

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6-12 Case Study 10: Digital Terrain Modeling and Distributed Soil Erosion Simulation/Measurement for Minimizing Environmental Impact of Military Training

- *Subject Area:* DEM generation and soil erosion modeling
- *Purpose:* To adequately model soil erosion and transport for land use management
- *Data Set:* Digital Elevation Models (DEM)

a. Introduction.

(1) The conservation of soil on military land is a priority among land use managers, second only to the protection of threatened and endangered species. A realistic model of soil erosion and subsequent transport will provide managers the information required to better plan military activities, such as training. A better model of the various factors that contribute to soil loss will give insight into the best temporal and spatial use of military land.

(2) The optimal soil loss model incorporates information regarding the diurnal, seasonal, and temporary elements influencing soil properties, as well as incorporating terrain details. Prior to this 1997 study, soil loss models tended to measure soil loss along a linear slope, calculated as the average slope across the study area. Models with these simple slope inputs do not consider the dynamic nature of slope terrain and its consequential control on soil erosion, transport, and deposition. The study summarized here attempted to improve upon existing soil erosion models by incorporating details associated with an undulating surface. The model extracted high resolution terrain information from a digital elevation model (DEM) to better mimic erosional provenance and sediment sinks within a watershed.

b. *Description of Methods.* This study applied three sediment erosion/deposition models to 30- and 10-m DEM data. The models included CASC2D, a two-dimensional rain-fall/runoff model, USPED, an improved Universal Soil Loss Equation model, and SIMWE (SIMulated Water Erosion), a landscape scale erosion/deposition model. All models attempted to simulate watershed response to military training scenarios.

(1) The first model, the CASC2D is a two-dimensional rainfall-runoff model that simulates spatially variable surface runoff. This modeling process can be found in GIS/remote sensing software packages (http://www.engr.uconn.edu/~ogden/casc2d/casc2d_home.html). Model inputs include runoff hydrographs, and water infiltration rate and depth, surface moisture, surface runoff depth, and channel runoff depth.

(2) The second model, the Revised Universal Soil Loss Equation (RUSLE; see equation 6-3), is the most widely used empirical erosion model, and is best applied to homogeneous, rectangular agricultural fields. The equation quantifies major factors that affect erosion by water. The LS (slope length factor) accounts for only the steepness of the terrain over a given area. The authors of this study developed an LS analog for the RUSLE and refined the soil loss equation creating the Unit Stream Power Erosion and Deposition

(USPED) model. This model increases the accuracy of erosion and deposition prediction on uneven terrain.

$$A = R \times K \times LS \times C \times P \quad 6-3$$

where

- A = estimated average soil loss in tons per acre per year
- R = rainfall-runoff erosivity factor
- K = soil erodibility factor
- LS = slope length factor
- C = cover-management factor
- P = support practice factor.

(3) See <http://www.iwr.msu.edu/rusle/about.htm> for details on the Revised Universal Soil-Loss Equation.

(4) The two models described above use statistical averages of hill slope segments for the entire watershed, leading to inaccurate outputs. The SIMulated Water Erosion (SIMWE) model, the third model used in this study, overcomes these shortcomings by adding a continuity equation. SIMWE is based on the solution of the continuity equation (solved by Green's function Monte Carlo Method) that describes the flow of sediment over the landscape area. The factors included in the SIMWE model include measurements relating to steady-state water flow, detachment and transport capacities, and properties of soil and ground cover. The primary advantage of this model is its ability to predict erosion and deposition on a complex terrain on a landscape-scale, thereby improving land use assessments.

c. Remotely Sensed DEM Data. In an effort to minimize environmental impacts at military training sites, CERL scientists evaluated the effectiveness of applying standard soil loss equations with the use of DEM at varying resolutions. The optimal pixel size for landscape level erosion and deposition modeling ranges from 5 to 20 m. Most readily available DEM data is at the 30-m resolution. Higher resolution DEM data are slowly becoming more available ; for older DEM data sets and the easily accessible Landsat data, it is possible to interpolate the low resolution data and resample the data at a finer resolution. For this study the authors converted 30-m resolution data to 10-m resolution data by applying a regularized spline with tension (RST) method, a spatial interpolation tool included in some GIS software. The method is a smoothing function, which interpolates the resampled data from scattered data (RST was developed by Lubos Mitas at North Carolina State University).

d. Study Results. The authors illustrated the issues associated with modeling soil loss over a large area by evaluating a mountainous, 3000-km² region in Fort Irwin, California. Topographic inputs into the models served as both a tool in evaluating erosion potential and in determining the quality of the DEM. Low quality DEMs hold a high proportion of noise in the data. The noise in the data creates two related problems: 1) the signals could easily be interpreted as landscape features, and 2) large terrain features could be obscured by the noise. Resampling and smoothing techniques using the RST reduced the noise and produced a 10-m resolution DEM. This process better highlighted prominent topographic features.

(1) The potential for net erosion/deposition was calculated using two different resolutions (the 30-m DEM and a 10-m DEM developed by the resampling of the 30-m data).

These calculations provided the test required to determine the effectiveness of the smoothing and resampling techniques. The visual analysis of the image overlaid onto the 10-m resolution DEM revealed little noise. The USPED model is described as being “very sensitive to artifacts in a DEM as it is a function of second order derivatives (curvatures) of the elevation surface.” With the reduced noise in the data, the USPED model is predicted to accurately assess soil erosion and deposition.

(2) Sediment flow rates were calculated for a subset area from within a 36-km² area of Fort McCoy, Wisconsin. The rate was determined with the use of the SIMWE, which solves for the continuity of mass equation. The results indicated high sediment flow rates in valley centers and varying flow rates in adjacent areas. The SIMWE model compared well with the USPED model results

(3) The USPED and SIMWE models were also compared in an analysis of soil transport in the Fort McCoy, Wisconsin, area. Topographic potential for erosion and deposition were estimated with the USPED model using a 30-m and a 10-m DEM. The 10-m data were again derived from the 30-m data by a smoothing and resampling technique.

(4) The GIS map is based on the 10-m data denoting areas of high potential for soil erosion, typically shown to be hilly areas adjacent to streams. This landscape model showed areas of temporary deposition, where soil and sediment resided before entering the main stream. The map created with the 30-m data inadequately predicted the areas of soil loss; it was suggested this was the result of concentrated flow in valleys. Furthermore, artificial waves of erosion and deposition were shown in flat areas. This was due to the vertical resolution of up to 1 m in the 30-m pixel size DEM. The 10-m data maintains a lower 0.1-m vertical resolution.

(5) When the 10-m resolution DEM was used with the USPED model, intense erosion was predicted in the hilly regions adjacent the main streams and tributaries. Deposition continued to be evident in the concave areas. Distinct from the map derived with 30-m DEM, the 10-m resolution DEM GIS map indicated high erosion in areas with concentrated flow that could reach the main streams. The artificial pattern of erosion/deposition along nearly flat contours was not depicted in the 10-m GIS data.

e. Conclusions. The CASC2D, USPED, and SIMWE soil erosion models significantly advanced the simulation of runoff, erosion, and sediment transport and deposition. With the application of factors relating to three dimensions, these models better predict the spatial distribution and motion of soil and sediments in a watershed. The 10-m resolution was shown to be most advantageous in revealing the detail required to model soil erosion and deposition. The 10 m resolution was easily developed from 30-m pixel sized data with the use of software resampling tools followed by a smoothing algorithm. In summary, this work potentially improves land management and should reduce land maintenance and restoration costs.

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Appendix A References

a. Government Sources.

- Ballard, J. R. and J. A. Smith (2002) Tree Canopy Characterization for EO-1 Reflective and Thermal Infrared Validation Studies: Rochester, New York. [ERDC/EL TR-02-33](#), U.S. Army Engineer Research and Development Center, Vicksburg, MS.
- Bolus, Robert L. (1994) A SPOT Survey of Wild Rice in Northern Minnesota. *Journal of Imaging Science and Technology*, **38** (6): 594-597.
- Bolus, Robert L. and A. Bruzewicz (2002) Evaluation of New Sensors for Emergency Management, Cold Regions Research and Engineering Laboratory, ERDC/CRREL TR-02-11.
- Campbell, Michael V. and Robert L. Fisher (2003) Utilization of High Spatial Resolution Digital Imagery, ERDC TEC report, pending publication.
- Clark, R.N., G.A. Swayze, A.J. Gallagher, T.V.V. King, and W.M. Calvin (1993), The U.S. Geological Survey, Digital Spectral Library: Version 1: 0.2 to 3.0 microns, U.S. Geological Survey Open File Report 93-592: 1340, <http://speclab.cr.usgs.gov>. Version 4 of the spectral library was available as of 2002.
- Dunbar, Joseph, B., J. Stefanov, M. Bishop, L. Peyman-Dove, J.L. Lloopis, W.L. Murphy, R.F. Ballard (2003) An Integrated Approach for Assessment of Levees in the Lower Rio Grande Valley, ERDC, Vicksburg, MS, pending publication.
- Hargrave, Michael, John Simon Isaacson, and James A. Zeidler (1998), Archeological Investigations at the Huffman prairie Flying Field Site: Archeological, Geophysical, and Remote Sensing Investigations of the 1910 Wright Brother's Hangar, Wright-Patterson Air Force Base, Ohio, Report Number 98/98.
- Jet Propulsion Laboratory (1999) ASTER Spectral Library, California Institute of Technology, Pasadena, CA, available on the Internet at: <http://speclib.jpl.nasa.gov/>.
- LaPotin, Perry, Robert Kennedy, Timothy Pangburn, and Robert Bolus (2001), Blended Spectral Classification Techniques for Mapping Water Surface Transparency and Chlorophyll Concentration, *Photogrammetric engineering and Remote Sensing*, **67** (9):1059-1065.
- Lichvar, Bob, Greg Gustina, and Robert L. Bolus (2002) Duration and Frequency of Pondered Water on Arid Southwestern Playas, Wetlands Regulatory Assistance Program, ERDC TN –WRAP –02-02.

Lowe Engineers LLC, and SAIC (2003) Kissimmee River Restoration Remote Sensing Pilot Study Project Final Report, generated in support by USACE Jacksonville District and the South Florida Water Management District, unpublished contract report.

U.S. Army Corps of Engineers, Civilian and Commercial Imagery Office (2003) In *Geospatial Manual*, Engineering Manual 1110-01-2909, Appendix I, publication anticipated for October 2003.

U.S. Army Corps of Engineers (1979) Remote Sensing Applications Guide, Parts 1-3, Planning and Management Guidance, Engineer Pamphlet 70-1-1.

Tracy, Brian, Dr. Robert L. Bolus, and Emily S. Bryant (2002 and 2003) U.S. Army Corps of Engineers, Remote Sensing Fundamentals, PROSPECT No. 196.

Tracy, Brian T. and Steven F. Daly (2003) River Ice Delineation with RADARSAT SAR, Committee on river Ice Processes and the Environment (CGU-HS) report, Abstracts of the 12th Workshop on the Hydraulics of Ice Covered Rivers, Edmonton, AB, 18 – 20 June, 10p.

Warren, Steven (1998) Digital Terrain Modeling and Distributed Soil Erosion Simulation/Measurement for Minimizing Environmental Impact of Military Training, USACERL Interim Report 99/12.

Websites used in the production of the manual:

<http://rst.gsfc.nasa.gov/start.html>
http://rst.gsfc.nasa.gov/Sect3/Sect3_1.html (NASA-vegetation interpretation)
<http://speclab.cr.usgs.gov/spectral.lib04/spectral-lib04.html>
<http://www.saj.usace.army.mil/dp/Kissimmee/Kissimmee2.html>

b. Non-government Sources.

American Society of Photogrammetry (1983) Manual of Remote Sensing Volumes 1 & 2, 2nd Edition, Editor in Chief: Robert N. Colwell, 2440 pp.

Carsey, F. (1989) Review and Status of Remote Sensing of Sea Ice. *IEEE J. Oceanic Engineering*, **14** (2): 127-138.

Congalton, R. and K. Green. (1999) *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. CRC/Lewis Press, Boca Raton, FL.

Congalton, R. (1991) A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*. **37**: 35-46.

Jensen, J. R. (1996) *Introductory Digital Image Processing: A remote sensing perspective, 2nd Edition*. NJ: Prentice-Hall.

Kriebel, K.T. (1976), *Remote Sensing of Environment*, 4: 257-264.

Lillesand and Kiefer, 1994, *Remote sensing and Image Interpretation, Third Edition*, John Wiley and Sons, Inc. New York, 750pp.

Lillesand and Kiefer, 1994, *Remote sensing and Image Interpretation, Third Edition*, New York: John Wiley and Sons, Inc.

Pedely, Jeffrey A., Jeffrey Morissette, James A. Smith (2002) Comparison of EO1 Landsat-7 ETM+ and EO-1 Ali images over Rochester, New York. In *Proceeding of SPIE Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery VIII*, Sylvia S. Shen; Paul E. Lewis Editors vol. 4725, p. 357-365.

Sabins, F. F. (2000) *Remote Sensing: Principles and Interpretation*. NY: W.H. Freeman and Company.

Stoner, E.R., and M.F. Baumgardner (1981) Characteristic variations in reflectance of surface soils, *Soil Science American Journal*, 45: 1161-1165.

S.A. Drury (1990) *A Guide to Remote Sensing*. Oxford, 199 pp.

Websites used in the production of the manual:

<http://crssa.rutgers.edu/courses/remsens/remensing9/>- unsupervised classification
<http://www.cla.sc.edu/geog/rslab/rscnew/Figure%202>
http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj_f.html (map projections)
Peter H. Dana, Department of Geography, University of Texas at Austin, 1995.
<http://www.nrcan-rncan.gc.ca/inter/index.html>
http://www.shf.ac.uk/~bryant/211lectures/2001/211L11_2001.rtf -supervised classification
<http://www.geog.buffalo.edu/~lbian/rsoc17.html>
http://www.directionsmag.com/pressreleases.php?press_id=6936
<http://dipin.kent.edu/secchi.htm>

Recommended Web sites:

<http://emma.la.asu.edu/~stefanov/research.html> soils
http://www.ghcc.msfc.nasa.gov/archeology/remote_sensing.html archeology
http://www.learnremotesensing.org/modules/image_classification/index.php?case=nrv&target=appearance_training_data_poly
<http://www.frw.ruu.nl/nicegeo.html#gis>
<http://rst.gsfc.nasa.gov/Front/overview.html>
<http://www.cla.sc.edu/geog/rslab/Rsc/rsc-frames.html>

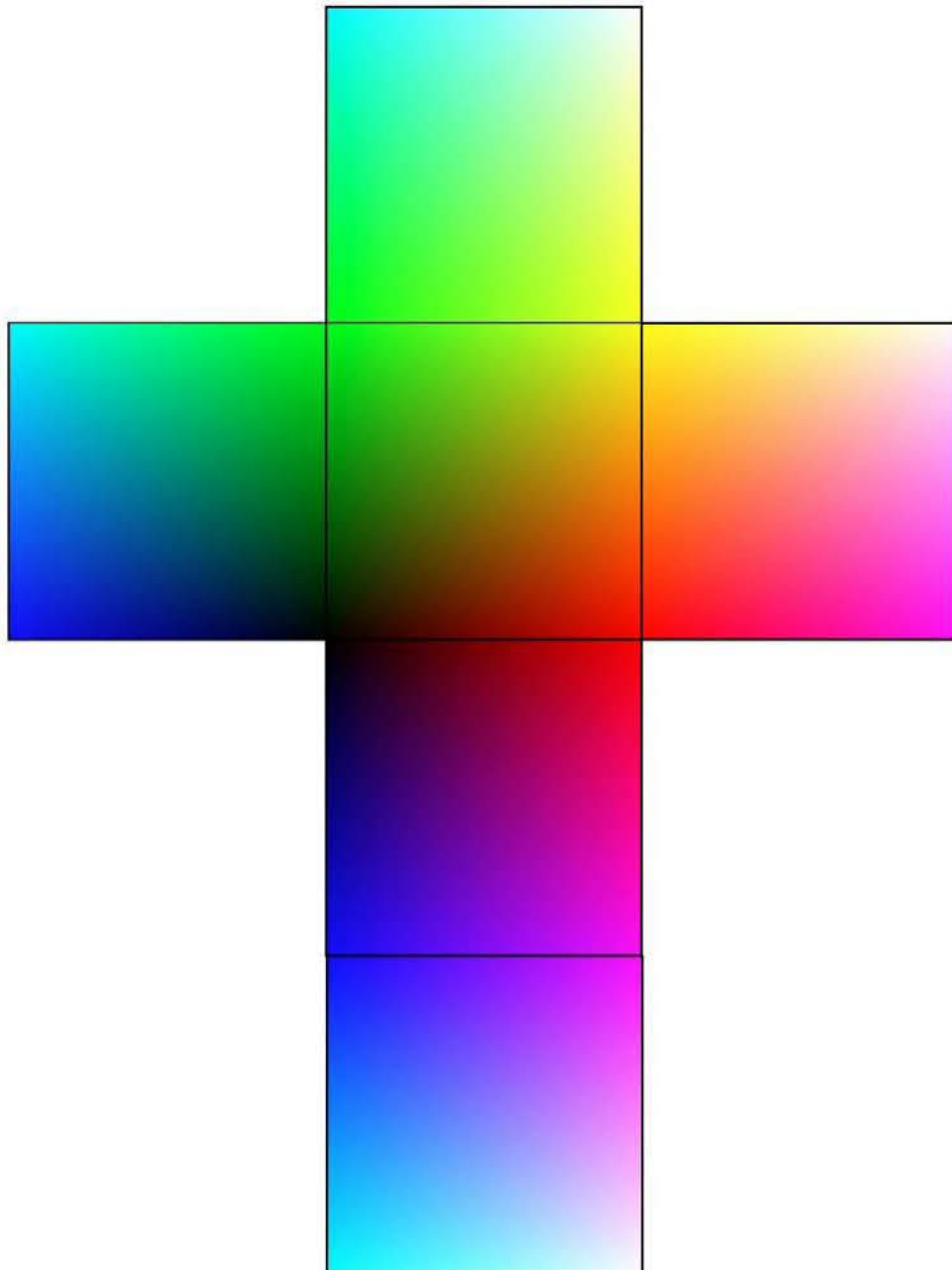
Appendix B

Regions of the Electromagnetic Spectrum and Useful TM Band Combinations

Spectrum Region	Wavelength range	Use	
UV	0.300 – 0.446 μm	Florescent materials such as hydrocarbons and rocks. Monitor ozone in stratosphere	
Visible - blue	0.446 – 0.500 μm	Soil/vegetation discrimination, ocean productivity, cloud cover, precipitation, snow, and ice cover	Urban features
Visible - green	0.500 – 0.578 μm	Corresponds to the green reflectance of healthy vegetation and sediment in water.	
Visible - red	0.579 – 0.7 μm	Helpful in distinguishing healthy vegetation, plant species, and soil/geological boundary mapping	
Near infrared (NIR)	0.7 – 0.80 μm	Delineates healthy verses unhealthy or fallow vegetation, vegetation biomass, crop identification (near infrared) soil, and rocks	Surface water, snow, and ice
	0.80 – 1.10 μm	Delineates vegetation, penetrating haze and water/land boundary mapping	
Mid-infrared	1.60 – 1.71 μm (SWIR)	Soil and leaf moisture; can discriminate clouds, snow, and ice. Used to remove the effects of thin clouds and smoke	
	2.01 – 2.40 μm	Geologic mapping and plant and soil moisture, particularly useful for mapping hydrothermally altered rocks	
Thermal IR	3.0 – 100 μm	Monitoring temperature variations in land, water, ice, and forest fires (and volcanic fire)	
	6.7 – 7.02 μm	Upper-tropospheric water vapor	
	10.4 – 12.5 μm	Vegetation classification, and plant stress analysis, soil moisture and geothermal activity mapping, cloud top and sea surface temperatures.	
Microwave	1 μm to 1 m	Useful for mapping soil moisture, sea ice, currents, and surface winds, snow wetness, profile measurements of atmospheric ozone and water vapor, detection of oil slicks	

	Color Plane			Applications
	Red	Green	Blue	
Landsat TM Band Combination	3	2	1	True Color. Water depth, smoke plumes visible
	4	3	2	Similar to IR photography. Vegetation is red, urban areas appear blue. Land/water boundaries are defined but water depth is visible as well.
	4	5	3	Land/water boundaries appear distinct. Wetter soil appears darker.
	7	4	2	Algae appear light blue. Conifers are darker than deciduous
	6	2	1	Highlights water temperature.
	7	3	1	Helps to discriminate mineral groups. Saline deposits appear white, rivers are dark blue.
	4	5	7	Mineral differentiation.
	7	2	1	Useful for mapping oil spills. Oil appears red on a dark background.
	7	5	4	Identifies flowing lava as red/yellow. Hot lava appears yellow. Outgassing appears as faint pink.

Appendix C
Paper model of the color cube/space



To generate the color cube/space cut along perimeter and fold at horizontal and vertical lines. Cube edges will need to be adhered with tape.

Appendix D: Satellite Sensors

Satellites and sensors are commissioned and deployed annually. The list presented here is an attempt to briefly review the utility of only a few sensors. This list, though not fully comprehensive, is a good starting point in referencing sensors.

For an extensive list of satellite sensors (acronyms and full names) see
http://ioc.unesco.org/oceanteacher/resourcekit/M3/Data/Measurements/Instrumentation/gcmd_sensors.htm.

Sensor	Spatial Resolution (metric)	Band/Wavelength or Frequency Detection	Application	URL
AATSR	1000m	0.555µm (green), 0.659µm (red), 0.865µm (NIR), 1.6µm (SWIR), 3.7µm (TIR), 10.85µm (TIR), 12.0µm (TIR)	Atmosphere, forest, vegetation, oceans, coasts, weather & climate	http://telsat.belspo.be/satellites/satellitresult.asp?var=56
AC	250	0.89-1.58µm	Used to atmospherically correct high-spatial, low-spectral resolution multispectral sensors	http://eo1.gsfc.nasa.gov/Technology/AtmosCorr.htm
ACE-FTS	0.02-1cm 4km vertical resolution	2-13 µm (infrared)	Measures the temperature, vertical distribution of trace gases and aerosols and thin clouds	http://www.space.gc.ca/asc/eng/csa_sectors/space_science/atmospheric/scisat/fts.asp
AIRS		Measures 2,300 spectral channels: 0.4 - 1.7 µm and 3.4 - 15.4 µm	Weather, climate, O ₃ , and greenhouse gasses	http://telsat.belspo.be/satellites/satellitresult.asp?var=92
ALI	30 m (10 m – panchromatic)	10 bands across 0.433-2.35 µm	Land use studies, mineral resource assessment, coastal processes research and climate change studies	http://eo1.gsfc.nasa.gov/miscPages/TechForum3.html
AMI (SAR and wind Scattometer)	30 m	37.5 – 77 mm	Ocean surface winds and mean sea level	http://www.eoc.nasda.go.jp/guide/satellite/sendata/ami_e.html
AMSR	5 to 50km depending on frequency band	8 frequency bands from 6.9GHz to 89GHz bands respectively	Water vapor content, precipitation, sea surface temperature, sea surface wind, sea ice, and clouds (detectable night and day)	http://www.eoc.nasda.go.jp/guide/satellite/sendata/amsr_e.html

AVHRR 2/3	1 6m Pan – 8m	0.42 - 0.50mm 0.52 - 0.60mm 0.61 - 0.69mm 0.76 - 0.89mm Pa : 0.52 - 0.69mm	Land and coastal zone monitoring of such phenomena as: desertification, deforestation, coastal zone pollution, resource exploration, land use, fire detection (and temperature), and vegetation indices.	http://edcdaac.usgs.gov/1KM/avhrr_sensor.html
AVNIR	16 km	Band1 : 0.42 - 0.50mm	For precise land coverage observation	http://www.eoc.nasda.go.jp/guide/satellite/sensdata/avnir_e.html
AVNIR-2	10 m	Band1 : 0.42 - 0.50 Band2 : 0.52 - 0.60 Band3 : 0.61 - 0.69 Band4 : 0.76 - 0.89	Land-use classification	http://www.eoc.nasda.go.jp/guide/satellite/sensdata/avnir2_e.html
EROS	1.8m	0.5 - 0.9µm	Very high resolution imagery	http://www.ccrs.nrcan.gc.ca/ccrs/data/satsens/eros/erostek_e.html
ERS	5.8m	0.5 - 0.75 µm + NIR, and mid IR	High resolution imagery	http://www.spaceimaging.com/products/irs/irs_technical_overview.htm
GEROS	V, N, & S, IR- 250m Infrared - 1km	23 visible and near-infrared bands 6 short-wave length infrared bands 7 middle & thermal infrared bands	Land, ocean, clouds sensitive to chlorophyll, dissolved organic substance, surface temperature, vegetation distribution, vegetation biomass, distribution of snow and ice, and albedo of snow and ice	http://www.oso.noaa.gov/goes/goes-calibration/index.htm
HYPERION	30 m	250 bands with in the 0.4 - 2.5 µm range	Measures ice sheet mass balance, cloud and aerosol heights, minute land topography changes, and vegetation characteristics	http://eo1.usgs.gov/
IKONOS	1m and 4m	Visible and infrared	Very high resolution imagery	http://www.spaceimaging.com/products/ikonos/index.htm
ILAS	1km Stratosphere monitoring	7.14 - 11.76mm 2 - 8mm 12.80 - 12.83mm 753 - 784nm	Measures the vertical profiles of O ₃ , NO ₂ , aerosols, H ₂ O, CFC ₁₁ , CH ₄ , N ₂ O, ClONO ₂ , temperature, & pressure	http://www.eoc.nasda.go.jp/guide/satellite/sensdata/ilas2_e.html
IRS	5.8 – 70 m	0.52 - 0.59 0.62 - 0.68 0.77 - 0.86 1.55 – 1.70 Pan: 0.5 – 0.75	Vegetation (forest and agriculture), water, and urban features	http://www.fas.org/spp/guide/india/earth/irs.htm

Landsat1-7 TM	30	Band 1: blue, 0.45-0.52µm	Water, forest, soil/vegetation, and urban features	http://landsat7.usgs.gov/general.html
ETM+	Bands 1-7: 30 Band 6 at 60m	Band 2: green, 0.52-0.60µm Band 3: red, 0.63-0.69µm Band 4: near IR, 0.76-0.90µm Band 5: mid IR, 1.55-1.74µm Band 6: thermal IR 10.40-12.50µm Band 7: mid IR, 2.08-2.35µm	Detects healthy vegetation Distinguishes plant species, soil and geologic boundaries Vegetation biomass, emphasizes soil/crop & land/water boundaries Plant water content/vegetation health, distinguishes clouds, snow and ice Crop stress detection, heat intensity, insecticide applications, thermal pollution and geothermal mapping Geologic and soil mapping and plant/soil moisture content	http://landsat7.usgs.gov/about.html
MSS	30 Pan: 15	TM bands 1-7 Pan: 0.52 - 0.90 µm Band 1: green, 0.50-0.60µm Band 2: red, 0.60-0.70µm Band 3: near IR, 0.70-0.80µm Band 4: near IR, 0.80-1.10µm	See TM Bands 1-7 above. Used to spatially sharpen TM and MSS color composites Sediment in water and urban features Soil / geologic boundary discrimination Vegetation biomass and health Vegetation discrimination, penetrating haze, and water/land boundaries	http://edc.usgs.gov/products/satellite/mss.html
LIS	4km	0.77765µm	Monitors lightening	http://www.eoc.nasda.gov/guide/satellite/sendata/lis_e.html
MISR	275 m to 1.1 km	blue, green, red, and near-infrared	Tropospheric Aerosol Data	http://terra.nasa.gov/About/MISR/about_misr.html
MODIS	250 m, 500 m, 1000 m	0.4 to 14.4 µm; Details at: http://modis.gsfc.nasa.gov/about/specs.html	Aerosol concentrations over land and water, fire detection (biomass burned), land-use, vegetation	http://www-misr.jpl.nasa.gov/
ORBVIEW-3	1 m, 4 m	450 – 520 nm 520 – 600 nm 625 – 695 nm 760 – 900 nm	Urban, crop, terrain detail for 3-dimensional mapping.	http://www.orbimage.com/corp/orbimage_system/ov1/
POLDER	7km	443, 490, 565, 665, 763, 765, 865, and 910 nm	Aerosols, clouds, over ocean and land surfaces	http://www.eoc.nasda.gov/guide/satellite/sendata/polder_e.html

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PR	250 km	13.796 GHz and 13.802 GHz	Measures and maps rainfall (3-D)	http://www.eoc.nasda.gov/guide/satellite/sendata/pr_e.html
PRISM	2.5 m	0.52 - 0.77mm	For digital elevation mapping	http://www.nasda.go.jp/projects/sat/alos/component_e.html
QUICKBIRD	62 cm to 2.5 m	Blue: 450 - 520 nm Green: 520 - 600 nm Red: 630 - 690 nm Near-IR: 760-890 nm Pan: 450 - 900 nm	Forest fires, urban, vegetation, surveillance	http://www.satimagingcorp.com/gallery-quickbird.html
RADARSAT	10, 25, 50, and 100 m	Microwave c-band (5.6 cm)	Land-use/cover, change detection	http://www.rsi.ca/
SeaWinds	50 km	Frequency of 13.4 GHz	Ocean wind speed and direction	http://www.eoc.nasda.gov/guide/satellite/sendata/seawinds_e.html
SPOT				http://www.spot.com/
• PAN	10 m	Band 1: green-red, 0.51 - 0.73 µm	Useful for visual interpretation and improving low spatial resolution multi-spectral data	
• XS	20 m	Band 1: green, 0.50-0.59µm Band 2: red, 0.61-0.68µm Band 3: near IR, 0.79-0.89µm Band 4: short-wave IR, 1.5-1.75µm	Monitors healthy vegetation Distinguishes plant species, soil, and geologic boundaries Vegetation biomass and emphasizes soil/crop and land/water boundaries Soil and leaf moisture	
TMI	6-50 km	10.7, 19.4, 21.3, 37, and 85.5 GHz	Rainfall rates and precipitation profiles: http://trmm.gsfc.nasa.gov/overview_dir/tmi.html	

Appendix E

Satellite Platforms and sensors

<u>Satellite</u>	<u>On board sensors</u>	<u>URL</u>
ALI	Hyperion	http://eo1.usgs.gov/instru/ali.asp
ALOS	PRISM AVNIR-2 PALSAR	http://www.nasda.go.jp/projects/sat/alos/index_e.html
ADEOS	AVNIR OCTS NSCAT TOMS POLDER IMG ILAS RIS	http://www.eorc.nasda.go.jp/ADEOS/
ADEOS-II	AMSR GLI SeaWinds POLDER ILAS-2	http://www.eorc.nasda.go.jp/guide/satellite/satdata/adeos2_e.html
AQUA	AMSR-E AIRS AMSU CERES HSB MODIS	http://aqua.nasa.gov/
ERS-1	AMI SCAT RA ATSR-M LRR PRARE	http://earth.esa.int/ers/
ERS-2	Above plus: AMI/SAR ATSR GOME MWS RA	http://earth.esa.int/ers/
JERS-1	SAR OPS	http://www.eorc.nasda.go.jp/JERS-1/
LANDSAT	ETM+ MSS TM	http://geo.arc.nasa.gov/sge/landsat/landsat.html
MOS-1/1b	MESSR	http://www.restec.or.jp/eng/data/satellite/mos.html
NOAA-11 thru -17	VTIR MSR Amsu	http://www.noaa.gov/satellites.html
RADAR SAT	Avhrr HIRS/3 POES SAR	http://www.space.gc.ca/asc/eng/csa_sectors/earth/radarsat1/radarsat1.asp

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SPOT	HRVIR HRV	http://www.spot.com/
TERRA	ASTER CERES MISR MODIS MOPITT PR	http://terra.nasa.gov/About/
TRMM	VIRS TMI CERES LIS	http://trmm.gsfc.nasa.gov

Appendix F Airborne Sensors

Presented here is a short list of common airborne sensors and their general performance capabilities. For an larger list of airborne sensors (acronyms and full names) see <http://carstad.gsfc.nasa.gov/Topics/instrumentlist.htm> and http://ioc.unesco.org/oceanteacher/resourcekit/M3/Data/Measurements/Instrumentation/gcmd_sensors.htm.

Sensor	Spatial Resolution (metric)	Band/ Wavelength or Frequency	Application	General Information
AC	250	0.89-1.58µm	Used to atmospherically correct high-spatial, low-spectral resolution multispectral sensors	http://eo1.gsfc.nasa.gov/Technology/AtmosCorr.htm
ACE-FTS	0.02–1 cm 4km vertical resolution	2-13 µm (infrared)	Measures the temperature, vertical distribution of trace gases and aerosols an thin clouds	http://www.space.gc.ca/asc/eng/csa_sectors/space_science/atmospheric/scisat/fts.asp
ATM	10- to 20-cm vertical resolution	LIDAR-based sensor (microwave)	Beach topography, ice mapping, sea-surface elevation, and wave morphologies	http://aol.wff.nasa.gov/ATMindex.html
AVIRIS	4 – 20 m	400 - 2500 nm	Aerosols, ice, and water quality mapping and ecologic and geologic applications	http://popo.jpl.nasa.gov/html/aviris.overview.html and http://popo.jpl.nasa.gov/html/aviris.free_data.html
CAMIS	26 – 156 cm	450, 550, 650 and 800 nm	Terrestrial and oceanographic applications	http://www.flidata.com/prod02.htm
CASI	0.5 – 10 m	400 – 1000nm	Environmental monitoring, forestry, pipeline engineering, military, agriculture, and water quality	http://www.itres.com/
EMERGE	0.3 – 0.6 m	Visible and infrared	Land use and agricultural surveys	http://www.emergeweb.com/
HYDICE		400 - 2500 nm	Agriculture, forestry, environmental, mapping, disaster management, and surveillance	http://www.oss.godrich.com/HyperspectralDigitalImageryCollectionExperiment.shtml
HYMAP	2 – 10 m	VIS,NIR, SWIR, MIR and TIR	Agriculture, forestry, environmental, urban, geologic, and soil mapping	http://www.intspec.com/
IFSAR	Can at collect <1 m	Microwave region	Topography	
JPL Airsar	100 m	Microwave region	All-weather terrain imager. Can penetrate forest canopy	http://airsar.jpl.nasa.gov/index.html
SHOALS	4 – 8 m	Visible and infrared	Bathymetry	http://shoals.sam.usace.army.mil/
TIMS	~1 – 50 m	Thermal infrared (8-12 µm)	Mineral mapping and archeologic applications	http://www.dfrc.nasa.gov/airsci/ER-2/tims.html

Appendix G

TEC's Imagery Office (TIO)

The following is taken from Appendix I of the Geospatial Engineer Manual (EM 1110-1-2902), which outlines the procedures for acquiring image data.

G-1 Development of TEC's Imagery Office (TIO).

a. To help Army agencies/organizations avoid duplicating commercial and civil imagery purchases, the Office of the Assistant Chief of Engineers designated TEC in 1990 to act as the U.S. Army Commercial and Civil Imagery (C2I) Acquisition Program Manager. To accomplish this task, the TIO was initiated with the added focus on educating the soldier on the uses, types, and availability of commercial satellite imagery. As Army use of this imagery increased and as the number of satellites increased, the TIO has grown to keep up with the demand. Currently, TIO provides thousands of dollars of imagery support to its customers, and is an active participant in National Imagery and Mapping Agency's Commercial Imagery Strategy.

b. TIO is the designated repository of selected commercial satellite imagery data pertaining to terrain analysis and water resources operations worldwide. These data support worldwide military applications and operations. TIO executes the Commercial Imagery Program for TEC and the Army. The current revision of Army Regulation 115-11, "Geospatial Information and Services," strengthens the role of TIO as the point of contact for acquisition of commercial satellite imagery in the Army.

G-2 How to Order Commercial Satellite Imagery.

a. USACE Commands are required to first coordinate with TIO before purchasing satellite imagery from a commercial vendor. USACE organizations with requirements for commercial satellite imagery must forward requests to TIO for research, acquisition, and distribution of the data. The requests can be submitted as follows:

TIO@tec.army.mil

Telephone: 703-428-6909

Fax: 703-428-8176

Online Request Form

www.tec.army.mil/forms/csiform1.html

b. Each request should include the following information:

- Geographic area of interest. Please provide Upper Left and Lower Right coordinates (e.g., 27 00 00N 087 00 00W) and path/row, if known.
- Acceptable date range for data coverage (e.g., 5 January 1999 to 3 March 2000).
- Cloud cover and quality restrictions (e.g., less than 10 percent cloud cover, no haze, 10 degrees off nadir).

- Satellite system/sensor. (For basic satellite information, access www.tec.army.mil/TIO/satlink.htm.)
- Desired end product (digital or hard copy and preferred media type; e.g., CD-ROM).
- Point of contact, mailing and electronic address, and telephone number.

c. Purchased Commercial Satellite Imagery Submission to the Commercial Satellite Imagery Library (CSIL)

d. Commercial satellite imagery that the TIO purchases for customers is disseminated upon receipt to the requestor as well as to the CSIL. This provides data access for DoD/Title 50 users.

Appendix H

Example Contract - Statement of Work (SOW)

Laser Fluorescence Oil Spill Surveillance

Statement of Work

2/14/96

To: DOE/NV Remote Sensing Laboratory
From: RSGISC, U. S. Army Corps of Engineers

1.0 Purpose

The purpose of this SOW is to demonstrate proof-of-concept of an airborne fluorescence imaging system capable of sensing oil on land and in wetlands. These are issues of concern to the Corps.

2.0 Background

The U.S. Coast Guard Research and Development Center (R&D Center) and Environment Canada have sponsored experiments with a Laser Environmental Airborne Fluorimeter (LEAF) spot sensor for the detection of oil on water in land-locked pools. The tests successfully demonstrated that oils fluoresce with distinct spectral signatures when excited by a laser source.

In order to develop the fluorescence concept into a practical field instrument for supporting oil spill response operations, an upgrade to an imaging sensor is necessary. The EG&G, Santa Barbara, Special Technologies Laboratory (STL) is prototyping an airborne Laser Induced Fluorescence Imager (LIFI) which can be applied to the detection of oil spills on land and in wetlands.

3.0 Objectives/ Scope

The DOE/NV Remote Sensing Laboratory (RSL) and STL will design and perform measurements to test airborne LIFI technology for the detection of oil-on-land and in wetlands.

1. Acquire laboratory and ground fluorescence spectra of several types of spilled oil on land and in wetlands in the presence of both organic and inorganic background materials. This can be used to define the source intensity needed for required signal levels and resolve major technical issues such as spatial resolution, swath width, aircraft altitude, and speed.

2. Acquire imagery from airborne LIFI over oiled targets for proof of concept.

4.0 Requirements

Task 1

A series of laboratory measurements will be collected to measure the fundamental fluorescence properties of the oils and background materials. Optimal sensing specification for oils depend on the fluorescence efficiency of the oil as well as the spectral and spatial resolution required for the application.

Task 2

Outdoor laser range measurements will be made for up to 20 target/background combinations. These should include crude, diesel and home heating oils, on sand, gravel, soil and vegetation organic backgrounds. Measurements will address the fluorescence efficiency, emission spectra, duration and the effects of oil aging over a period of up to six weeks. The effects of the wetness of the backgrounds on the emission efficiency, duration and spectra will be addressed.

Task 3

When the STL LIFI system becomes airborne, imagery from flight tests over oil targets will be collected. It is planned to operate at an altitude of 300 ft agl and provide a swath of 60 ft., 512 pixels wide or about 1.4 in. per pixel in the cross track direction. The spectral range will be 300nm with 128 channels covering the visible portion of the spectrum. Excitation will be at 355nm.

5.0 Schedule

The STL shall coordinate its airborne data collection schedule to coincide with its other sponsored flight test programs. All ground data will be collected preliminary to airborne testing. All reports and deliverables will be completed within six months of data collection.

6.0 Deliverables

Deliverable 1 - Presentation at Oil Spill Program Review

Test planning will be presented at the Oil Spill Program review and meetings required by the Oil Spill Program Manager [FY96].

Deliverable 2 - Technical Report

A written summary report will be delivered to the Oil Spill Program Manager NLT six months after acquisition of the data.

Deliverable 3 - Distribution of Data

All laboratory, ground and airborne data will become the property of and be transmitted to the RS/GIS Center in digital computer compatible format.

Appendix I
Example Acquisition – Memorandum of Understanding (MOU)

CONDITIONS FOR DATA ACQUISITION DURING
THE 1999 AIG HYMAP USA GROUPSHOOT CAMPAIGN

This Memorandum of Understanding, Conditions for Data Acquisition During the 1999 AIG HyMap USA Groupshoot Campaign (MOU) is entered into between Analytical Imaging and Geophysics LLC ("AIG") a limited liability company, with its principal place of business located at 4450 Arapahoe Avenue, Suite 100, Boulder, Colorado, 80303, USA, and _____ ("Sponsor"), a _____ corporation, with its principal place of business located at _____.

WHEREAS, AIG is acting as the coordinator for various Sponsors for the acquisition of HyMap data, the 1999 AIG/HYVISTA North American Group Shoot ("Group Shoot"), and the Sponsor is will to acquire data using the HyMap sensor system.

WHEREAS, this MOU outlines the conditions for HyMap data acquisition as part of the Group Shoot. It establishes the guidelines for AIG and HyVista Corporation ("HyVista") efforts to acquire data using the HyMap sensor system for sponsor-specified flight locations.

NOW, THEREFORE, in consideration of the premises and the agreements and covenants of the parties set forth in this Agreement, the parties hereto agree as follows:

DEFINITIONS

As used in this Agreement, the following terms have the following meanings:

"Individual Site" means: a 2.3 kilometer wide x 20 kilometer long area.

"Scene" means: an image cube of an Individual Site (2.3 kilometers by 20 kilometers) at 5 meter spatial resolution and 126 spectral bands.

"Research Mode" means: Scenes acquired which may be available to anyone.

"Proprietary Mode" means: Scenes acquired which are only available to the Sponsor ordering acquisition.

OBLIGATIONS OF AIG

AIG shall use its best efforts to perform the services and deliver the group Scene and the Sponsor's Scene(s), listed in Exhibit A, within 8 weeks after completion of the mission. All work shall be performed in a workmanlike and professional manner to industry standards. All work will be performed using AIG facilities,

excepting HyMap data acquisition and items below indicated by (HyVista), which will be performed by HyVista Corporation.

AIG agrees to supply the following for each Scene either on CDs or tape:

- Image data in units of radiance ($\mu\text{W}/\text{cm}^2/\text{nm}/\text{sr}$); BIL format data files with corresponding ENVI header files (HyVista)
- GPS positions of the plane during data acquisition (HyVista)
- Dark current measurements (HyVista)
- Spectral calibration parameters: band centers and band shape (HyVista)
- Image data corrected to apparent reflectance using an atmospheric model; BIL format data files with corresponding ENVI header files
- A single-band image of precision geocorrected data
- Geocorrection information sufficient to precision geocode other bands/results

OBLIGATIONS OF SPONSOR

Sponsors shall supply the start and finish coordinates of each Individual Site in latitude/longitude pairs (decimal degrees using the WGS84 datum). Larger areas can be covered at an incremental cost. If such areas are to be covered, in order to provide uninterrupted coverage of adjacent data strips, a 20% overlap for each strip with its neighbor should be allowed. AIG and HyVista Corporation accept no responsibility for sponsors supplying incorrect coordinates for survey sites; sponsors will be charged in full for the full data acquisition fee in these instances.

DATA ACQUISITION

Data will be acquired at a date nominated by AIG and HyVista with input from the Sponsor. Data will be acquired in weather conditions to the satisfaction of AIG and HyVista. Sponsor will be notified of proposed acquisition of data from an elected study site not less than 24 hours prior to acquisition. AIG and HyVista reserve the right to omit data acquisition for a Sponsor's chosen site if adverse weather conditions preclude the acquisition of data to corporate quality standards.

DATA QUALITY

All data presented to Sponsor shall bear full 126-channel coverage. To keep turbulence effects to a minimum the scanner is mounted on a stabilized platform the Jena SM 2000. The geometric integrity of the data therefore will be within the platform performance characteristics as supplied by the manufacturers and the operators will endeavor to keep turbulence effects to a minimum or abort the line if the motion is too great. Cloud cover will be less than 10 percent total for a named study area. Spatial accuracy of the data is limited by the on-board GPS of the aircraft.

Should a sponsor be dissatisfied with the data quality, the following procedure will be followed: The data in question will be supplied for a quality control assessment to 2 impartial experts, one selected by each

party. The impartial experts will have no professional or financial interest in their selector's organization. The impartial experts will assess the data quality, and judge whether the data is supplied in accordance to HyVista's specifications for the survey. Should the experts judge that data meets or exceeds HyVista's quoted data quality specifications, then the data will be supplied and the sponsor will be liable to pay agreed data acquisition costs, and all costs incurred in the data assessment. Should the experts judge that the supplied data does not meet HyVista's quoted data quality specifications, then the data will not be supplied.

PAYMENT

The cost of a Research Mode Scene is Five Thousand US Dollars (\$5,000.00). The cost of a Proprietary Mode Scene is Ten Thousand US Dollars (\$10,000.00). The Group Shoot Scene is also delivered to the Sponsor at no additional cost. Custom acquisitions and larger areas can be covered at an incremental cost and volume discounts may be applied. These additional Scenes shall be listed in Appendix E.

Invoices will be issued upon signature of this MOU and payment is net 30 days. In instances where AIG and HyVista acquire only a portion of a requested block of data due to adverse weather conditions or other unforeseen circumstances, AIG and HyVista will refund a portion of the fee at a rate proportional to the agreed fee for full data coverage. In the event that no Sponsor data are acquired AIG will refund Sponsor all payments received.

POINTS OF CONTACT

Dr. Fred A. Kruse is designated as the AIG point of contact for this program.

AIG	Sponsor:_____
Fred A. Kruse	Contact:_____
Senior Research Scientist	Title:_____
Analytical Imaging and Geophysics LLC	Address:_____
4450 Arapahoe Ave, Suite 100	Address:_____
Boulder, CO 80303	Address:_____
Phone: 303-499-9471	Phone:_____
FAX: 303-665-6090	FAX:_____
Email: kruse@aigllc.com	Email:_____

TERM AND TERMINATION

The Agreement shall enter into force on the Effective Date and shall continue until terminated as provided in this Section 8. After all Scenes have been delivered to Sponsor and payment received this Agreement shall terminate.

CONFIDENTIALITY

Both Sponsor and AIG acknowledge and agree that both parties own confidential, proprietary and secret information related to various aspects of Sponsor's and AIG's respective business and technology.

As used in this Agreement, "Confidential Information" consists of (i) any information designated by either party as confidential, and (ii) any information relating to either party's product plans, client lists, product designs, product costs, product prices, product names, finances, marketing plans, business opportunities, personnel, research, development or know-how, except such information which the parties agree in writing is not confidential. Each party shall use the other party's Confidential Information solely for implementing its obligations under this Agreement. Confidential Information shall not include information that (i) is known to each at the time of disclosure to the other party, (ii) has become publicly known through no wrongful act of the other party, (iii) has been rightfully received from a third party authorized to make such disclosure without restriction, or (iv) has been approved for release by written authorization of the other party.

Each party will not use in any way for its own account or the account of any third party, nor disclose to any third party (excepting HyVista), any such Confidential Information revealed to it by the other party. Each party agrees to protect any Confidential

Information from disclosure to others with at least the same degree of care as that which is accorded to its own proprietary information, but in no event with less than reasonable care. In the event of termination of this Agreement, there shall be no use or disclosure by either party of any Confidential Information.

Each party agrees to notify the other party promptly in the event of any breach of confidentiality or security under conditions in which it would appear that any Confidential Information was disclosed in violation of this Agreement, prejudiced or exposed to loss. Each party shall, upon request of the other party, take all reasonable steps necessary to recover any compromised trade secrets disclosed to or placed in the possession of the other party by virtue of this Agreement.

Each party agrees to use Confidential Information under carefully controlled conditions for the purposes set forth in this Agreement, and to inform all persons who are given access to Confidential Information by either party that such materials are confidential trade secrets of the other party. Each party expressly agrees it shall be fully responsible for the conduct of all its employees, contractors, agents and representatives who may in any way breach this Agreement.

Each party acknowledges that any breach of any of its obligations under this Section 7 is likely to cause or threaten irreparable harm to the other party, and, accordingly, each party agrees that in such event, the other party shall be entitled to equitable relief to protect its interest therein, as well as money damages.

WARRANTY AND INDEMNIFICATION

Sponsor shall defend, indemnify and hold harmless AIG from and against all claims, liability, losses, damages and expenses (including attorneys' fees and court costs) arising from or in connection with the use or application of AIG's work by Sponsor or any direct or indirect purchaser or licensee of Sponsor.

AIG SHALL NOT BE LIABLE TO SPONSOR FOR ANY DIRECT, INDIRECT, SPECIAL, AND/OR CONSEQUENTIAL DAMAGES WHATSOEVER, WHETHER CAUSED BY AIG'S NEGLIGENCE, ERRORS, OMISSIONS, STRICT LIABILITY, BREACH OF CONTRACT, BREACH OF WARRANTY OR OTHER CAUSE OR CAUSES WHATSOEVER INCLUDING BUT NOT LIMITED HYVISTA CORPORATIONS INABILITY TO GATHER THE HYMAP DATA SCENES.

GENERAL PROVISIONS

No Assignability. The parties agree that this Agreement is not assignable or transferable by AIG without the prior written consent of Sponsor.

No Agency Relationship. This Agreement does not establish any agency, joint venture, or partnership relationship between the

parties, and neither party can bind the other by any contract or representation.

Notices. All notices provided for in this Agreement shall be in writing and will be deemed effective when either served by personal delivery or sent by express, registered or certified mail, postage prepaid, return receipt requested, to the other party at the corresponding mailing address set forth on the first page hereof or at such other address as such other party may hereafter designate by written notice in the manner aforesaid.

Modification. The parties acknowledge and agree that this Agreement may only be modified by the mutual written agreement of the parties.

Entire Agreement. The written terms and provisions in this Agreement constitute the entire agreement and understanding between the parties relating to the subject matter hereof and supersede all previous communications, proposals, representations, and understandings, whether oral or written, relating thereto. This Agreement may be executed in two or more counterparts, each of which shall be deemed an original and all of which together shall constitute one instrument.

Governing Law. This Agreement shall be governed by and construed and enforced in accordance with the laws of the State of Colorado, U.S.A., without regard to the conflict of laws provisions thereof. Both AIG and Sponsor agree and consent to personal jurisdiction and venue in the state and federal courts in the State of Colorado, U.S.A. All actions relating to or arising out of this Agreement may be brought only in federal or state courts in the State of Colorado, U.S.A.

Binder. This Agreement is binding on and inures to the benefit of the parties, their respective heirs, assigns, and legal representatives.

Severability. In case any one or more of the provisions contained in this Agreement shall, for any reason, be held to be invalid, illegal, or unenforceable in any respect, such invalidity, illegality, or unenforceability shall not affect any other provisions of this Agreement, and this Agreement shall be construed as if such valid, illegal, or unenforceable provision had never been contained herein.

Binding Agreement. Each party agrees and acknowledges that it has read this Agreement, understands it, and agrees to be bound by the terms and conditions herein.

IN WITNESS WHEREOF, this Agreement is executed by and between the parties as of the Effective Date.

AIG

SPONSOR:

By: _____

By: _____

Name: James M. Young

Name: _____

Title: Contracts Manager

Title: _____

Date: _____

Date: _____

Glossary

This glossary was compiled from Internet Sites at the USGS, NASA, Goddard Space Center, Canadian Center for Remote Sensing, and the ASPRS

DISCLAIMER: Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

A

Absolute temperature	Temperature measured on the Kelvin scale, whose base is absolute zero, i.e. -273 °C (0 °C is expressed as 273 °K).
Absorptance	A measure of the ability of a material to absorb EM energy at a specific wavelength.
Absorption band	Wavelength interval within which electromagnetic radiation is absorbed by the atmosphere or by other substances.
Absorptivity	Capacity of a material to absorb incident radiant energy.
Achromatic vision	The perception by the human eye of changes in brightness, often used to describe the perception of monochrome or black and white scenes.
Active remote sensing	Remote sensing methods that provide their own source of electromagnetic radiation to illuminate the terrain. Radar is one example.
Acuity	A measure of human ability to perceive spatial variations in a scene. It varies with the spatial frequency, shape, and contrast of the variations, and depends on whether the scene is colored or monochrome.
Additive primary colors	Blue, green, and red. Filters of these colors transmit the primary color of the filter and absorb the other two colors.
Adiabatic cooling	Refers to decrease in temperature with increasing altitude.
Advanced very high resolution radiometer (AVHRR)	Crosstrack multispectral scanner on a NOAA polar-orbiting satellite that acquires five spectral bands of data (0.55 to 12.50 µm) with a ground resolution cell of 1.1 by 1.1 km.
Aerial magnetic survey	Survey that records variations in the earth's magnetic field.
Aeromagnetic	Aeromagnetic is descriptive of data pertaining to the Earth's magnetic field which has been collected from an airborne sensor.
AGL	Above ground level.
Air base	Ground distance between optical centers of successive overlapping aerial photographs.
Airborne imaging spectrometer (AIS)	Along-track multispectral scanner with spectral bandwidth of 0.01 µm.
Airborne visible and infrared imaging spectrometer (AVIRIS)	Experimental airborne along-track multispectral scanner under development at JPL to acquire 224 images in the spectral region from 0.4 to 2.4 µm.
AID--Agency for International Development	The United States Federal agency for international development projects.
Albedo (A)	Ratio of the amount of electromagnetic energy reflected by a surface to the amount of energy incident upon it.
Albers Equal Area Projection	The Albers Equal Area projection is a method of projection on which the areas of all regions are shown in the same proportion of their true areas. The meridians are equally spaced straight lines converging at a common point, which is normally beyond the pole. The angles between them are less than the true angles. The parallels are unequally spaced concentric circular arcs centered on the point of convergence of the meridians. The meridians are radii of the circular arcs. The poles are normally circular arcs enclosing the same angle as that enclosed by the

other parallels of latitude for a given range of longitude. Albers Equal Area is frequently used in the ellipsoidal form for maps of the United States in the National Atlas of the United States, for thematic maps, and for world atlases. It is also used and recommended for equal-area maps of regions that are predominantly east-west in extent.

Along-track scanner	Scanner with a linear array of detectors oriented normal to flight path. The IFOV of each detector sweeps a path parallel with the flight direction.
Alteration	Changes in color and mineralogy of rocks surrounding a mineral deposit that are caused by the solutions that formed the deposit. Suites of alteration minerals commonly occur in zones.
Amplitude	For waves, the vertical distance from crest to trough.
Analog display	A form of data display in which values are shown in graphic form, such as curves. Differs from digital displays in which values are shown as arrays of numbers.
Analogue image	An image where the continuous variation in the property being sensed is represented by a continuous variation in image tone. In a photograph, this is achieved directly by the grains of photosensitive chemicals in the film; in an electronic scanner, the response in millivolts is transformed to a display on a cathode-ray tube where it may be photographed.
Angular beam width	In radar, the angle subtended in the horizontal plane by the radar beam.
Angular field of view	Angle subtended by lines from a remote sensing system to the outer margins of the strip of terrain that is viewed by the system.
Angular resolving power	Minimum separation between two resolvable targets, expressed as angular separation.
Anomaly	An area on an image that differs from the surrounding, normal area. For example, a concentration of vegetation within a desert scene constitutes an anomaly.
Antenna	Device that transmits and receives microwave and radio energy in radar systems.
Aperture	Opening in a remote sensing system that admits electromagnetic radiation to the film in radar systems.
APL	Applied Physics Laboratory of John Hopkins University.
Apollo	U.S. lunar exploration program of satellites with crews of three astronauts.
Apparent thermal inertia (ATI)	An approximation of thermal inertia calculated as one minus albedo divided by the difference between daytime and nighttime radiant temperatures.
ARC Export	EXPORT creates an ARC/INFO interchange file to transfer coverages, INFO data files, text files, and other ARC/INFO files between various computer systems. An interchange file contains all coverage information and appropriate INFO file information in a fixed length, ASCII format. It can be fully or partially compressed as well as uncompressed ASCII depending upon the given EXPORT option.
ARC SECOND	1/3600th of a degree (1 second) of latitude or longitude.
ARC/INFO	ARC/INFO is a geographic information system (GIS) used to automate, manipulate, analyze, and display geographic data in digital form. ARC/INFO is a proprietary system developed and distributed by the Environmental Systems Research Institute, Inc., in Redlands, California.
ArcUSA	Designed by ESRI, ArcUSA is a general-purpose database used to generate thematic maps of the conterminous United States at the State and county levels. The database contains cartographic information, tabular information, and indices and is designed for a wide range of applications.

Areal	Relating to or involving an area.
Artifact	A feature on an image, which is produced by the optics of the system or by digital image processing, and sometimes masquerades as a real feature.
ASA index	Index of the American Standards Association designating film speed, or sensitivity to light. Higher values indicate higher sensitivity. The ASA index has been replaced by the ISO index.
Ascending node	Direction satellite is traveling relative to the Equator. An ascending node would imply a northbound Equatorial crossing.
ATI	Apparent Thermal Inertia.
Atmosphere	Layer of gases that surrounds some planets.
Atmospheric correction	Image-processing procedure that compensates for effects of selectivity scattered light in multispectral images.
Atmospheric shimmer	An effect produced by the movement of masses of air with different refractive indices, which is most easily seen in the twinkling of stars.
Atmospheric window	Wavelength interval within which the atmosphere readily transmits electromagnetic radiation.
Attributes	Attributes, also called feature codes or classification attributes, are used to describe map information represented by a node, line, or area. For example, an attribute code for an area might identify it to be a lake or swamp; an attribute code for a line might identify a road, railroad, stream, or shoreline.
Attitude	Angular orientation of remote sensing system with respect to a geographic reference system.
AVHRR	Advanced Very High Resolution Radiometer, a multispectral imaging system carried by the TIROS-NOAA series of meteorological satellites.
AVIRIS	Airborne visible and infrared imaging spectrometer.
Azimuth	Geographic orientation of a line given as an angle measured in degrees clockwise from north.
Azimuth direction	In radar images, the direction in which the aircraft is heading. Also called flight direction.
Azimuth resolution	In radar images, the spatial resolution in the azimuth direction.
B	
Background	Area on an image or the terrain that surrounds an area of interest, or target.
Backscatter	In radar, the portion of the microwave energy scattered by the terrain surface directly back toward the antenna.
Backscatter coefficient	A quantitative measure of the intensity of energy returned to a radar antenna from the terrain.
Band	A wavelength interval in the electromagnetic spectrum. For example, in Landsat images the bands designate specific wavelength intervals at which images are acquired.
Bandwidth	The total range of frequency required to pass a specific modulated signal without distortion or loss of data. The ideal bandwidth allows the signal to pass under conditions of maximum AM or FM adjustment. (Too narrow a bandwidth will result in loss of data during modulation peaks. Too wide a bandwidth will pass excessive noise along with the signal.) In FM, radio frequency signal bandwidth is determined by the frequency deviation of the signal.
Base height ratio	Air base divided by aircraft height. This ratio determines vertical exaggeration on stereo models.

Batch processing	Method of data processing in which data and programs are entered into a computer that carries out the entire processing operation with no further instructions.
Bathymetry	Configuration of the seafloor.
Beam	A focused pulse of energy.
BIA--Bureau of Indian Affairs, Department of the Interior	The BIA serves Indian and Alaska Native tribes living on or near reservations. The BIA administers and manages approximately 52 million acres of land held in trust for Indians by the United States and works with local tribal governments on issues including road construction and maintenance, social services, police protection, and economic development.
BIL (Band-Interleaved-by-Line)	BIL is a CCT tape format that stores all bands of satellite data in one image file. Scanlines are sequenced by interleaving all image bands. The CCT header appears once in a set.
Bilinear	The term bilinear is referring to a bilinear interpolation. This is simply an interpolation with two variables instead of one.
Bin	One of a series of equal intervals in a range of data, most commonly employed to describe the divisions in a histogram.
Binary	Based upon the integer two. Binary Code is composed of a combination of entities that can assume one of two possible conditions (0 or 1). An example in binary notation of the digits 111 would represent $(1 \times 2) + (1 \times 2) + (1 \times 2) = 4 + 2 + 1 = 7$.
Bit	Contraction of binary digit, which in digital computing represents an exponent of the base 2.
BIP--Band-Interleaved-by-Pixel	When using the BIP image format, each line of an image is stored sequentially, line 1 all bands, line 2 all bands, etc. For example, the first line of a three-band image would be stored as p1b1, p1b2, p1b3, p2b1, p2b2, p2b3, where p1b1 indicates pixel one, band one, p1b2 indicates pixel one, band two, etc.
Blackbody	An ideal substance that absorbs the entire radiant energy incident on it and emits radiant energy at the maximum possible rate per unit area at each wavelength for any given temperature. No actual substance is a true blackbody, although some substances, such as black lamps, approach this property.
Blind spot	The point of the optic nerve to the retina where no radiation is detected by the eye.
BLM--Bureau of Land Management, Department of the Interior	Under the Federal Land Policy and Management Act of 1976, the BLM administers and manages approximately 300 million acres of public lands primarily located in the western half of the lower 48 States and Alaska. Public lands in the U.S. contain mineral and timber reserves, support habitat for a host of wildlife, and provide recreational opportunities.
BOR--Bureau of Reclamation, Department of the Interior	The BOR was chartered in 1902 with the responsibility to reclaim arid lands in the western U.S. for farming by providing secure, year-around water supplies for irrigation. The BOR's responsibilities since have expanded to include generating hydroelectric power; overseeing municipal and industrial water supplies, river regulation, and flood control; enhancing fish and wildlife habitats; and researching future water and energy requirements.
BPI--Bits Per Inch	The tape density to which the digital data were formatted.
Brightness	Magnitude of the response produced in the eye by light.
Brute Force Radar	See real-aperture radar.
BSQ--Band Sequential	BSQ is a CCT tape format that stores each band of satellite data in one image file for all scanlines in the imagery array. The CCT headers are recorded on each band.
Byte	A group of eight bits of digital data.

C	
Calibration	Process of comparing an instrument's measurements with a standard.
Calorie	Amount of heat required to raise the temperature of 1g of water by 1 °C.
Camouflage detection photographs	Another term for IR color-photograph.
Cardinal point effect	In radar, very bright signatures caused by optimally oriented corner reflectors, such as buildings.
Cartographic	Pertaining to cartography, the art or practice of making charts or maps.
Cathode ray tube (CRT)	A vacuum tube with a phosphorescent screen on which images are displayed by an electron beam.
C band	Radar wavelength region from 3.8 to 7.5 cm.
CCD	Charge-coupled detector.
CCT	Computer-compatible tape.
CD-ROM--Compact Disc-Read Only Memory	CD-ROM is a computer peripheral that employs compact disc technology to store large amounts of data for later retrieval. The capacity of a CD-ROM disk is over 600 megabytes, the equivalent of over 250,000 typewritten pages.
Centerpoint	The optical center of a photograph.
Change-detection images	An image prepared by digitally comparing scenes acquired at different times. The gray tones or colors of each pixel record the amount of difference between the corresponding pixels of the original images.
Channels	A range of wavelength intervals selected from the electromagnetic spectrum.
Charge-coupled detector (CCD)	A device in which electrons are stored at the surface of a semiconductor.
Chlorosis	Yellowing of plant leaves resulting from an imbalance in the iron metabolism caused by excess concentrations of copper, zinc, manganese, or other elements in the plant.
Chromatic vision	The perception by the human eye of changes in hue.
CIR	Color infrared.
Circular scanner	Scanner in which a faceted mirror rotates about a vertical axis to sweep the detector IFOV in a series of circular scan lines on the terrain.
Classification	Process of assigning individual pixels of an image to categories, generally based on spectral reflectance characteristics.
Coastal zone color scanner (CZCS)	A satellite-carried multi-spectral scanner designed to measure chlorophyll concentrations in the oceans.
Coherent radiation	Electromagnetic radiation whose waves are equal in length and are in phase, so that waves at different points in space act in unison, as in laser and synthetic aperture radar.
Color composite image	Color image prepared by projecting individual black-and-white multispectral images, each through a different color filter. When the projected images are superposed, a color composite image results.
Color ratio composite image	Color composite image prepared by combining individual ratio images for a scene using a different color for each ratio image.
Complementary colors	Two primary colors of light (one additive and the other subtractive) that produce white light when added together. Red and cyan are complimentary colors.
Computer-compatible tape (CCT)	The magnetic tape on which the digital data for Landsat MSS and TM images are distributed.
Conduction	Transfer of electromagnetic energy through a solid material by molecular interaction.
Cones	Receptors in the retina, which are sensitive to color. There are cones sensitive to the red, green, and blue components of light.

Contact print	A reproduction from a photographic negative in direct contact with photosensitive paper.
Context	The known environment of a particular feature on an image.
Contrast	The ratio between the energy emitted or reflected by an object and its immediate surroundings.
Contrast enhancement	Image-processing procedure that improves the contrast ratio of images. The original narrow range of digital values is expanded to utilize the full range of available digital values.
Contrast ratio	On an image, the reflectance ratio between the brightest and darkest parts of an image.
Contrast stretching	Expanding a measured range of digital numbers in an image to a larger range, to improve the contrast of the image and its component parts.
Convection	Transfer of heat through the physical movement of matter.
Corner reflector	Cavity formed by two or three smooth planar surfaces intersecting at right angles. Electromagnetic waves entering a corner reflector are reflected directly back toward the source.
Corps	US Army Corps of Engineers (USACE)
COSMIC	Computer Software Management and Information Center, University of Georgia. This facility distributes computer programs developed by U.S. government-funded projects.
Cross polarized	Describes a radar pulse in which the polarization direction of the return is normal to the polarization direction of the transmission. Cross-polarized images may be HV (horizontal transmit, vertical return) or VH (vertical transmit, horizontal return).
Cross track scanner	Scanner in which a faceted mirror rotates about a horizontal axis to sweep the detector IFOV in a series of parallel scan lines oriented normal to the flight direction.
CRT	Cathode ray tube.
Cubic convolution	A high order resampling technique in which the brightness value of a pixel in a corrected image is interpolated from the brightness values of the 16 nearest pixels around the location of the corrected pixel.
Cut off	The digital number in the histogram of a digital image, which is set to zero during contrast stretching. Usually this is a value below which atmospheric scattering makes a major contribution.
CWA	Clean Water Act
Cycle	One complete oscillation of a wave.
CZCS	Coastal Zone color scanner.
D	
Dangling ARC	An arc having the same polygon on both its left and right sides and having at least one node that does not connect to any other arc. See dangling node.
Dangling node	The dangling endpoint of a dangling arc. Often identifies that a polygon does not close properly, that arcs do not connect properly, or that an arc was digitized past its intersection with another arc. In many cases, a dangling node may be acceptable. For example, in a street centerline map, cul-de-sacs are often represented by dangling arcs.
Data collection system (DCS)	On Landsats 1 and 2, the system that acquired information from seismometers, flood gauges, and other measuring devices. These data were relayed to ground receiving stations.

Datum	In surveying, a reference system for computing or correlating the results of surveys. There are two principal types of datums: vertical and horizontal. A vertical datum is a level surface to which heights are referred. In the United States, the generally adopted vertical datum for leveling operations is the national geodetic vertical datums of 1929 (differing slightly from mean sea level). The horizontal datum, used as a reference for position, is defined by: the latitude and longitude of an initial point, the direction of a line between this point and a specified second point, and two dimensions which define the spheroid. In the United States, the initial point for the horizontal datum is located at Meade's Ranch in Kansas.
Defense Meteorological Satellite Program (DMSP)	A U.S. Air Force meteorological satellite program with satellites circling in sun-synchronous orbit. Imagery is collected in the visible- to near-infrared band (0.4 to 1.1 micrometers) and in the thermal-infrared band (about 8 to 13 micrometers) at a resolution of about three kilometers. While some of the data is classified, most unclassified data is available to civilian users.
DEM--Digital Elevation Models	The U.S. Geological Survey produces five primary types of digital elevation model data. They are: 7.5-minute DEM (30- x 30-m data spacing, cast on Universal Transverse Mercator (UTM) projection or 1- x 1-arc-second data spacing). Provides coverage in 7.5- x 7.5-minute blocks. Each product provides the same coverage as a standard USGS 7.5-minute map series quadrangle. Coverage: Contiguous United States, Hawaii, and Puerto Rico. - Degree DEM (3- x 3-arc-second data spacing). Provides coverage in 1- x 1-degree blocks. Two products (three in some regions of Alaska) provide the same coverage as a standard USGS 1-x 2-degree map series quadrangle. The basic elevation model is produced by or for the Defense Mapping Agency (DMA), but is distributed by USGS in the DEM data record format. Coverage: United States 30-minute DEM (2- x 2-arc-second data spacing). Consists of four 15- x 15-minute DEM blocks. Two 30-minute DEMs provide the same coverage as a standard USGS 30- x 60-minute map series quadrangle. Saleable units will be 30- x 30-minute blocks, that is, four 15- x 15-minute DEMs representing one half of a 1:100,000-scale map. Coverage: Contiguous United States, Hawaii. 15-minute Alaska DEM (2- x 3-arc-second data spacing, latitude by longitude). Provides coverage similar to a 15-minute DEM, except that the longitudinal cell limits vary from 20 minutes at the southernmost latitude of Alaska to 36 minutes at the northern most latitude limits of Alaska. Coverage of one DEM will generally correspond to a 1:63,360-scale quadrangle. 7.5-minute Alaska DEM (1- x 2-arc-second data spacing, latitude by longitude). Provides coverage similar to a 7.5-minute DEM, except that the longitudinal cell limits vary from 10 minutes at the southernmost latitude of Alaska to 18 minutes at the northernmost latitude limits of Alaska.
Densitometer	Optical device for measuring the density of photographic transparencies.
Density, of images	Measure of the opacity, or darkness, of a negative or positive transparency.
Density, of materials (ρ)	Ratio of mass to volume of a material, typically expressed as grams per cubic centimeter.

Density slicing	Process of converting the continuous gray tones of an image into a series of density intervals, or slices, each corresponding to a specific digital range. The density slices are then displayed either as uniform gray tones or as colors.
Depolarized	Refers to a change in polarization of a transmitted radar pulse as a result of various interactions with the terrain surface.
Depression angle (y)	In radar, the angle between the imaginary horizontal plane passing through the antenna and the line connecting the antenna and the target.
Descending Node	Direction satellite is traveling relative to the Equator. A descending node would imply a southbound Equatorial crossing.
Detectability	Measure of the smallest object that can be discerned on an image.
Detector	Component of a remote sensing system that converts electromagnetic radiation into a recorded signal.
Developing	Chemical processing of an exposed photographic emulsion to produce an image.
Dielectric constant	Electrical property of matter that influences radar returns. Also referred to as complex dielectric constant.
Difference image	Image prepared by subtracting the digital values of pixels in one image from those in a second image to produce a third set of pixels. This third set is used to form the difference image.
Diffuse reflector	Surface that reflects incident radiation nearly equally in all directions.
Digital display	A form of data display in which values are shown as arrays of numbers.
Digital image	An image where the property being measured has been converted from a continuous range of analogue values to a range expressed by a finite number of integers, usually recorded as binary codes from 0 to 255, or as one byte.
Digital image processing	Computer manipulation of the digital-number values of an image.
Digital number (DN)	Value assigned to a pixel in a digital image.
Digitization	Process of converting an analog display into a digital display.
Digitizer	Device for scanning an image and converting it into numerical format.
Directional filter	Mathematical filter designed to enhance on an image those linear features oriented in a particular direction.
Distortion	On an image, changes in shape and position of objects with respect to their true shape and position.
Diurnal	Daily.
DLG--Digital Line Graph	A DLG is line map information in digital form. The DLG data files include information about planimetric base categories, such as transportation, hydrography, and boundaries.
DMA--Defense Mapping Agency	The DMA was established in 1972, when mapping, charting, and geodesy functions of the Defense Community were combined into this joint Department of Defense agency. The mission of the Agency is to: produce and distribute to the Joint Chiefs of Staff, unified and specified commands, military departments, and other department of defense users, timely and uniquely tailored mapping, charting, and geodetic products, services, and training; provide nautical charts and marine navigational data to worldwide merchant marine and private vessel operators; and maintain liaison with civil agencies and other national and international scientific and other organizations engaged in mapping, charting, and geodetic activities. The above activities were handled by the DMA Combat Support Center until the Center was disbanded in 1995 and responsibilities were transferred to the National Imagery Mapping Agency (NIMA)
Doppler principle	Describes the change in observed frequency that electromagnetic or other waves undergo as a result of the movement of the source of waves relative to the observer.

Doppler radar	The weather radar system that uses the Doppler shift of radio waves to detect air motion that can result in tornadoes and precipitation, as previously-developed weather radar systems do. It can also measure the speed and direction of rain and ice, as well as detect the formation of tornadoes sooner than older radars.
Doppler shift	A change in the observed frequency of EM or other waves caused by the relative motion between source and detector. Used principally in the generation of synthetic-aperture radar images.
DOQQ	Digital ortho-quarter quadrangle
Drainage Basin	Geographic area or region containing one or more drainage areas that discharge run-off to a single point.
DTM--Digital Terrain Model	A DTM is a land surface represented in digital form by an elevation grid or lists of three-dimensional coordinates.
Dwell time	Time required for a detector IFOV to sweep across a ground resolution cell.

E

Earth Observing System (EOS)	A series of small- to intermediate-sized spacecraft that is the centerpiece of NASA's Mission to Planet Earth (MTPE). Planned for launch beginning in 1998, each of each of the EOS spacecraft will carry a suite of instruments designed to study global climate change. MTPE will use space-, aircraft-, and ground-based measurements to study our environment as an integrated system. Designing and implementing the MTPE is, of necessity, an international effort. The MTPE program involves the cooperation of the U.S., the European Space Agency (ESA), and the Japanese National Space Development Agency (NASDA). The MTPE program is part of the U.S. interagency effort, the Global Change Research Program.
EDAC--Earth Data Analysis Center	EDAC, also known as the Technology Applications Center (TAC), has served as a NASA center since 1964. EDAC operates under the objective of transferring Earth-observing technologies to the user community. It supports and works directly with industries developing technologies related to space science and collaborating with them to enhance and encourage the user community to adopt the new technologies. EDAC also supports and works with public agencies, private citizens, educational organizations, and volunteer groups to ensure ready accessibility to NASA generated space imagery.
EDC	EROS Data Center.
Edge	A boundary in an image between areas with different tones.
Edge enhancement	Image-processing technique that emphasizes the appearance of edges and lines.
Ektachrome	A Kodak color positive film.
Electromagnetic radiation	Energy propagated in the form of and advancing interaction between electric and magnetic fields. All electromagnetic radiation moves at the speed of light.
Electromagnetic spectrum	Continuous sequence of electromagnetic energy arranged according to wavelength or frequency.

El Niño	A warming of the surface waters of the eastern equatorial Pacific that occurs at irregular intervals of 2-7 years, lasting 1-2 years. Along the west coast of South America, southerly winds promote the upwelling of cold, nutrient-rich water that sustains large fish populations that sustain abundant sea birds, whose droppings support the fertilizer industry. Near the end of each calendar year, a warm current of nutrient-pool tropical water replaces the cold, nutrient-rich surface water. Because this condition often occurs around Christmas, it was named El Niño (Spanish for boy child, referring to the Christ child). In most years the warming last only a few weeks or a month, after which the weather patterns return to normal and fishing improves. However, when El Niño conditions last for many months, more extensive ocean warming occurs and economic results can be disastrous. El Niño has been linked to wetter, colder winters in the United States; drier, hotter summers in South America and Europe; and drought in Africa. See ENSO.
Emission	Process by which a body radiates electromagnetic energy. Emission is determined by kinetic temperature and emissivity.
Emissivity (e)	Ratio of radiant flux from a body to that from a blackbody at the same kinetic temperature and emissivity.
Emittance	A term for the radiant flux of energy per unit area emitted by a body. (Now obsolete).
Emulsion	Suspension of photosensitive silver halide grains in gelatin that constitutes the image-forming layer on photographic film.
Energy flux	Radiant flux.
Enhancement	Process of altering the appearance of an image so that the interpreter can extract more information.
ENSO (El Niño-Southern Oscillation)	Interacting parts of a single global system of climate fluctuations. ENSO is the most prominent known source of interannual variability in weather and climate around the world, though not all areas are affected. The Southern Oscillation (SO) is a global-scale seesaw in atmospheric pressure between Indonesia/North Australia, and the southeast Pacific. In major warm events El Niño warming extends over much of the tropical Pacific and becomes clearly linked to the SO pattern. Many of the countries most affected by ENSO events are developing countries with economies that are largely dependent upon their agricultural and fishery sectors as a major source of food supply, employment, and foreign exchange. New capabilities to predict the onset of ENSO event can have a global impact. While ENSO is a natural part of the Earth's climate, whether its intensity or frequency may change as a result of global warming is an important concern.
EOSAT	The commercial company that took over operations of the Landsat system in 1985.
Ephemeris	A table of predicted satellite orbital locations for specific time intervals. The ephemeris data help to characterize the conditions under which remotely sensed data are collected and are commonly used to correct the sensor data prior to analysis.
ERBSS	Earth Radiation Budget Sensor System, carried by NOAA satellites.
EREP	Earth Resources Experiment Package, carried on Skylab and consisting of cameras and multispectral scanner.
EROS	Earth Resources Observation System.
EROS Data Center (EDC)	Facility of the U.S. Geological Survey at Sioux Falls, South Dakota, that archives, processes, and distributes images.
ERTS	Earth Resource Technology Satellite, now called Landsat.
ESA	European Space Agency, based in Paris. A consortium between several European states for the development of space science, including the launch of remote-sensing satellites.

ETC	Earth-terrain camera.
Evaporative cooling	Temperature drop caused by evaporation of water from a moist surface.
Exitance	The radiant flux.
F	
False color image	A color image where parts of the non-visible EM spectrum are expressed as one or more of the red, green, and blue components, so that the colors produced by the Earth's surface do not correspond to normal visual experience. Also called a false-color composite (FCC). The most commonly seen false-color images display the very-near infrared as red, red as green, and green as blue.
False color photograph	Another term for IR color photograph.
Far range	The portion of a radar image farthest from the aircraft or spacecraft flight path.
Fiducial Marks	A set of four marks located in the corners or edge-centered, or both, of a photographic image. These marks are exposed within the camera onto the original film and are used to define the frame of reference for spatial measurements on aerial photographs. Opposite fiducial marks connected, intersect at approximately the image center of the aerial photograph.
Film	Light-sensitive photographic emulsion and its base.
Film speed	Measure of the sensitivity of photographic film to light. Larger numbers indicate higher sensitivity.
Film Types	Photographic products for use in image interpretation are commonly generated from the following film types: • Black-and-White Panchromatic (B&W): This film primarily consists of a black-and-white negative material with a sensitivity range comparable to that of the human eye. It has good contrast and resolution with low graininess and a wide exposure range. • Black-and-White Infrared (BIR): With some exceptions, this film is sensitive to the spectral region encompassing 0.4 <u>micrometers</u> to 0.9 micrometers. It is sometimes referred to as near-infrared film because it utilizes only a narrow portion of the total infrared spectrum (0.7 micrometers to 0.9 micrometers). • Conventional Color: This film contains three emulsion layers that are sensitive to blue, green, and red (the three primary colors of the visible spectrum). This film replicates colors as seen by the human eye and is commonly referred to as normal or natural color. Color film is a valuable image interpretation tool because the human eye can discern a greater variety of color tones than gray tones. • Color Infrared (CIR): This film, originally referred to as camouflage-detection film because of its warfare applications, differs from conventional color film because its emulsion layers are sensitive to green, red, and near-infrared radiation (0.5 micrometers to 0.9 micrometers). Used with a yellow filter to absorb the blue light, this film provides sharp images and penetrates haze at high altitudes. Color-infrared film also is referred to as false-color film.
	Mathematical procedure for modifying values of numerical data.
Filter, optical	A material that, by absorption or reflection, selectivity modifies the radiation transmitted through an optical system.

Flight path	Line on the ground directly beneath a remote sensing aircraft or spacecraft. Also called flight line.
Fluorescence	Emission of light from a substance following exposure to radiation from an external source.
F-number	Representation of the speed of a lens determined by the focal length divided by diameter of the lens. Smaller numbers indicate faster lenses.
Focal length	In cameras, the distance from the optical center of the lens to the plane at which the image of a very distant object is brought into focus.
Foreshortening	A distortion in radar images causing the lengths of slopes facing the antenna to appear shorter on the image than on the ground. It is produced when radar wave fronts are steeper than the topographic slope.
Format	Size of an image
Forward overlap	The percent of duplication by successive photographs along a flight line.
Fovea	The region around that point on the retina intersected by the eye's optic axis, where receptors are most densely packed. It is the most sensitive part of the retina.
Frequency (v)	The number of wave oscillations per unit time or the number of wavelengths that pass a point per unit time.
F-stop	Focal length of a lens divided by the diameter of the lens's adjustable diaphragm. Smaller numbers indicate larger openings, which admit more light to the film.
G	
GAC--Global Area Coverage	GAC data are derived from a sample averaging of the full resolution AVHRR data. Four out of every five samples along the scan line are used to compute one average value and the data from only every third scan line are processed, yielding 1.1 km by 4 km resolution at the subpoint.
Gamma	This is a unit of magnetic intensity.
GCP	Ground-control point. GCPs are physical points on the ground whose positions are known with respect to some horizontal coordinate system and/or vertical datum. When mutually identifiable on the ground and on a map or photographic image, ground control points can be used to establish the exact spatial position and orientation of the image to the ground. Ground control points may be horizontal control points, vertical control points, or both.
Gemini	U.S. program of two-man earth-orbiting spacecraft in 1965 and 1966.
Geodetic	Of or determined by geodesy; that part of applied mathematics which deals with the determination of the magnitude and figure either of the whole Earth or of a large portion of its surface. Also refers to the exact location points on the Earth's surface.
Geodetic accuracy	The accuracy with which geographic position and elevation of features on the Earth's surface are mapped. This accuracy incorporates information in which the size and shape of the Earth has been taken into account.
Geographic information system (GIS)	A data-handling and analysis system based on sets of data distributed spatially in two dimensions. The data sets may be map oriented, when they comprise qualitative attributes of an area recorded as lines, points, and areas often in vector format, or image oriented, when the data are quantitative attributes referring to cells in a rectangular grid usually in raster format. It is also known as a geobased or geocoded information system.
Geometric correction	Image-processing procedure that corrects spatial distortions in an image.

Georegistered	An image that has been geographically referenced or rectified to an Earth model, usually to a map projection. Sometimes referred to as geocoded or geometric registration.
Geostationary	Refers to satellites traveling at the angular velocity at which the earth rotates; as a result, they remain above the same point on earth at all times.
Geostationary Operational Environmental Satellite (GOES)	a NOAA satellite that acquires visible and thermal IR images for meteorological purposes such as: • Provide continuous day and night weather observations; • Monitor severe weather events such as hurricanes, thunderstorms, and flash floods; • Relay environmental data from surface collection platforms to a processing center; • Perform facsimile transmissions of processed weather data to low-cost receiving stations; • Monitor the Earth's magnetic field, the energetic particle flux in the satellite's vicinity, and x-ray emissions from the sun; • Detect distress signals from downed aircraft and ships. points 35,790 km (22,240 miles) above the equator at 75 degrees west and 135 degrees west. GOES satellites have an equatorial, Earth-synchronous orbit with a 24-hour period, a visible resolution of 1 km, an IR resolution of 4 km, and a scan rate of 1864 statute miles in three minutes. See geostationary. The transmission of processed weather data (both visible and infrared) by GOES is called weather facsimile (WEFAX). GOES WEFAX transmits at 1691+ mhz and is accessible via a ground station with a satellite dish antenna. GOES carries the following five major sensor systems: 1. The imager is a multispectral instrument capable of sweeping simultaneously one visible and four infrared channels in a north-to-south swath across an east-to-west path, providing full disk imagery once every thirty minutes. 2. The sounder has more spectral bands than the imager for producing high quality atmospheric profiles of temperature and moisture. It is capable of stepping one visible and eighteen infrared channels in a north-to-south swath across an east-to-west path. 3. The Space Environment Monitor (SEM) measures the condition of the Earth's magnetic field, the solar activity and radiation around the spacecraft, and transmits these data to a central processing facility. 4. The Data Collection System (DCS) receives transmitted meteorological data from remotely located platforms and relays the data to the end-users. 5. The Search and Rescue Transponder can relay distress signals at all times, but cannot locate them. While only the polar-orbiting satellite can locate distress signals, the two types of satellites work together to create a comprehensive search and rescue system.
Geostationary orbit	An orbit at 41 000 km in the direction of the Earth's rotation, which matches speed so that a satellite remains over a fixed point on the Earth's surface.
Geosynchronous (aka GEO)	geostationary.

Geothermal	Refers to heat from sources within the earth.
Goddard Space Flight Center (GSFC)	The NASA facility at Greenbelt, Maryland, that is also a Landsat ground receiving station.
GMT	Greenwich mean time. This international 24-h system is used to designate the time at which Landsat images are acquired.
GOES	
Gossan	Surface occurrence of iron oxide formed by the weathering of metallic sulfide ore minerals.
GPS--Global Positioning System	The GPS is a worldwide satellite navigation system that is funded and supervised by the U.S. Department of Defense. GPS satellites transmit specially coded signals. These signals are processed by a GPS receiver that computes extremely accurate measurements, including 3-dimensional position, velocity, and time on a continuous basis
Granularity	Graininess of developed photographic film that is determined by the texture of the silver grains.
GRASS--Geographic Resources Analysis Support System	GRASS is a product of the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL) in Champaign, Illinois. It is an integrated set of programs designed to provide digitizing, image processing, map production, and geographic information system capabilities to its users.
Gray scale	A sequence of gray tones ranging from black to white.
Grid format	irregularly distributed points, or along survey lines, to values referring to square cells in a rectangular array. It forms a step in the process of contouring data, but can also be used as the basis for a raster format to be displayed and analyzed digitally after the values have been rescaled to the 0-255 range.
Ground-control point	A geographic feature of known location that is recognizable on images and can be used to determine geometric corrections.
Ground range	On radar images, the distance from the ground track to an object.
Ground-range image	Radar image in which the scale in the range direction is constant.
Ground receiving station	
Ground resolution cell	Area on the terrain that is covered by the IFOV of a detector.
Ground swath	Width of the strip of terrain that is imaged by a scanner system.
GSFC	Goddard Space Flight Center
H	
	Refers to waves in which the component frequencies are whole-number multiples of the fundamental frequency.
HCMM	Heat Capacity Mapping Mission, the NASA satellite launched in 1978 to observe thermal properties of rocks and soils. It remained in orbit for only a few months.
Heat capacity-(c)	temperature rise or fall. Expressed in calories per gram per degree centigrade. Also called thermal capacity.
Heat Capacity Mapping Mission (HCMM)	NASA satellite orbited in 1978 to record daytime and nighttime visible and thermal IR images of large areas.
Highlights	
High-pass filter	A spatial filter that selectively enhances contrast variations with high spatial frequencies in an image. It improves the sharpness of images and is a method of edge enhancement.
HIRIS-High Resolution Imaging Spectrometer	Possibly to be carried by the Space Shuttle.
HIRS-High Resolution Infrared Spectrometer	Carried by NOAA satellites.

Histogram	A means of expressing the frequency of occurrence of values in a data set within a series of equal ranges or bins, the height of each bin representing the frequency at which values in the data set fall within the chosen range. A cumulative histogram expresses the frequency of all values falling within a bin and lower in the range. A smooth curve derived mathematically from a histogram is termed the probability density function (PDF).
HORIZONTAL POLARIZATION	Transmission of microwaves so that the electric lines of force are horizontal, while the magnetic lines of force are vertical.
HRPT--High Resolution Picture Transmission	HRPT data are full resolution image data transmitted to a ground station as they are collected. The average instantaneous field-of-view of 1.4 milliradians yields a HRPT ground resolution of approximately 1.1 km at the satellite nadir from the nominal orbit altitude of 833 km (517 mi).
HRV--High Resolution Visible Imaging Instrument	The HRV instrument is a multispectral radiometer designed for SPOT spacecraft. The HRV instrument provides for high-resolution imaging in the visible and near-infrared portions of the electromagnetic spectrum. The first three SPOT satellites carry twin HRVs that operate in a number of viewing configurations and in different spectral modes. Some of those viewing configurations and spectral modes include one HRV only operating in a dual spectral mode (i.e., in both panchromatic mode and multispectral mode); two HRVs operating in the twin-viewing configuration (i.e., one HRV in panchromatic mode and one HRV in multispectral mode); and two HRVs operating independently of each other (i.e., not in twin-viewing configuration).
Hue	In the IHS system, represents the dominant wavelength of a color.
HYDROLOGY	Scientific study of the waters of the Earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of ground water.
HYPSOGRAPHY	level, especially the measurement and mapping of land elevation.
I	
IFOV	Instantaneous field of view.
IHS	Intensity, hue, and saturation system of colors.
Image	Pictorial representation of a scene recorded by a remote sensing system. Although image is a general term, it is commonly restricted to representations acquired by non-photographic methods.
Image dissection	The breaking down of a continuous scene into discrete spatial elements, either by the receptors on the retina, or in the process of capturing the image artificially.
Image striping	A defect produced in line scanner and push-broom imaging devices produced by the non-uniform response of a single detector, or amongst a bank of detectors. In a line-scan image the stripes are perpendicular to flight direction, but parallel to it in a push-broom image.
Image swath	See ground swath.
Incidence angle	In radar, the angle formed between an imaginary line normal to the surface and another connecting the antenna and the target.
Incident energy	Electromagnetic radiation impinging on a surface.

Index of refraction (n)	Ratio of the wavelength or velocity of electromagnetic radiation in a vacuum to that in a substance.
Instantaneous field of view (IV or IFOV)	Solid angle through which a detector is sensitive to radiation. In a scanning system, the solid angle subtended by the detector when the scanning motion is stopped.
Intensity	In the IHS system, brightness ranging from black to white.
Interactive processing	results and can alter the instructions to the computer to achieve desired results.
Interpretation	The process in which a person extracts information from an image.
Interpretation key	interpreter to identify an object on an image.
IR	Infrared region of the electromagnetic spectrum that includes wavelengths from 0.7 μ m to 1 mm.
IR color photograph	Color photograph in which the red-imaging layer is sensitive to photographic IR wavelengths, the green-imaging layer is sensitive to red light, and the blue-imaging layer is sensitive to green light. Also known as camouflage detection photographs and false-color photographs.
ISO index	Index of the International Standards Organization, designating film speed in photography. Higher values indicate higher sensitivity.
Isotherm	Contour line connecting points of equal temperature. Isotherm maps are used to portray surface-temperature patterns of water bodies.

J

Japanese National Space Development Agency (NASDA)	The agency reports to the Japanese Ministry of Science and Technology.
JNC--Jet Navigation Chart	The JNC series provides worldwide coverage at a scale of 1:2,000,000. The information on these charts are suitable for aeronautical long-range, high-altitude, high-speed travel; map features include cities, roads, railroads, lakes, principal drainage, and permanent snow/ice areas. The polar regions are in a Transverse Mercator projection. All other regions are presented in the Lambert Conformal Conic projection.
Johnson Space Flight Center	A NASA facility in Houston, Texas.
JPL	Jet Propulsion Laboratory, a NASA facility at Pasadena, California, operated under contract by the California Institute of Technology.

K

Ka band	Radar wavelength region from 0.8 to 1.1 cm.
Kelvin Units	A Kelvin Unit refers to a thermometric scale in which the degree intervals are equal to those of the Celsius scale and in which zero (0) degrees equals -273.15 degrees Celsius (absolute zero)
Kernel	Two-dimensional array of digital numbers used in digital filtering.
Kinetic energy	The ability of a moving body to do work by virtue of its motion. The molecular motion of matter is a form of kinetic energy.
Kinetic temperature	Internal temperature of an object determined by random molecular motion. Kinetic temperature is measured with a contact thermometer.
Kodachrome	A Kodak color positive film.

L

LAC--Local Area	LAC are full resolution data recorded on an onboard tape recorder for
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Coverage	subsequent transmission during a station overpass. The average instantaneous field-of-view of 1.4 milliradians yields a LAC ground resolution of approximately 1.1 km at the satellite nadir from the nominal orbit altitude of 833 km.
LACIE	Large Area Crop Inventory Experiment
Lambert Azimuthal Equal Area Projection	Azimuthal projections are formed onto a plane, which is usually tangent to the globe at either pole, the Equator, or any intermediate point. The Lambert Azimuthal Equal Area projection is a method of projecting maps on which the azimuth or direction from a given central point to any other point is shown correctly and also on which the areas of all regions are shown in the same proportion of their true areas. When a pole is the central point, all meridians are spaced at their true angles and are straight radii of concentric circles that represent the parallels. This projection is frequently used in one of three aspects: The polar aspect is used in atlases for maps of polar regions and of the Northern and Southern Hemispheres; the equatorial aspect is commonly used for atlas maps of the Eastern and Western Hemispheres; and the oblique aspect is used for atlas maps of continents and oceans.
Lambert Conformal Conic Projection	The Lambert Conformal Conic Projection is derived by the projection of lines from the center of the globe onto a simple cone. This cone intersects the Earth along two standard parallels of latitude, both of which are on the same side of the equator. All meridians are converging straight lines that meet at a common point beyond the limits of the map. Parallels are concentric circles whose center is at the intersection point of the meridians. Parallels and meridians cross at right angles, an essential of conformality. chosen to enclose two-thirds of the north to south map area. Between these parallels, the scale will be too small, and beyond them, too large. If the north to south extent of the mapping is limited, maximum scale errors will rarely exceed one percent. Area exaggeration between and near the standard parallels, is very slight; thus, the projection provides good directional and shape relationships for areas having their long axes running in an east to west belt.
LANDSAT (formerly ERTS)	The Landsat program, first known as the Earth Resources Technology Satellite (ERTS) Program, is a development of the National Aeronautics and Space Administration (NASA) in association with NOAA, USGS, and the Space Imaging. The activities of these combined groups led to the concept of dedicated Earth-orbiting satellites, the defining of spectral and spatial requirements for their instruments, and the fostering of research to determine the best means of extracting and using information from the data. The first satellite, ERTS 1, was launched on 7/23/72. The second satellite was launched on 1/22/75. Concurrently the name of the satellites and program was changed to emphasize its prime area of interest (land resources). The first two satellites were designated as Landsats 1 and 2. Landsat 3 was launched on 3/5/78. Landsat 4 was launched on 7/16/82. Landsat 5 (launched 3/1/84) is currently in service providing selected data to worldwide researchers.
Laplacian filter	A form of nondirectional digital filter.
Large-format camera (LFC)	An experiment first carried on the Space Shuttle in October 1984.
Laser	Light artificially stimulated electromagnetic radiation: a beam of coherent radiation with a single wavelength.
Latitude (aka the geodetic latitude)	The angle between a perpendicular at a location, and the equatorial plane of the Earth.

Latent image	Invisible image produced by the photochemical effect of light on silver halide grains in the emulsion of film. The latent image is not visible until after photographic development.
Layover	In radar images, the geometric displacement of the objects toward the near range relative to their base.
L band	
Lens	One or more pieces of glass or other transparent material shaped to form an image by refraction of light.
LEVEL 1b	discrete data sets and to which Earth location and calibration information have been appended, but not applied.
LFC	Large-format camera. The LFC was a high altitude aerial mapping camera scaled up to operate from the Space Shuttle in Earth-orbital altitudes. LFC specifications included: • Film Format Size: 9 x 18 inches (23 x 46 cm) • Lens Aperture: F/6.0 -Lens Focal Length: 12 inches (30.5 cm) • Exposure Interval: 7.5 sec. • Exposure Range: 1/250 to 1/31.25 seconds • Ground Resolution: 20 meters at 160 nautical miles • Ground Coverage: 120 x 240 nautical miles at 160 nm
	Light intensity detection and ranging, which uses lasers to stimulate fluorescence in various compounds and to measure distances to reflecting surfaces.
Light	Electromagnetic radiation ranging from 0.4 to 0.7 μ m in wavelength that is detectable by the human eye.
Light meter	Device for measuring the intensity of visible radiation and determining the appropriate exposure of photographic film in a camera.
Lineament	Linear topographic or tonal feature on the terrain and on images, maps, and photographs that may represent a zone of structural weakness.
Linear	Adjective that describes the straight line-like nature of features on the terrain or on images and photographs.
Lineation	The one-dimensional alignment of internal components of a rock that cannot be depicted as an individual feature on a map.
Line drop out	The loss of data from a scan line caused by malfunction of one of the detectors in a line scanner.
Line-pair	Pair of light and dark bars of equal widths. The number of such line-pairs aligned side by side that can be distinguished per unit distance expresses the resolving power of an imaging system.
Line scanner	An imaging device, which uses a mirror to sweep the ground surface normal to the flight path of the platform. An image is built up as a strip comprising lines of data.
Look angle	The angle between the vertical plane containing a radar antenna and the direction of radar propagation. Complementary to the depression angle.
Look direction	Direction in which pulses of microwave energy are transmitted by a radar system. The look direction is normal to the azimuth direction. Also called range direction.
Look-up table (LUT)	A mathematical formula used to convert one distribution of data to another, most conveniently remembered as a conversion graph.
Longitude	The angular distance from the Greenwich meridian (0 degree), along the equator. This can be measured either east or west to the 180th meridian (180 degrees) or 0 degree to 360 degrees W.
Low-sun-angle photograph	Aerial photograph acquired in the morning, evening, or winter when the sun is at a low elevation above the horizon.

Luminance	Quantitative measure of the intensity of light from a source.
Mach band	An optical illusion of dark and light fringes within adjacent areas of contrasted tone. It is a psychophysiological phenomenon, which aids human detection of boundaries or edges.
Median filter	A spatial filter, which substitutes the median value of DN from surrounding pixels for that recorded at an individual pixel. It is useful for removing random noise.
Mercator Projection	Mercator is a conformal map projection, that is, it preserves angular relationships. Mercator was designed and is recommended for navigational use and is the standard for marine charts. Mercator is often and inappropriately used as a world map projection in atlases and for wall charts where it presents a misleading view of the world because of the excessive distortion of area in the higher latitude areas.
Mercury	U.S. program of one-man, earth-orbiting spacecraft in 1962 and 1963.
Microwave	Region of the electromagnetic spectrum in the wavelength range of 0.1 to 30 cm.
Mid-infrared (MIR)	The range of EM wavelengths from 8 to 14 μm dominated by emission of thermally generated radiation from materials; also known as thermal infrared.
Mie scattering	The scattering of EM energy by particles in the atmosphere with comparable dimensions to the wavelength involved.
Minimum ground separation	Minimum distance on the ground between two targets at which they can be resolved on an image.
Minus-blue photographs	Black-and-white photographs acquired using a filter that removes blue wavelengths to produce higher spatial resolution.
Mixed pixel	A pixel whose DN represents the average energy reflected or emitted by several types of surface present within the area that it represents on the ground; sometimes called a mixel.
Modular optoelectric multispectral scanner (MOMS)	An along-track scanner carried on the Space Shuttle that recorded two bands of data.
Modulate	To vary the frequency, phase, or amplitude of electromagnetic waves.
Modulation transfer function (MTF)	A method of describing spatial resolution.
MOMS	Modular optoelectric multispectral scanner.
MOS-1	Marine Observation Satellite, launched by Japan in 1987.
Mosaic	Composite image or photograph made by piecing together individual images or photographs covering adjacent areas.
MSS	Multispectral scanner system of Landsat that acquires images of four wavelength bands in the visible and reflected IR regions.
Multiband camera	System that simultaneously acquires photographs of the same scene at different wavelengths.
Multispectral classification	Identification of terrain categories by digital processing of data acquired by multispectral scanners.
Multispectral scanner	Scanner system that simultaneously acquires images of the same scene at different wavelengths.
N	
NAD27--North American Datum of 1927	NAD27 is defined with an initial point at Meads Ranch, Kansas, and by the parameters of the Clarke 1866 ellipsoid. The location of features on USGS topographic maps, including the definition of 7.5-minute quadrangle corners, are referenced to the NAD27.

NAD83--North American Datum of 1983	NAD83 is an Earth-centered datum and uses the Geodetic Reference System 1980 (GRS 80) ellipsoid, unlike NAD27, which is based on an initial point (Meade's Ranch, Kansas). Using recent measurements with modern geodetic, gravimetric, astrodynamic, and astronomic instruments, the GRS 80 ellipsoid has been defined as a best fit to the worldwide geoid. Because the NAD83 surface deviates from the NAD27 surface, the position of a point based on the two reference datums will be different.
Nadir	Point on the ground directly in line with the remote sensing system and the center of the earth.
NAPP--National Aerial Photography Program	NAPP was established to coordinate the collection of aerial photography covering the 48 contiguous States and Hawaii every five years. NAPP's goals are to ensure that photography with uniform scale, quality, and cloud-free coverage be made available to meet the requirements of several Federal and State agencies. The program was initiated in 1980 as the National High Altitude Photography (NHAP) program. In 1987, the program was renamed to NAPP when the flying height for the program changed from 40,000 feet to 20,000 feet. NAPP photography is available in black and white, and in most cases, color-infrared. The program is administered by the U.S. Geological Survey's National Mapping Division. NAPP imagery is used by the USGS for photo revision and land use land cover characterization work on the standard series maps at 1:24,000; 1:100,000 and 1:250,000 scales.
NASA	National Aeronautical and Space Administration.
NDVI--Normalized Difference Vegetation Index	index, i.e., the difference between Channel 2 and 1) and the sum of Channels 2 and 1. Thus $NDVI = (\text{channel } 2 - \text{channel } 1) / (\text{channel } 2 + \text{channel } 1)$.
Nearest Neighbor Resampling	When correcting image data points, the nearest neighbor technique assigns for each new pixel that pixel value which is closest in relative location to the newly computed pixel location.
Near infrared (NIR)	The shorter wavelength range of the infrared region of the EM spectrum, from 0.7 to 2.5 μm . It is often divided into very-near infrared (VNIR) covering the range accessible to photographic emulsions (0.7 to 1.0 μm), and the short-wavelength infrared (SWIR) covering the remainder of the NOR atmospheric window from 1.0 to 2.5 μm .
Near range	Refers to the portion of a radar image closest to the aircraft or satellite flight path.
Negative photograph	Photograph on film or paper in which the relationship between bright and dark tones is the reverse of that of the features on the terrain.
NESDIS--National Environmental Satellite, Data and Information Service	NESDIS is the element in NOAA that is responsible for establishing a digital archive of data collected from the current generation of NOAA operational polar orbiting satellites
NHAP	National High Altitude Photography program of the U.S. Geological Survey.
NOAA	National Oceanic and Atmospheric Administration.
Noise	Random or repetitive events that obscure or interfere with the desired information.
Nondirectional filter	Mathematical filter that treats all orientations of linear features equally.
Non-selective scattering	The scattering of EM energy by particles in the atmosphere which are much larger than the wavelengths of the energy, and which causes all wavelengths to be scattered equally.
Non-spectral hue	A hue which is not present in the spectrum of colors produced by the analysis of white light by a prism of diffraction grating. Examples are brown, magenta, and pastel shades.

Nonsystematic distortion	Geometric irregularities on images that are not constant and cannot be predicted from the characteristics of the imaging system.
Normal color film	Film in which the colors are essentially true representations of the colors of the terrain.
NSSDC	National Space Science Data Center.
O	
Oasis	A spot in a desert made fertile by water, which normally originates as groundwater.
Oblique photograph	Photograph acquired with the camera intentionally directed at some angle between horizontal and vertical orientations.
OMS	Orbital maneuvering system.
ONC--Operational Navigation Chart	The ONC series covers most of the world landmass areas at 1:1,000,000 scale. At this scale it takes 62 charts to cover the conterminous United States. Information on these charts includes cities and landmarks, drainage, and relief (shown by shading and contours). International and State boundaries are shown, but not county boundaries.
Orbit	Path of a satellite around a body such as the earth, under the influence of gravity.
Orthophotograph	A vertical aerial photograph from which the distortions due to varying elevation, tilt, and surface topography have been removed, so that it represents every object as if viewed directly from above.
Orthophotoscope	An optical-electronic device, which converts a normal vertical aerial photograph to an orthophotograph.
Ortho-correction	Correction applied to satellite imagery to account for terrain-induced distortion.
Overlap	Extent to which adjacent images or photographs cover the same terrain, expressed as a percentage.
P	
Panchromatic film	
Parallax	Displacement of the position of a target in an image caused by a shift in the observation system.
Parallax difference	between two points, which represent two locations on the ground with different elevations.
Parallel-polarized	Describes a radar pulse in which the polarization of the return is the same as that of the transmission. Parallel-polarized images may be HH (horizontal transmit, horizontal return) or VV (vertical transmit, vertical return).
Pass	In digital filters, refers to the spatial frequency of data transmitted by the filter. High-pass filters transmit high-frequency data; low-pass filters transmit low-frequency data.
Passive microwaves	Radiation in the 1 mm to 1 m range emitted naturally by all materials above absolute zero.
Passive remote sensing	terrain.
Path-and-row index	System for locating Landsat MSS and TM images.
Pattern	Regular repetition of tonal variations on an image or photograph.
Periodic line dropout	Defect on Landsat MSS or TM images in which no data are recorded for every sixth or sixteenth scan line, causing a black line on the image.

Periodic line striping	Defect on Landsat MSS or TM images in which every sixth or sixteenth scan line is brighter or darker than the others. Caused by the sensitivity of one detector being higher or lower than the others.
Photodetector	Device for measuring energy in the visible-light band.
Photogeology	Mapping and interpretation of geologic features from aerial photographs.
Photograph-	Representation of targets on film that results from the action of light on silver halide grains in the film's emulsion.
Photographic IR	Short-wavelength portion (0.7 to 0.9 μm) of the IR band that is detectable by IR color film or IR black-and-white film.
Photographic UV	Long-wavelength portion of the UV band (0.3 to 0.4 μm) that is transmitted through the atmosphere and is detectable by film.
Photomosaic	Mosaic composed of photographs.
Photon	Minimum discrete quantity of radiant energy.
Photopic vision	Vision under conditions of bright illumination.
Picture element	In a digitized image, the area on the ground represented by each digital number. Commonly contracted to pixel.
Pitch	Rotation of an aircraft about the horizontal axis normal to its longitudinal axis that causes a nose-up or nose-down attitude.
Pixel	Contraction of picture element.
Planck's Law	An expression for the variation of emittance of a blackbody at a particular temperature as a function of wavelength.
Point spread function (PSF)	The image of a point source of radiation, such as a star, collected by an imaging device. A measure of the spatial fidelity of the device.
Polarization	The direction of orientation in which the electrical field vector of electromagnetic radiation vibrates.
Polar orbit	An orbit that passes close to the poles, thereby enabling a satellite to pass over most of the surface, except the immediate vicinity of the poles themselves.
Polarized radiation	Electromagnetic radiation in which the electrical field vector is contained in a single plane, instead of having random orientation relative to the propagation vector. Most commonly refers to radar images.
Positive photograph	Photographic image in which the tones are directly proportional to the terrain brightness.
Precision	Precision is a statistical measurement of repeatability that is usually expressed as a variance or standard deviation, root mean square or <u>RMS</u>, of repeated measurements. These are expressed as x, y coordinates of arcs, label points, and tics in either single or double precision in ARC/INFO. Single-precision coordinates have up to seven significant digits of precision. This allows for a level of accuracy of approximately 10 meters for a region whose extent is 1,000,000 meters across. Double-precision coordinates have up to 15 significant digits; this allows for the precision necessary to represent any desired map accuracy at a global scale.
Previsual symptom	A vegetation anomaly that is recognizable on IR film before it is visible to the naked eye or on normal color photographs. It results when stressed vegetation loses its ability to reflect photographic IR energy and is recognizable on IR color film by a decrease in brightness of the red hues.
Primary colors	A set of three colors that in various combinations will produce the full range of colors in the visible spectrum. There are two sets of primary colors, additive and subtractive.
Principal component analysis	The analysis of covariance in a multiple data set so that the data can be projected as additive combinations on to new axes, which express different kinds of correlation among the data.

Principal-component (PC) image	Digitally processed image produced by a transformation that recognizes maximum variance in multispectral images.
Principal point	Optical center of an aerial photograph.
Printout	Display of computer data in alphanumeric format.
Probability density function (PDF)	A function indicating the relative frequency with which any measurement may be expected to occur. In remote sensing it is represented by the histogram of DN in one band for a scene.
Projection	Orderly system of lines on a plane representing a corresponding system of imaginary lines on an adopted terrestrial or celestial datum surface. Also, the mathematical concept of such a system. For maps of the Earth, a projection consists of (1) a graticule of lines representing parallels of latitude and meridians of longitude or (2) a grid.
Pulse	Short burst of electromagnetic radiation transmitted by a radar antenna.
Pulse length	Duration of a burst of energy transmitted by a radar antenna, measured in microseconds.
Pushbroom scanner	An alternate term for an along-track scanner
Pushbroom system	An imaging device consisting of a fixed linear array of many sensors, which is swept across an area by the motion of the platform, thereby building up an image. It relies on sensors whose response and reading is nearly instantaneous, so that the image swathe can be segmented into pixels representing small dimensions on the ground.
Quantum	The elementary quantity of EM energy that is transmitted by a particular wavelength. According to the quantum theory, EM radiation is emitted, transmitted, and absorbed as numbers of quanta, the energy of each quantum being a simple function of the frequency of the radiation.
R	
	Acronym for radio detection and ranging. Radar is an active form of remote sensing that operates in the microwave and radio wavelength regions.
Radar altimeter	A non-imaging device that records the time of radar returns from vertically beneath a platform to estimate the distance to and hence the elevation of the surface; carried by Seasat and the EAS-ERS-1 platforms.
Radar cross section	A measure of the intensity of backscattered radar energy from a point target. Expressed as the area of a hypothetical surface, which scatters radar equally in all directions and which would return the same energy to the antenna.
Radar scattering coefficient	A measure of the back-scattered energy from a target with a large area. Expressed as the average radar cross section per unit area in decibels (db). It is the fundamental measure of the radar properties of a surface.
Radar scatterometer	terrain as a function of depression angle.
Radar shadow	Dark signature on a radar image representing no signal return. A shadow extends in the far-range direction from an object that intercepts the radar beam.
Radial relief displacement	The tendency of vertical objects to appear to lean radially away from the center of a vertical aerial photograph. Caused by the conical field of view of the camera lens.
Radian	Angle subtended by an arc of a circle equal in length to the radius of the circle 1 rad = 57.3°.

Radiance	Measure of the energy radiated by an object. In general, radiance is a function of viewing angle and spectral wavelength and is expressed as energy per solid angle.
Radiant energy peak	Wavelength at which the maximum electromagnetic energy is radiated at a particular temperature.
Radiant flux	Rate of flow of electromagnetic radiation measured in watts per square centimeter.
Radiant temperature	Concentration of the radiant flux from a material. Radiant temperature is the kinetic temperature multiplied by the emissivity to the one-fourth power.
Radiation	Propagation of energy in the form of electromagnetic waves.
Radiometer	Device for quantitatively measuring radiant energy, especially thermal radiation.
Random line dropout	In scanner images, the loss of data from individual scan lines in a nonsystematic fashion.
Range	In radar usage this is the distance in the direction of radar propagation, usually to the side of the platform in an imaging radar system. The slant range is the direct distance from the antenna to the object, whereas the distance from the ground track of the platform to the object is termed the ground range.
Range direction	See look direction.
Range resolution	In radar images, the spatial resolution in the range direction, which is determined by the pulse length of the transmitted microwave energy.
Raster	The scanned and illuminated area of a video display, produced by a modulated beam of electrons sweeping the phosphorescent screen line by line from top to bottom at a regular rate of repetition.
Raster format	A means of representing spatial data in the form of a grid of DN, each line of which can be used to modulate the lines of a video raster.
Raster pattern	Pattern of horizontal lines swept by an electron beam across the face of a CRT that constitute the image display.
Ratio image	An image prepared by processing digital multi-spectral data as follows: for each pixel, the value for one band that is divided the value of another. The resulting digital values are displayed as an image.
Rayleigh criterion	In radar, the relationship between surface roughness, depression angle, and wavelength that determines whether a surface will respond in a rough or smooth fashion to the radar pulse.
Rayleigh scattering	Selective scattering of light in the atmosphere by particle that is small compared with the wavelength of light.
RBV	Return-beam vidicon.
Real-aperture radar	Radar system in which azimuth resolution is determined by the transmitted beam width, which is in turn determined by the physical length of the antenna and by the wavelength.
Real time	Refers to images or data made available for inspection simultaneously with their acquisition.
Recognizability	Ability to identify an object on an image.
Rectilinear	Refers to images with no geometric distortion in which the scales in the horizontal and vertical directions are identical.
Redundancy	Information on an image, which is either not, required for interpretation or cannot be seen. Redundancy may be spatial or spectral. The term also refers to multispectral data where the degree of correlation between bands is so high that one band contains virtually the same information as all the bands.
Reflectance	it. Spectral reflectance is the reflectance measured within a specific wavelength interval.

Reflected energy peak	Wavelength (0.5 μm) at which maximum amount of energy is reflected from the earth's surface.
Reflected IR	consists primarily of reflected solar radiation.
Reflectivity	Ability of a surface to reflect incident energy.
Refraction	Bending of electromagnetic rays as they pass from one medium into another when each medium has a different index of refraction.
Registration	Process of superposing two or more images or photographs so that equivalent geographic points coincide.
Relief	Vertical irregularities of a surface.
Relief displacement	Geometric distortion on vertical aerial photographs. The tops of objects appear in the photograph to be radially displaced from their bases outward from the photograph's center point.
Remote sensing	Collection and interpretation of information about an object without being in physical contact with the object.
Resampling	The calculation of new DN for pixels created during geometric correction of a digital scene, based on the values in the local area around the uncorrected pixels.
Reseau marks	
Resolution	Ability to separate closely spaced objects on an image or photograph. Resolution is commonly expressed as the most closely spaced line-pairs per unit distance that can be distinguished. Also called spatial resolution.
Resolution target	Series of regularly spaced alternating light and dark bars used to evaluate the resolution of images or photographs.
Resolving power	A measure of the ability of individual components. And of remote sensing systems, to separate closely spaced targets.
Reststrahlen band	In the IR region, refers to absorption of energy as a function of silica content.
Return	In radar, a pulse of microwave energy reflected by the terrain and received at the radar antenna. The strength of a return is referred to as return intensity.
Return-beam vidicon (RBV)	a vacuum tube; the image is scanned with an electron beam and transmitted or recorded. Landsat 3 used a pair of RBV's to acquire images.
Ringling	Fringe-like artifacts produced at edges by some forms of spatial-frequency filtering.
Rods	The receptors in the retina that are sensitive to brightness variations.
Roll	Rotation of an aircraft that causes a wing-up or wing-down attitude.
Roll compensation system	Component of an airborne scanner system that measures and records the roll of the aircraft. This information is used to correct the imagery for distortion due to roll.
Rough criterion	In radar, the relationship between surface roughness, depression angle, and wavelength that determines whether a surface will scatter the incident radar pulse in a rough or intermediate fashion.
Roughness	In radar, the average vertical relief of a small-scale irregularities of the terrain surface. Also called surface roughness
RMSE (Root Mean Square Error)	The RMSE statistic is used to describe accuracy encompassing both random and systematic errors. The square of the difference between a true test point and an interpolated test point divided by the total number of test points in the arithmetic mean. The square root of this value is the root mean square error.
S	
SAMII	Stratospheric Aerosol Measurement experiment, carried by Nimbus-7.

SAMS	Stratospheric and Mesospheric Sounder, carried by Nimbus-7.
SAST (Scientific Assessment and Strategy Team)	SAST is an interdisciplinary team of senior scientists and engineers from various Federal Government agencies assigned to assess and report on the damage caused by the flood of 1993 and to provide assistance and advice to Federal officials responsible for making decisions with respect to the flood recovery in the Upper Mississippi and Missouri River basin.
Satellite	An object in orbit around a celestial body.
Saturation	In the IHS system, represents the purity of color. Saturation is also the condition where energy flux exceeds the sensitivity range of a detector.
SBUV	Solar Back-scatter Ultraviolet Instrument, carried by NOAA satellites.
Scale	Ratio of distance on an image to the equivalent distance on the ground.
Scan line	Narrow strip on the ground that is swept by IFOV of a detector in a scanning system.
Scanner	An imaging system in which the IFOV of one or more detectors is swept across the terrain.
Scanner distortion	Geometric distortion that is characteristic of cross-track scanner images.
Scan skew	Distortion of scanner images caused by forward motion of the aircraft or satellite during the time required for scanning completion.
Scattering	Multiple reflections of electromagnetic waves by particles or surfaces.
Scattering coefficient curves	Display of scatterometer data in which relative backscatter is shown as a function of incidence angle.
Scatterometer	Nonimaging radar device that quantitatively records backscatter of terrain as a function of incidence angle.
Scene	Area on the ground that is covered by an image or photograph.
Scotopic vision	Vision under conditions of low illumination, when only the rods are sensitive to light. Visual acuity under these conditions is highest in the blue part of the spectrum.
Seasat	NASA unmanned satellite that acquired L-band radar images in 1978.
Sensitivity	Degree to which a detector responds to electromagnetic energy incident on it.
Sensor	Device that receives electromagnetic radiation and converts it into a signal that can be recorded and displayed as either numerical data or an image.
Shaded relief	Shading added to an image that makes the image appear to have three-dimensional aspects. This type of enhancement is commonly done to satellite images and thematic maps utilizing digital topographic data to provide the appearance of terrain relief within the image.
Shuttle imaging radar (SIR)	L-band radar system deployed on the Space Shuttle.
Sidelap	Extent of lateral overlap between images acquired on adjacent flight lines.
Side-looking airborne radar (SLAR)	An airborne side scanning system for acquiring radar images.
Side-scanning sonar-	Active system for acquiring images of the seafloor using pulsed sound waves.
Side-scanning system-	or orbit path but offset to one side.
Signal	Information recorded by a remote sensing system.
Signal to noise ratio (S/N)	The ratio of the level of the signal carrying real information to that carrying spurious information as a result of defects in the system.
Silver halide	Silver salts that are especially sensitive to visible light and convert to metallic silver when developed.
SIR	Shuttle Imaging Radar, synthetic-aperture radar experiments carried aboard the NASA Space Shuttle in 1981 and 1984.

Skylab	U.S. Earth-orbiting workshop that housed three crews of three astronauts in 1973 and 1974.
Skylight	Component of light that is strongly scattered by the atmosphere and consists predominantly of shorter wavelengths.
Slant range	In radar, an imaginary line running between the antenna and the target.
Slant-range distance	Distance measured along the slant range.
Slant-range distortion	Geometric distortion of a slant-range image.
Slant-range image	In radar, an image in which objects are located at positions corresponding to their slant-range distances from the aircraft path. On slant-range images, the scale in the range direction is compressed in the near-range region
SLAR	Side-looking airborne radar.
SMIRR	Shuttle Multispectral Infrared Radiometer, a non-imaging spectroradiometer carried by the NASA Space Shuttle covering ten narrow wavebands in the 0.5-2.4 m range.
SMMR	Scanning Multichannel Microwave Radiometer, carried by Nimbus-7.
Smooth criterion	In radar, the relationship between surface roughness, depression angle, and wavelength that determines whether a surface will scatter the incident radar pulse in a smooth or intermediate fashion.
Software	Programs that control computer operations.
Sonar	Acronym for sound navigation ranging. Sonar is an active form of remote sensing that employs sonic energy to image the seafloor.
Space Shuttle	U.S. manned satellite program in the 1980s, officially called the Space Transportation System (STS).
Space Station	A planned series of three polar-orbiting, sun-synchronous satellites to be launched by NASA, the European Space Agency, and the Japanese Space Agency in the 1990s. They will carry a large range of remote-sensing devices.
Spatial-frequency filtering	The analysis of the spatial variations in DN of an image and the separation or suppression of selected frequency ranges.
Specific heat	The ratio of the heat capacity of unit mass of a material to the heat capacity of unit mass of water.
Spectral hue	A hue that is present in the spectral range of white light and is analyzed by a prism or diffraction grating.
Spectral reflectance	Reflectance of electromagnetic energy at specified wavelength intervals.
Spectral sensitivity	Response, or sensitivity, of a film or detector to radiation in different spectral regions.
Spectral vegetation index	An index of relative amount and vigor of vegetation. The index is calculated from two spectral bands of AVHRR imagery.
Spectrometer	Device for measuring intensity of radiation absorbed or reflected by a material as a function of wavelength.
Spectroradiometer	A device that measures the energy reflected or radiated by materials in narrow EM wavebands.
Spectrum	Continuous sequence of electromagnetic energy arranged according to wavelength or frequency.
Specular	Refers to a surface that is smooth with respect to the wavelength of incident energy.
SPOT	Système Probatoire d'Observation de la Terre. Unmanned French remote sensing satellite orbiting in the late 1980s.
Stefan-Boltzmann constant	$5.68 \times 10^{-12} \text{ W} \cdot \text{cm}^{-2} \cdot \text{K}^{-4}$.
Stefan-Boltzmann law	States that radiant flux of a blackbody is equal to the temperature to the fourth power times the Stefan-Boltzmann constant.
Stereo base	Distance between a pair of correlative points on a stereo pair that are oriented for stereo viewing.

Stereo model	Three-dimensional visual impression produced by viewing a pair of overlapping images through a stereoscope.
Stereo pair	Two overlapping images or photographs that may be viewed stereoscopically.
Stereopsis	The ability for objects to be perceived in three dimensions as a result of the parallax differences produced by the eye base.
Stereoscope	Binocular optical device for viewing overlapping images or diagrams. The left eye sees only the left image, and the right eye sees only the right image.
SSU	Stratosphere Sounding Unit, carried by NOAA-series satellites.
Subscene	A portion of an image that is used for detailed analysis.
Subtractive primary colors	Yellow, magenta, and cyan. When used as filters for white light, these colors remove blue, green and red light, respectively.
Sunglint	Bright reflectance of sunlight caused by ripples on water.
Sun-synchronous	Earth satellite orbit in which the orbit plane is nearly polar and the altitude is such that the satellite passes over all places on earth having the same latitude twice daily at the same local sun time.
Sun-synchronous orbit	A polar orbit where the satellite always crosses the Equator at the same local solar time.
Supervised classification	Digital-information extraction technique in which the operator provides training-site information that the computer uses to assign pixels to categories.
Surface phenomenon	Interaction between electromagnetic radiation and the surface of a material.
Surface roughness	See roughness.
Synthetic-aperture radar (SAR)	Radar system in which high azimuth resolution is achieved by storing and processing data on the Doppler shift of multiple return pulses in such a way as to give the effect of a much longer antenna.
Synthetic stereo images	Stereo images constructed through digital processing of a single image. Topographic data are used to calculate parallax.
System	Combination of components that constitute an imaging device.
Systematic distortion	Geometric irregularities on images that are caused by known and predictable characteristics.

T

Target	Object on the terrain of specific interest in a remote sensing investigation.
TDRS	Tracking and Data Relay Satellite
Telemeter	To transmit data by radio or microwave links.
Terrain	Surface of the earth.
Texture	Frequency of change and arrangement of tones on an image.
Thematic Data	Thematic data layers in a data set are layers of information that deal with a particular theme. These layers are typically related information that logically go together. Examples of thematic data would include a data layer whose contents are roads, railways, and river navigation routes.
Thematic Mapper (TM)	A cross-track scanner deployed on Landsat that records seven bands of data from the visible through the thermal IR regions.
Thermal capacity (c)	See heat capacity.
Thermal conductivity (K)	Measure of the rate at which heat will pass through a material, expressed in calories per centimeter per second per degree Centigrade.
Thermal crossover	On a plot of radiant temperature versus time, the point at which temperature curves for two different materials intersect.
Thermal diffusivity (k)	Governs the rate at which temperature changes within a substance, expressed in centimeters squared per second.

Thermal inertia (P)	Measure of the response of a material to temperature changes, expressed in calories per square centimeter per square root of second.
Thermal IR	IR region from 3 to 14 μm that is employed in remote sensing. This spectral region spans the radiant power peak of the earth.
Thermal IR image	Image acquired by a scanner that records radiation within the thermal IR band.
Thermal IR multispectral scanner (TIMS)	Airborne scanner that acquires multispectral images within the 8-to-14mm band of the thermal IR region.
Thermal model	Mathematical expression that relates thermal and other physical properties of a material to its temperature. Models may be used to predict temperature for given properties and conditions.
Thermography	thermograms, have been used to detect tumors and monitor blood circulation.
THIR	Temperature-Humidity Infrared Radiometer, carried by Nimbus-7.
Tie-point	used in the co-registration of images.
TIMS	Thermal IR multispectral scanner.
TM	Thematic Mapper.
Tone	Each distinguishable shade of gray from white to black on an image.
Topographic inversion	Ridges appear to be valleys, and valleys appear to be ridges. The illusion is corrected by orienting the image so that the shadows trend from the margin of the image to the bottom.
Topographic reversal	A geomorphic phenomenon in which topographic lows coincide with structural highs and vice versa. Valleys are eroded on crests of anticlines to cause topographic lows, and synclines form ridge, or topographic highs.
TOVS	
Tracking and Data Relay Satellite (TDRS)	Geostationary satellite used to communicate between ground receiving stations and satellite such as Landsat.
Training area	A sample of the Earth's surface with known properties; the statistics of the imaged data within the area are used to determine decision boundaries in classification.
Trade-off	As a result of changing one factor in a remote sensing system, there are compensating changes elsewhere in the system; such a compensating change is known as a trade-off.
Training site	Area of terrain with known properties or characteristics that is used in supervised classification.
Transmissivity	Property of a material that determines the amount of energy that can pass through the material.
Transparency	Image on a transparent photographic material, normally a positive image.
Transpiration	Expulsion of water vapor and oxygen by vegetation.
Travel time	In radar, the time interval between the generation of a pulse of microwave energy and its return from the terrain.
Tristimulus color theory	A theory of color relating all hues to the combined effects of three additive primary colors corresponding to the sensitivities of the three types of cone on the retina.
U	
Unsupervised classification	pixels to categories with no instructions from the operator.

UTM--Universal Transverse Mercator Projection	UTM is a widely used map projection that employs a series of identical projections around the world in the mid-latitude areas, each spanning six degrees of longitude and oriented to a meridian. This projection is characterized by its conformality; that is, it preserves angular relationships and scale plus it easily allows a rectangular grid to be superimposed on it. Many worldwide topographic and planimetric maps at scales ranging between 1:24,000 and 1:250,000 use this projection.
UV	wavelengths from 0.01 to 0.4m.
V	
Variance	A measure of the dispersion of the actual values of a variable about its mean. It is the mean of the squares of all the deviations from the mean value of a range of data.
VAS	Atmospheric Sounder, carried by GEOS satellites
Vector	Any quantity, which has both magnitude and direction, as opposed to scalar that has only magnitude.
Vector Data	Vector data, when used in the context of spatial or map information, refers to a format where all map data is stored as points, lines, and areas rather than as an image or continuous tone picture. These vector data have location and attribute information associated with them.
Vector format	The expression of points, lines, and areas on a map by digitized Cartesian coordinates, directions, and values.
Vegetation anomaly	Deviation from the normal distribution or properties of vegetation. Vegetation anomalies may be caused by faults, trace elements in soil, or other factors.
Vertical exaggeration	In a stereo model, the extent to which the vertical scale appears larger than the horizontal scale.
Vertical Positional Accuracy	Vertical positional accuracy is based upon the use of USGS source quadrangles, which are compiled to meet National Map Accuracy Standards (NMAS). NMAS vertical accuracy requires that at least 90 percent of well defined points tested be within one half contour interval of the correct value. Comparison to the graphic source is used as control to assess digital positional accuracy.
Vidicon	An imaging device based on a sheet of transparent material whose electrical conductivity increases with the intensity of EM radiation falling on it. The variation in conductivity across the plate is measured by a sweeping electron beam and converted into a video signal. Now largely replaced by cameras employing arrays of charge-coupled devices (ccds).
Vignetting	A gradual change in overall tone of an image from the center outwards, caused by the imaging device gathering less radiation from the periphery of its field of view than from the center. Most usually associated with the radially increasing angle between a lens and the Earth's surface, and the corresponding decrease in the light-gathering capacity of the lens.
Visible radiation	Energy at wavelengths from 0.4 to 0.7mm that is detectable by the human eye.
Visual dissonance	The disturbing effect of seeing a familiar object in an unfamiliar setting or in an unexpected color.
VISSR	Visible Infrared Spin-Scan Radiometer carried by the GOES satellites.
Volume scattering	In radar, interaction between electromagnetic radiation and the interior of a material.

W	
Watt (W)	Unit of electrical power equal to rate of work done by one ampere under a potential of one volt.
Wavelength	Distance between successive wave crests or other equivalent points in a harmonic wave.
Wien's displacement law	Describes the shift of the radiant power peak to shorter wavelengths as temperature increases.
WRS--Worldwide Reference System	The WRS is a global indexing scheme designed for the Landsat program based on nominal scene centers defined by path and row coordinates.
X	
X band	Radar wavelength region from 2.4 to 3.8 cm.
Y	
Yaw	Rotation of an aircraft about its vertical axis so that the longitudinal axis deviates left or right from the flight line.
Z	
ZENITH	Zenith is the point on the celestial sphere vertically above a given position or observer.
Zephyr	A Mediterranean term for any soft, gentle breeze.

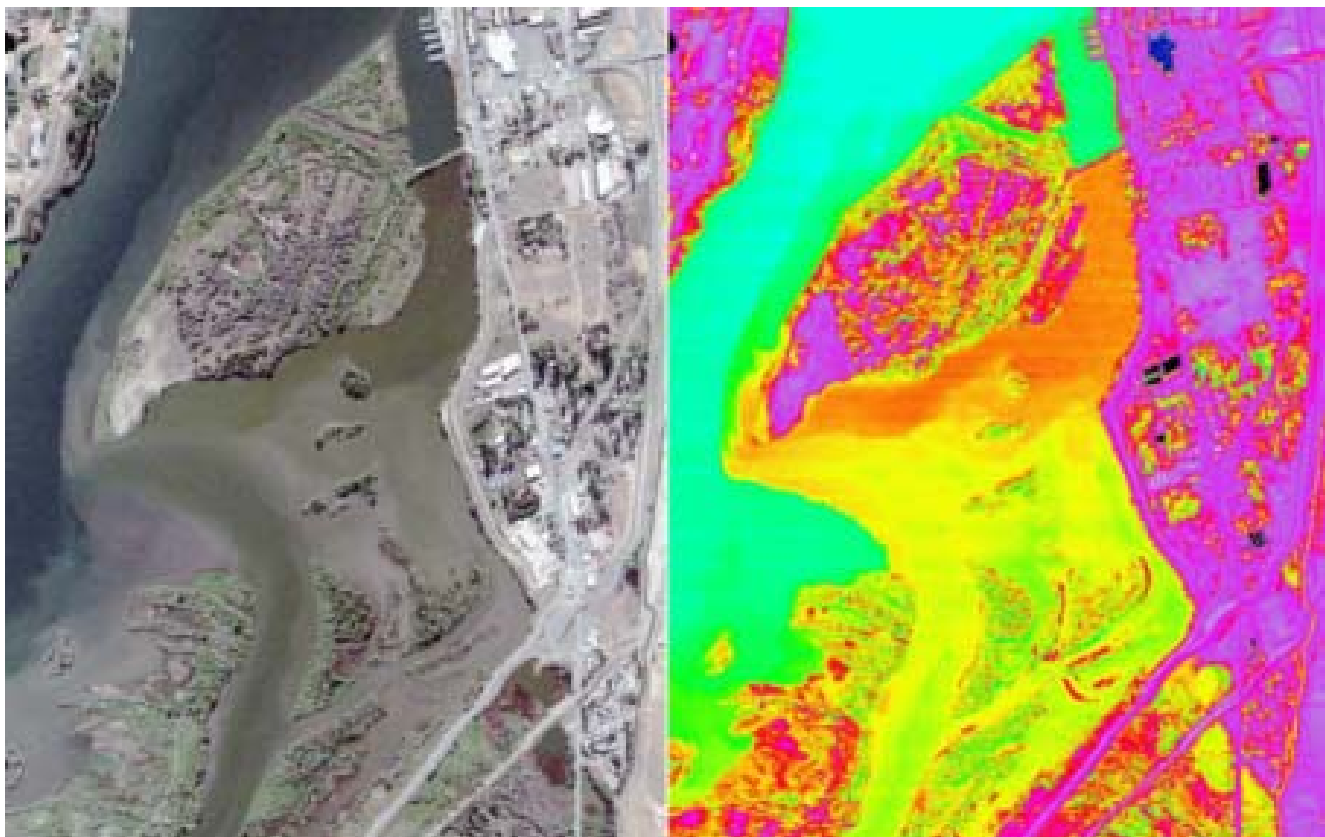
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RECLAMATION

Managing Water in the West

Series Report Number D-8260-05-05

Remote Sensing Technology: Guidelines and Applications within the Bureau of Reclamation



U.S. Department of the Interior
Bureau of Reclamation

September 2005

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Remote Sensing & Geographic Information Group, D882600

Technical Memorandum No. D-8260-05-05

Remote Sensing Technology: Guidelines and Applications with the Bureau of
Reclamation

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Abstract

Remote sensing might be defined as looking at something without touching it. Such a broad definition could also include weather radar views of precipitation and deriving earth interior structures from earthquake waves. Traditionally remote sensing includes looking at the Earth from aerial and satellite perspectives and interpreting the imagery, the perspective followed in this document. Topics include the physics of remote sensing, data sources, image processing, and preparation of data for inclusion in a geographic information system (GIS) for further analyses. A summary of former and current Denver Office remote sensing studies is appended to show the variety of possible topics.

Part I. Overview of Technology

1. *Glossary and Abbreviations*

The field of remote sensing and geographic information systems has accumulated a great number of technical words and phrases and acronyms. These are listed at the start of this report for reference and to help in understanding the later discussion.

Absorption: the removal of energy from the radiation spectrum.

Albedo: the percentage of incident light reflected from a surface. Equivalent to Reflectance.

Anti-solar point: the location from the viewer directly opposite the sun; the potential shadow location. The point on the sphere 180 degrees from the sun.

Aspect: the azimuth towards which a sloping surface is facing.

Attitude: the orientation of a viewing platform, such as an aircraft.

Azimuth: the horizontal orientation angle, 0 degrees = North, 90 degrees = East, etc.

Backscatter: the reverse deflection of radiation roughly towards the source.

Band: pertaining to a particular range of wavelengths.

Band combination: a set of bands used for visualization or computation.

Band ratioing: the division of an imagery band by another to reduce shadowing effects and enhance differences.

BGR: blue-green-red; an order of displaying color bands; opposite of RGB order.

Blackbody: a totally absorbing body that does not reflect radiation. Note: In thermal equilibrium, a blackbody absorbs and radiates at the same rate; the radiation will just equal the absorption when thermal equilibrium is maintained. This hypothetical body consists of a sufficient number of molecules emitting and absorbing electromagnetic radiation in all parts of the electromagnetic spectrum so that all incident radiation is completely absorbed and in all wavelengths bands and in all directions, maximum possible emission is effected.

CAD: computer aided design; a set of points, lines, polygons, shapes, text often without the rigorous topological rules of vectors.

Calibration: the adjustment of numerical values to a standard reference.

CIR: color-infrared, or false-color infrared A visualization that views the green, red, and near-infrared bands as blue, green, and red, often used in vegetation studies, where healthy green vegetation appears as bright red in the display or print.

Charge coupled device: (CCD) the type of light sensing device in digital cameras.

Clustering techniques: One pass, Fuzzy C Means, Minimum Distribution Angle, Adaptive resonance, K means, ISODATA, self-organization, etc.

Color style: the digital representation of colors, as 4-, 8-, 16-, 24-, and 32-bit numbers.

Cross-track scanning: the use of an imaging instrument whose view sweeps in a direction perpendicular to the forward motion of an aircraft or satellite viewing platform.

Data Base (DB): A computer-based management system for organizing data and descriptions.

DEM: digital elevation model, sometimes DTM, digital terrain model.

Differential Global Positioning System (DGPS): a GPS system that uses a base station for correcting and refining geographic positions.

DLG: digital line graph. Standard line vector product from the USGS.

DOQ, DOQQ: digital orthophoto (quarter)quad, a quadrangle version of an orthophoto.

DRG: digital raster graphic: an image of a scanned USGS topographic map including the collar information, georeferenced to the UTM grid.

Easting: a geographic coordinate east of some reference longitude.

Electromagnetic radiation: radiation made up of oscillating electric and magnetic fields and propagated at the speed of light. Includes gamma radiation, X-rays, ultraviolet, visible, and infrared radiation and radar and radio waves.

Elevation: (1) the height, usually above sea level. (2) the vertical orientation angle, 0 degrees = horizontal and 90 degrees = vertical.

Forward Fast Fourier Transform: the mathematical transformation of imagery into sinusoidal values of varying amplitude, frequency, and phase. Often used to start the removal of periodic noise in an image.

FLIR: Forward Looking Infra-Red. A sensor system for converting thermal imagery into television imagery.

Geographic Information System (GIS): a computer-based system for collecting, storing, retrieving, transforming, displaying, and analyzing spatial data.

Geostationary satellite: a satellite placed in an orbit about 22 thousand miles above the earth's equator such that its forward motion matches the rotation of the earth and it remains at a fixed longitude.

Global Positioning System (GPS): a system by which receiver equipment electronically monitors signals from a constellation of a couple dozen satellites to accurately determine the geographic position of the receiver in terms of latitude, longitude, and altitude.

Hyperspectral: imagery having dozens to hundreds of spectral bands at fine resolution.

IFSAR: interference synthetic aperture radar; a technique for analyzing radar imagery for fine detail.

Interference mode: a technique of analyzing radar imagery to reveal slight changes in elevation over time, such as those caused by tectonic and earthquake movements.

IR: infrared.

L1A and L1B: satellite imagery processing levels. L1A is essentially raw data. L1B is calibrated.

Lambertian reflector: a theoretical surface that reflects energy equally at all angles.

LIDAR: an instrument that determines distances by timing the return reflection of a laser beam.

Linear photodiode array: an imaging device whereby a scene is focused upon a line of photodiodes on an electronic microcircuit chip.

Mask: an image overlay whose numerical values specify the region of interest in other images.

Maximum likelihood classifier: an automated scheme of classifying pixels in an image based upon color resemblance to specified reference values.

Median filter: a numerical technique whereby a cluster, of specified extent, of adjacent pixels is examined for a median numerical value which is then placed in an output image at the cluster center. This removes the effects of extreme (noise) values.

Minimum distance to means classifier: an automated scheme of classifying pixels in an image by choosing the closest color match to specified reference values.

Mixed pixel: a color blending of numerous substances within the view of a single pixel.

Monochrome: sensed and displayed as intensity in only one spectral band; black & white.

Multispectral: having at least three spectral bands but usually less than ten.

Nadir: the location straight down from the viewpoint.

NIR: near infrared. The shortest wavelengths of the infrared region, nominally 0.75 to 3 μm .

Northing: a geographic position north of some reference latitude.

NTSC: a video format used in the USA and some other countries (PAL elsewhere). The code used to describe the United States system of color telecasting.

Othophoto: an image in which positional differences caused by the camera-landscape geometry, particularly by elevation, are removed by resampling. An orthophoto is a planimetrically correct image whereby features are in their true orthographic positions

PAL: "Phase Altering Line": a video format used in Europe and elsewhere, not in USA. Gathers data at a rate of 25 rather than 30 frames per second.

Panchromatic: same as monochrome, B&W, a single-band image.

Parallelepiped classifier: an automated scheme of classifying pixels in an image by partitioning band brightnesses at particular numerical ranges.

Pixel: smallest element of an image. Stands for “picture element”.

Planck’s Constant: the constant of proportionality (h) that relates the energy of a photon (E) with the frequency of the associated wave (η). where $h = 6.626 \times 10^{-34}$ joule•second.

Polarization: the forced orientation of the electric vector of electromagnetic energy.

Principal components analysis: a mathematical transformation of imagery data from a set of bands into the same number of bands but which are mathematically independent (orthogonal) of each other. The dominant variability appears in the first band (usually scene brightness) and the least in the last band (which appears as almost entirely noise). The transformation does not indicate the spectral causes of the resultant features, just that there is a significant difference.

Projection: any mathematical transformation of the globe onto some other usually flat surface.

Radiance: the spectral energy received by a sensor.

Raster: xy matrices of adjacent picture element values.

Rayleigh scatter: the scattering of radiation by very tiny aerosols and molecules in the atmosphere.

Remote Sensing (RS): the science the gathering of information about an object, area, or phenomenon through the analysis of data acquired by a device not in contact with them.

RGB: red-green-blue; also BGR for reverse order and R, G, B separately.

Reflectance: ratio of outgoing to incoming spectral energy. Also Albedo.

Resolution: the smallest distance represented by a single pixel.. It is minimum distance between two objects that a sensor can record distinctly.

SAR: synthetic aperture radar.

Scale: the ratio of a distance on a map or image to the real distance on the ground. Usually expressed in the form 1:5000, which is interpreted as 1 cm on the image represents 5000 cm on the ground, or in whatever units are preferred.

Signal to noise ratio: the strength of real data compared to noise values.

Spectrometer: a device that measures the intensity of radiation at different wavelengths.

Specular reflector: a mirror.

Stretching: the adjustment of a brightness distribution to a different range of values.

Supervised classification: a classification system by which a human analyst determines the classification of pixels.

SWIR: short-wave infrared. (1-3 μm).

Tasseled Cap: referring to the shape of a 2-dimensional distribution of pixel values (red and near-IR) of a scene containing vegetation.

TIN: triangular irregular network, a series of triangles often used to represent a continuous surface.

TIR: thermal infrared. Electromagnetic radiation emitted from the Earth's surface by all objects having a temperature warmer than absolute zero. Wavelengths in this range of the spectrum are within the infrared region, longer than 3 nanometers.

Training: the development of an automated classification system based upon known features and objects.

Transmissivity: the ratio of transmitted energy to the incoming energy.

Triangulation: the determination of positions by means of angles to other known positions.

Unsupervised classification: various automated classification systems.

UTM: Universal Transverse Mercator, a cylindrical, conformal projection system for generating maps of the curved Earth.

UV: ultraviolet. It is part of the electromagnetic spectrum that lies at wavelengths shorter than the violet range of the visible spectrum. The ultraviolet spectrum has wavelengths between 100 and 400 nanometers (nm).

Vector: a set of points, lines, polygons, and nodes used to describe feature locations, but with rigorous topological rules.

VNIR: visible and near infrared.

Wien's Displacement Law: For a blackbody, the product of the wavelength corresponding to the maximum radiance and the thermodynamic temperature is a constant. As a result, as the temperature rises, the maximum of the radiant energy shifts toward the shorter wavelength (greater frequency and energy) end of the spectrum. $\lambda_m = A/T$ where λ_m is the wavelength of maximum spectral emittance, $A = 2898 \mu\text{m}^\circ\text{K}$, and T = temperature, $^\circ\text{K}$. Thus, the wavelength of maximum emitted radiation is inversely proportional to the absolute ($^\circ\text{K}$) temperature.

Zenith: the location straight up from the viewpoint.

2. Physics of Remote Sensing

Remote sensing (RS) can be considered to have its origins in the 1800s with photography, though it was originally confined to views from the Earth's surface towards objects in the distance. The growing availability of aerial platforms in the 1900s provided vertical views of the Earth. Such were used primarily for general mapping and for military purposes. Altitudes for RS cameras can range from hand-held close-ups to balloons and aircraft as high as in the stratosphere. The second half of the 1900s introduced space-borne platforms for viewing the Earth. Weather satellites led the way, showing the organized cloud patterns around the globe. That was followed by satellites viewing the Earth surface at increasingly fine resolutions, though coarse resolutions are still appropriate for some global mappings.

RS generally examines objects, areas, and phenomena using the electromagnetic spectrum (Fig. 1; gamma, X-rays, ultraviolet, visible, infrared, thermal IR, microwave, radio), with wavelengths ranging by many orders of magnitude.

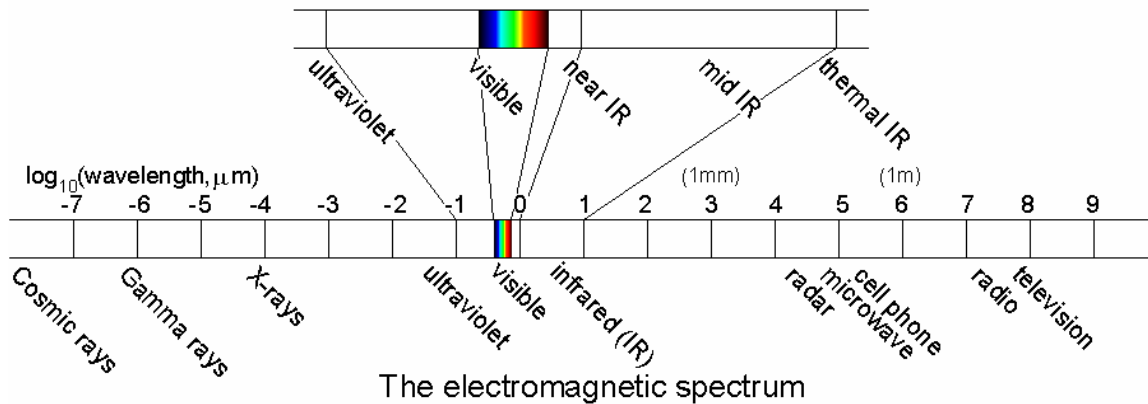


Fig. 1. The electromagnetic spectrum wavelengths cover many orders of magnitude.

The visible part of the spectrum is relatively narrow. The energy emitted by a theoretical black body has a distribution described by Planck's Law (Fig. 2), and the location of the peak energy is described by Wien's Law. As a substance becomes hotter, it emits more energy at all wavelengths, but the increase is greater at shorter wavelengths. The integral of Planck's Law curves gives the total energy as proportional to the fourth power of the absolute (Kelvin) temperature. The energy from the sun gets diluted by the distance to the Earth.

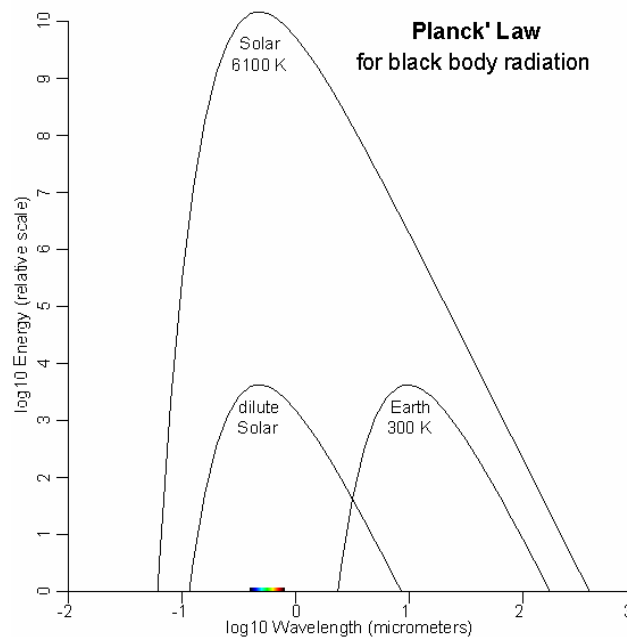


Fig. 2. Theoretical black body radiation from the Sun surface, diluted by distance to the Earth, and approximate radiation produced at Earth temperatures.

The total solar energy intercepted by some unit area is comparable to that emitted by a black body at a temperature of roughly 300°K and seen at close range. It is the balance of the incoming solar radiation and the outgoing Earth reflection and radiation that maintains a generally constant global temperature for the Earth.

The atmospheric gases absorb electromagnetic energy at chemically specific wavelengths, some of which are labeled in the darkened regions of Fig. 3 (adapted from <http://orbit-net.nesdis.noaa.gov/arad/fpdt/tutorial/absorb.html>). There are atmospheric “windows” (light regions of graph) which permit energy passage. The absorptions by these and other greenhouse gases keep the Earth significantly warmer than it would be without an atmosphere.

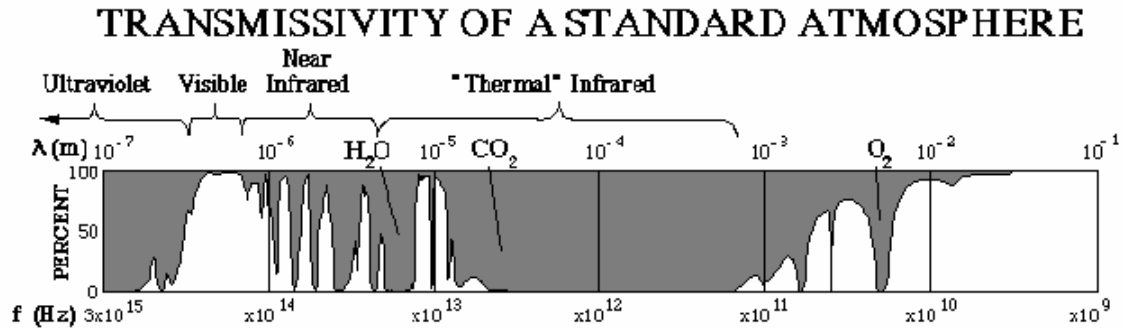


Fig. 3. Atmospheric absorptions of radiation.

RS need not be restricted to the electromagnetic spectrum. Other RS measurement styles use gravity and/or magnetic fields to probe into the Earth’s surface in search of anomalies. RS can use acoustic waves, such as sonar, earthquakes, and man-made sound pulses, to reveal objects and surfaces that are inaccessible by electromagnetic devices. However, this document will focus on electromagnetic-based of RS rather than these others.

Remote sensing detectors have greatly multiplied in types and spectral abilities, initially led by the field of astronomy and astrophysics. Photographic response to light intensity is logarithmic and even non-linear on the logarithmic scale. Photographic response starts in the near-infrared (NIR) and extends through the visible wavelengths to ultraviolet (UV) and x-rays. Electronic substitutes for photography provided linearities in signals, better sensitivities, and especially data in both longer and shorter wavelengths that are not accessible to photography. Detectors increased from single elements (photocell and photodiode scanners) to linear arrays (“pushbroom” scanners) to 2D arrays (digital cameras). The electronic data are most convenient for computer processing.

RS can be passive or active. Passive RS means that the electromagnetic radiation emitted or reflected from a surface is recorded. Examples are photography, videography, electronic cameras and some microwave devices. The sun is the usual illuminator for visible and near infrared (VNIR) bands. Thermal emission provides the signal at typical earth temperatures, mostly at thermal infrared (TIR) wavelengths of roughly 10 micrometers. Fires are easily detected at the short wave infrared (SWIR) wavelengths (roughly 3 to 5 micrometers).

Active means that the RS system illuminates its target and records the returning radiation. Examples are radar, LIDAR, and fluorescence. The latter anticipates that a surface will emit radiation in a longer wavelength (lesser energy) than that of the illumination.

Technologies have allowed an increase in spectral resolution. Monochrome (panchromatic) provides imagery in shades of gray, such as black-and-white photography. Traditional color imagery is produced by three bands, usually Red, Green, Blue (RGB). Infrared color imagery is usually presented as CIR, where the sensor band sequence of NIR, red, green are displayed as RGB. Multispectral systems have 3 to several spectral bands of data. Hyperspectral systems usually have dozens to hundreds of spectral bands of fine resolution. The transition from multispectral to hyperspectral is not precisely defined.

Color

Color to our eyes is the reception of red, green, and blue bands of light energy. Our brain then interprets intermediate colors based upon the proportion of those three. Colors are not linearly related to wavelength; red (R), yellow (Y), green (G), cyan (C), and blue (B) are not equally spaced in the spectrum. Magenta (M) is not even the color of a particular wavelength. Tans and browns do not exist as particular wavelengths but are composites of the primary colors, forming a diagonal line in the spectrum, increasing from blue to red.

The composition of color varies, depending upon whether the color is created by light sources or by light-absorbing substances or surfaces (Fig. 4).

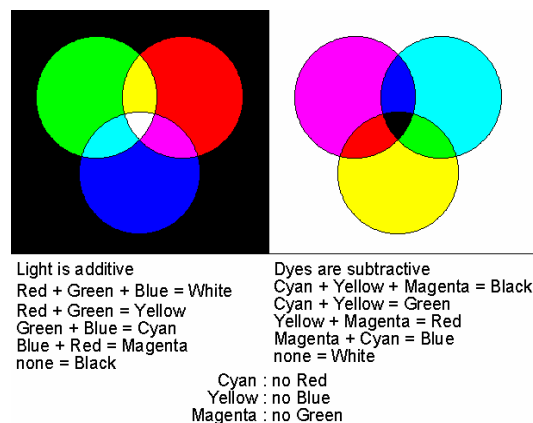


Fig. 4. Color combinations from light emitting and absorbing sources.

There are three primary colors for light sources, as provided by luminous bodies like the sun, lamps, and TV and computer screens: red, green, and blue. These combine in pairs to form yellow, cyan, and magenta. All three, of equal intensity, form white. The absence of all form black.

Dyes are examples of light absorbing substances. The three primary dye colors are yellow, cyan, and magenta. They may also be thought of as "not-blue", "not-red", and "not-green", respectively. They add in pairs to form red, green, and blue. All together make black. The absence of all makes white.

Color can also be defined as a combination (Fig. 5) of hue, intensity, and saturation (HIS). Hue defines a color on a circular scale of 0 to 360 degrees (or 0 to 255 to stay in the byte range). The six pure colors (B, M, R, Y, G, C, back to B) are at multiples of 60 degrees. Intensity indicates the brightness of the image pixel, ranging from black (0) to white (255). Saturation shows the richness of the color. A saturation of 0 produces a colorless grayscale according to the intensity value. A saturation of 255 produces a maximum of a pure color, shown in this illustration as green. The color fusion (pan sharpening) process, to be discussed elsewhere, allows a fine resolution panchromatic image to be colorized by a coarser 3-band color image. The color image is converted to HIS. The panchromatic image is substituted for the intensity. A revised color image is then calculated from the H, new I, and S.

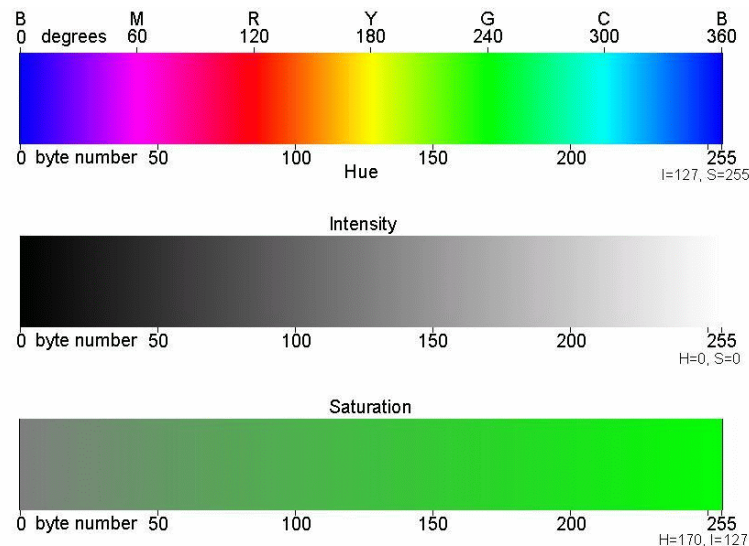


Fig. 5. The effects of color definition by hue, intensity, and saturation.

Sample Spectra

Photographic and eventually electronic recordings of the absorption spectra of thousands of substances, chemicals, and minerals were made over the past century for industrial and research purposes. Such spectra helped identify the presence of those specific substances in unknown materials. However, most plants have similar spectra; the differences are usually in the visible colors and caused by features such as flowers and autumn leaf colors that we can also see by our own eyes. Some common minerals have generally featureless spectra in the VNIR to SWIR range. Other minerals have spectra so unique that their presence in a mixture of substances can be readily detected. Fluorescence spectra are usually unique and can be excited by gamma, x-ray, and ultraviolet

illuminations. However, atmospheric absorptions of such illuminations restrict RS to very short observational distances. The following graphs were made using measurements from an ASDI Field Spectrometer - Full Range or gathered from similar spectra published by the USGS Spectral Laboratory. Those made using sunlight usually have noise bands from water vapor near 1.4 and 1.9 micrometers.

The following graphs show the spectra (horizontal axis: wavelength, 0.35 to 2.50 micrometers; vertical axis: reflectance) of several inorganic materials. Rocks and soils usually contain significant quantities of the quartz (Fig. 6) and feldspar (Fig. 7) minerals. Most have featureless spectra. However, some narrow bands, caused by water, can be seen in special minerals like opal. The bright carbonates (Fig. 8) have some distinctive narrow bands deep into the infrared. The copper carbonates show peaks in the blue and green. Various types of oxidized iron (Fig. 9) have a distinctive wide band in the very near infrared.

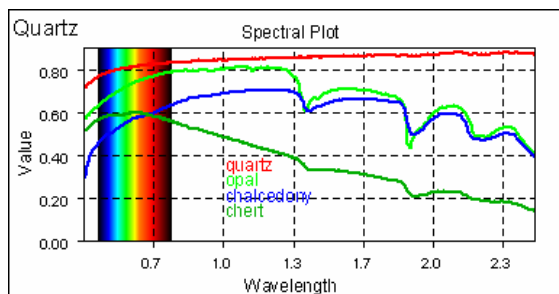


Fig. 6. Reflectance spectra of varieties of quartz minerals.

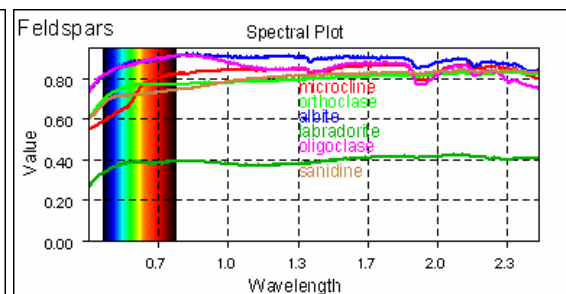


Fig. 7. Reflectance spectra of varieties of feldspar minerals.

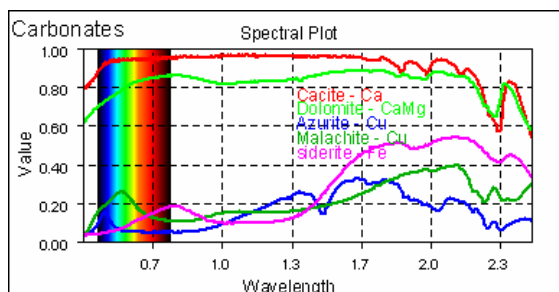


Fig. 8. Reflectance spectra of carbonate minerals.

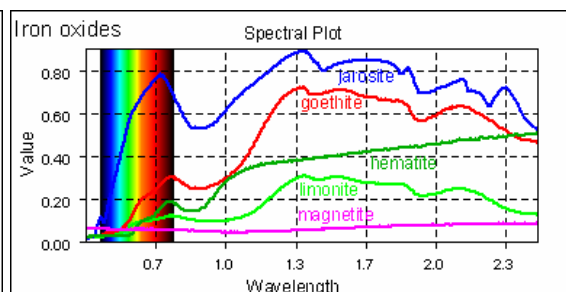


Fig. 9. Reflectance spectra of varieties of iron oxide minerals.

Some of the micas (Fig. 10) have a very narrow band in the middle of the spectrum. Feldspars and volcanic ash weather into the clays (Fig. 11), some of which are distinctive in their band shapes and placement.

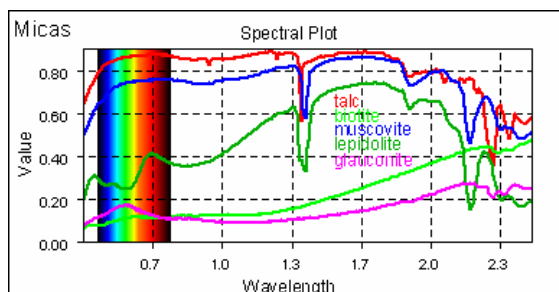


Fig. 10. Reflectance spectra of varieties of mica minerals.

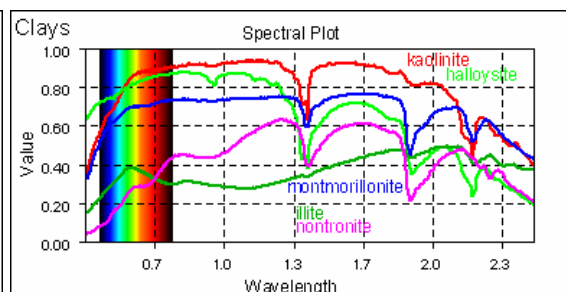


Fig. 11. Reflectance spectra of varieties of clay minerals.

Weather phenomena (Fig. 12) provide some special patterns. Blue sky becomes exponential in the blue to ultraviolet as a result of molecular scattering (the sky is pink on Mars because of scattering in the carbon dioxide atmosphere; Titan with a nitrogen and methane atmosphere has a different color). Such blue scattering and particle scattering from haze greatly degrade the remote sensing signal in the blue band. It is even worse in the near ultraviolet. In photography, a haze (meaning ultraviolet) filter is used to reduce the exposure of the blue band by ultraviolet scattering. Clouds, whether of water droplets or ice crystals, have multiple banding. Freshly fallen snow has deep black bands in the infrared.

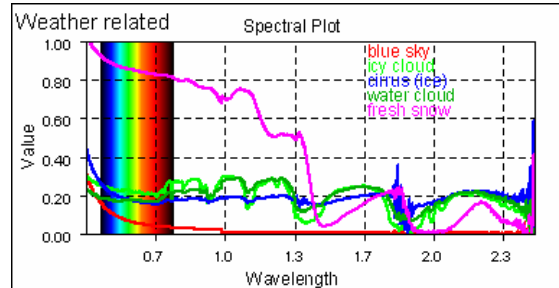


Fig.12. Reflectance spectra of weather related features.

Water (Fig. 13; note the vertical scale) strongly absorbs energy, especially in the infrared. (There is strong noise in the infrared caused by water bands in the atmosphere.) The colors in the visible and near infrared vary according to what is in or under the water.

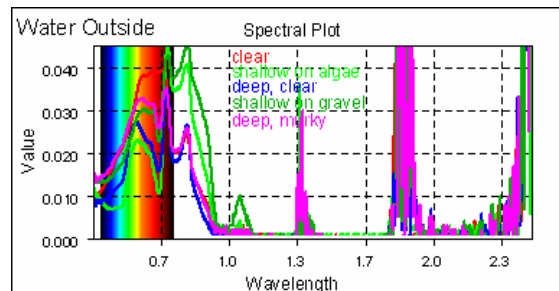


Fig 13. Reflectance spectra of water bodies.

Computer screens are light emission devices. Phosphorescent materials (Fig. 14) and light emitting diodes are made to glow. Liquid Crystal Displays (Fig. 15) shutter the light, while electrons control intensity of a CRT display. In both cases the ultraviolet light is much stronger than the green and red in order to get a similar intensity in the blue. Notice that the two different displays have different spectra. Both are dark in the infrared.

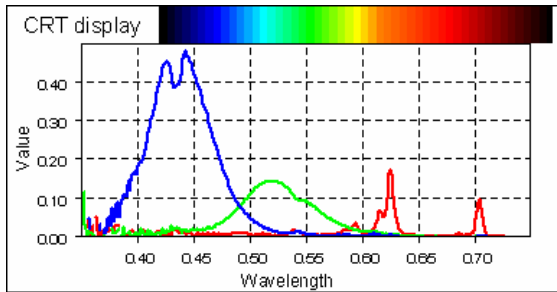


Fig. 14. Emission spectra of CRT computer display.

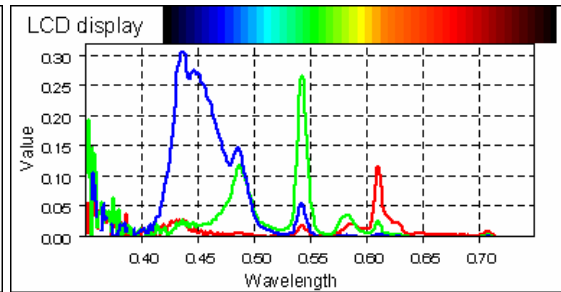


Fig. 15. Emission spectra of liquid crystal computer displays.

Green plants (Fig. 16) have a minor peak in the green wavelengths because chlorophyll strongly absorbs in the red. However, healthy green plants are very bright in the infrared. That enables their detection by false color infrared imagery. The main difference for plants is in the amplitude of the spectrum. Conifers are darker than deciduous trees. Grass is brightest.

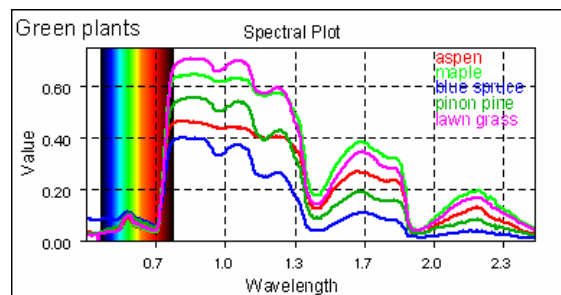


Fig. 16. Reflectance spectra of green plants.

Flower color variations (Fig. 17) are mostly in the visible wavelengths. Lichens (a combination of algae and fungus; Fig. 18), however, do not resemble green plants. Notice the wavy spectra in the infrared. The noxious wetland weed, purple loosestrife, can illustrate seasonal changes (Fig. 19). The green leaves look like most other green plants. The purple flowers have a special peak in the blue and ultraviolet, which makes them attractive to bees. Autumn makes the leaves dark red. Winter kills the foliage and makes it tan. Biocontrol insects seriously harm the health of purple loosestrife. As they chew greater percentages of the leaves there is a strong drop in brightness in the very near infrared (Fig. 20). Eventually the leaves turn a chocolate brown.

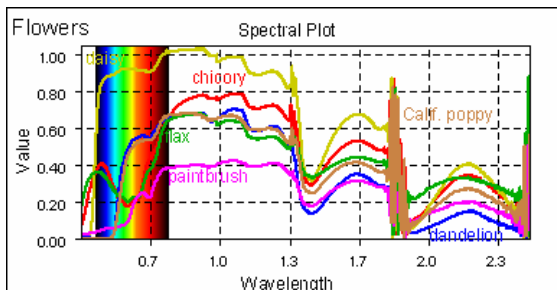


Fig. 17. Reflectance spectra of some flowers.

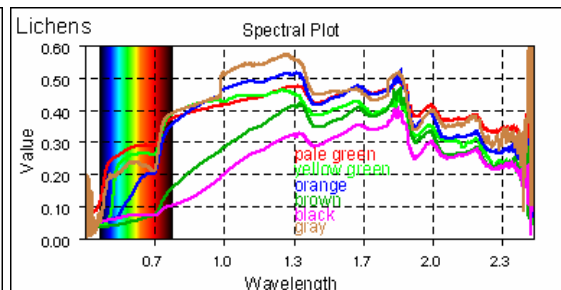


Fig. 18. Reflectance spectra of lichens.

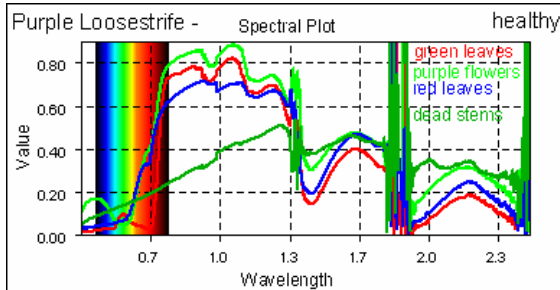


Fig. 19. Reflectance spectra of Purple loosestrife parts.

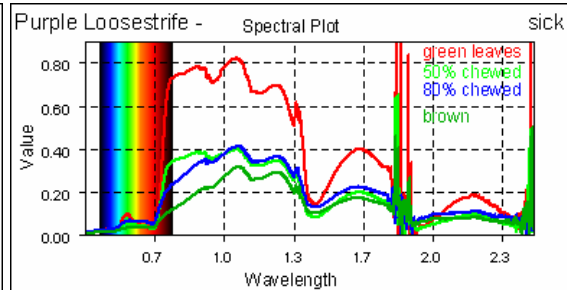


Fig. 20. Reflectance spectra of damaged purple loosestrife.

The spectra illustrated above were collected at about 2000 narrow wavelength intervals. Color photography collects in three broad bands: blue-green-red for natural color and green-red-NIR for false color infrared. Most Earth-observing satellites have similar broad-band sensors which must miss the very fine detail shown in these spectra. Special instruments aboard satellites, such as MODIS and ASTER, record 36 and 14 bands with some bands being broad and others narrow. Hyperspectral instruments are mostly mounted on aircraft. Apart from the limited view of the Hyperion hyperspectral instrument, satellite attempts have failed to become operational. Such instruments may have up to about 220 bands to record the spectral range illustrated in these graphs. The AVIRIS instrument is considered the best for hyperspectral work. Hyperspectral data need special techniques to remove atmospheric absorption effects from the spectra received at the sensor. A critical look at the graphs should show that hyperspectral data are excellent for a limited number of subjects but of no special additional value for others. Hyperspectral instruments produce such large volumes of data that computational time and storage considerations become huge and expensive.

Very fine spectral resolution also allows the determination of properties at increasing optical depths within a substance. The core of a spectral absorption band shows the top surface, while the “wings” of the band penetrate to greater depths. The weather satellites can use this technology for atmospheric properties, but it probably applies to water penetration as well.

All electronic media have a “mixed pixel” problem. That is a term that indicates that within the view of a single pixel there are many different objects with different spectral signatures. For example, a 30 meter pixel where a road is at a shoreline will have the road, water, bare soil, and vegetation all contributing to the signal of that pixel. This produces interpretation challenges, especially for automatic processing of scenes by computers. Some special techniques exist in several software packages to “unmix” the spectral signatures within hyperspectral pixels if a set of “end member” reference spectra are supplied to show the program what the pure target spectra look like.

Reflections and scattering

The incoming energy has many interactions on its way to the remote sensor. Though usually from the sun, this energy can come from the moon, lasers, and radars. The incident energy striking a surface divides into three components: absorbed, transmitted, and reflected. It is normally the reflected energy that is used in remote sensing.

All remote sensors record spectral energy, radiance, that actually gets to the sensor. This is usually different from the illumination of a scene and its reflectance (Fig. 21). The illumination may be scattered into direct and indirect, such as direct sunlight and diffuse light from the blue sky or from clouds. The surface can reflect, absorb, or transmit part of the illumination energy, usually with a spectral change. Energy coming from the surface can be absorbed or supplemented by atmospheric effects, such as haze and water vapor, or fully blocked, such as by clouds. Such processes often have a wavelength dependence. Precision remote sensing needs to account for all such processes that affect what actually is seen by the sensors.

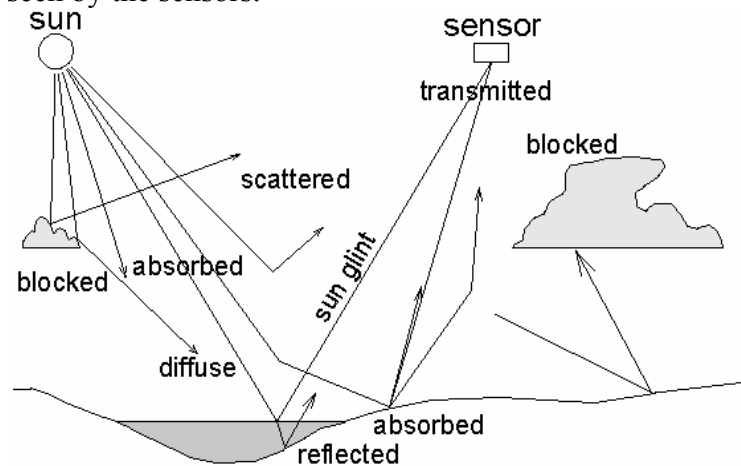


Fig. 21. Light can follow many paths on its way to the sensor.

The reflected energy may not follow traditional optical angles. An ideal specular reflector, such as a mirror, sends the energy at an angle of reflection equal to the angle of incidence. A near-perfect specular reflector, such as a wavy water surface, sends its energy at a variety of angles close to that of an ideal reflector. When a surface is mirror-like and positioned to reflect illumination into the sensor, sun glint often results, creating a bright spot (Fig. 22). Such sun glint can become a major problem in both aerial and satellite images.

The anti-solar point (at the potential shadow of the sensor on the imaged surface) and surrounding area is usually bright because of strong backscatter from most objects. Glass beads in paint provide the same effect for highway markers and signs. The illustration from the Winchester Wasteway, Washington, shows sun glint off calm water in the lower right and, opposite the nadir, a bright anti-solar spot in the upper left, where the sunshine is on sand dunes coated with volcanic ash from Mount St. Helens. Notice that the general ground is darker at the bottom of the image than at the top, creating challenges when

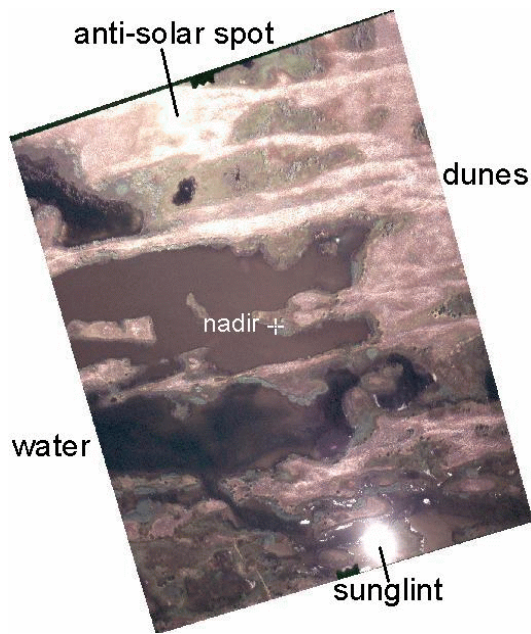


Fig. 22. Sun glint and anti-solar spot can appear bright.

mosaicking adjacent views and trying to match brightnesses. The solar illumination was uniform over the entire area, but the directional scattering was not uniform.

The anti-solar point is usually the brightest location in an image. Most substances preferentially reflect light back towards where it came from. Sometimes the shadow of the aerial platform (aircraft) can be seen at that location. The location at the opposite side of the image, through the image center, is sometimes the darkest location in the image. If trees are there, the camera sees not only the shaded side of the tree, but also its shadow. That same location is also the mirror position of the sun, producing a bright solar image on flat water surfaces. If the water has waves, a general sun glint is produced about the mirror position of the sun. The greater the amplitude of the waves, the greater the

lateral extent of the sun glint. Satellite views of the sun glint on ocean surfaces can estimate the amplitude of the waves for describing the state of the sea.

The ideal diffuse reflector (Lambertian) scatters the energy equally in all directions (Fig. 23). Most natural surfaces are not ideal. Instead there are energy peaks in the specular reflection direction and more so in the reverse direction to the incident energy. The latter causes brightening in a spot about the anti-solar point. In low altitude aerial photography there can be such brightening about the shadow of the aircraft. The effects of non-Lambertian surfaces appear as apparent non-uniform illumination when mosaics are made of aerial photographs.

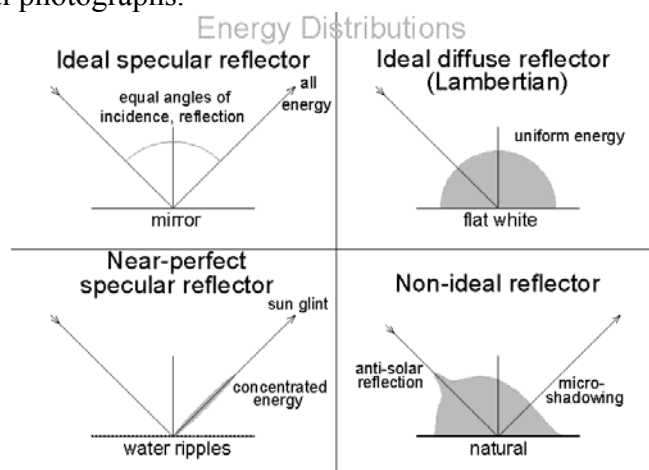


Fig. 23. Theoretical reflections seldom occur in nature.

In general, it is good to keep an open mind about what RS can do for a project. Technologies keep improving, allowing us to sense more and more phenomena at

increasing sensitivities and spectral resolutions. The traditional types of remote sensing, aerial photography and simple satellite imagery, are now being supplemented by many other types. The challenge is to determine the most appropriate technology for the task at hand. It may be “old” technology or something exotic.

Data Types

Image data are of two basic types, analog and digital. Analog data (Fig. 24) are continuously varying, such as the voltages in a photocell or optical density in photographic film. Analog data can be in either of three dimensions: point, line, or area. A prism or diffraction grating can split light into a spectrum for analog recording.

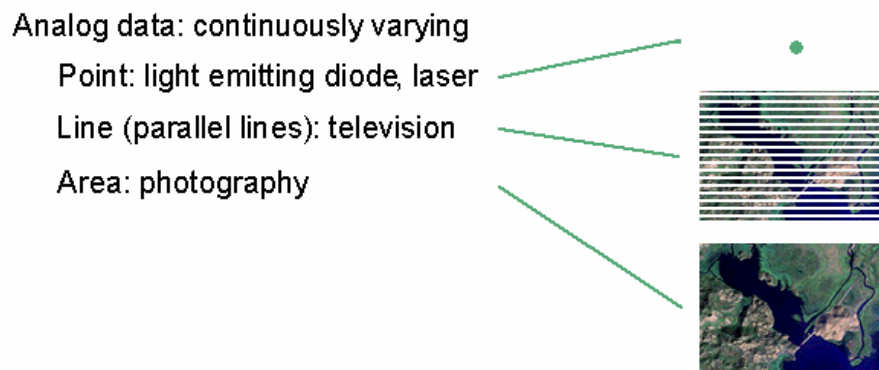


Fig. 24. Analog image data are continuously varying.

Digital data (Fig. 25) is quantized into integers for computer processing. The smallest image unit is known as a "pixel" or point picture element. It has a brightness value associated with it. Data can be recorded as monochrome (one color), multispectral (3 to a few colors), and hyperspectral (many colors). Data can be imaged as points, lines, and areas. Two-dimensional images can be made from single point sensors by cross-track scanning with forward motion. They can be made from line data (linear photodiode array) by forward motion perpendicular to the line. Digital cameras directly make two-dimensional images by use of two-dimensional array CCD (charge coupled device) sensors.

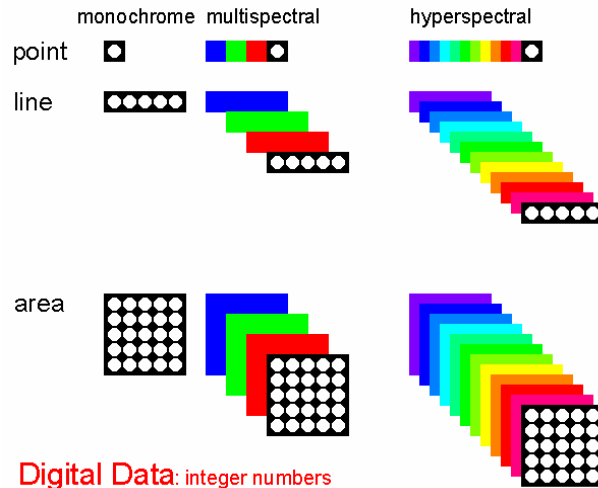


Fig. 25. Digital image data have specific numbers for each pixel.

Digital data can be quantized into any number of bits, or binary digits. Binary images have values of 0 and 1, black and white. Four-bit images have 16 levels of gray from black to white. Eight-bit (byte) images have 256 gray levels. 16-bit images have 65,536 gray levels.

Color images come in several types. Four-bit and eight-bit images have lookup tables assigning particular colors to the various integer numbers. 16-bit images usually have 5-bit (32 gray levels) shading for each of 3 colors (R=red, G=green, B=blue). 24-bit images have 8-bit (256 gray levels) shading for the 3 colors.

Resolution and scale

Resolution can be expressed, for digital images, as the pixel size. Weather satellite images can be as coarse as several kilometers per pixel. Aerial images and the newest generation of satellite images can achieve 1 meter pixels. Close-up photography can achieve sub-millimeter resolution if necessary.

Resolution is determined by a combination of three factors. First is the sensor system itself, such as the film grain size or the size of the CCD elements in a digital camera. Second is the optical system, expressed by the focal length of the lens.

Third is the altitude of the sensor above the subject. The resolution can be estimated in advance by simple trigonometry using similar triangles (Fig. 26). For detecting element size, d ; focal length, f ; and height, h ; the pixel size, p is given by $p = h * d / f$. Similar triangles can also be used to determine the total field of view of the image.

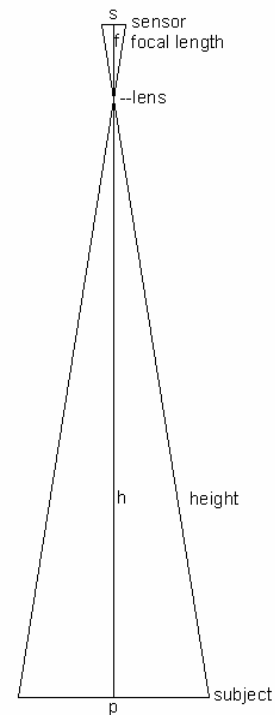


Fig. 26. Simple triangle for determining pixel size and view width.

A variety of surface resolutions are available from today's fleet of earth-observing satellites. Fig. 27 shows actual or simulated views, progressively zooming in on Henry Lake on the southwest side of Denver. In the upper left is a view of Colorado from a geostationary weather satellite (GOES) image, shown at 5 km resolution. It has the ability to do close-ups at 1 km. Next is a view from a polar orbiting weather satellite (NOAA-AVHRR) at 1 km resolution. An Indian satellite has a 2-band wide angle view at 180 meter resolution, useful for general vegetation mapping. The red band is simulated as the third image.

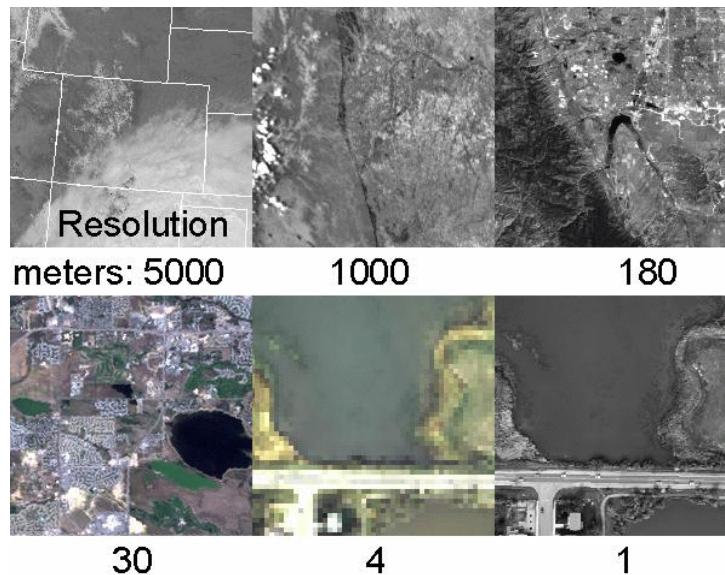


Fig. 27. A series of satellite views, at different resolutions, of Henry Lake, Southwest of Denver.

The Landsat TM series has 30 meter resolution in 6 bands (B,G,R, 2 NIR, and mid-IR) and a thermal-IR band of lesser resolution. The visible bands are displayed here in natural color.

The new high resolution satellites, IKONOS and Orbview-3, have 4 meter color in 4 bands: B,G,R, NIR. QuickBird has a similar camera, but a lower orbit gives it 2.4 meter color and 0.6 meter panchromatic resolution. The two lower rightmost views of the illustration show the same view of the south end of Henry Lake as simulated 4 meter color and 1 meter panchromatic.

The target in the Henry Lake study was an infestation of the invasive noxious weed purple loosestrife. The individual plants cannot be seen with even the finest satellite resolution. There is a “mixed-pixel” problem in addition to resolution; each pixel contains contributions of many items within the view - ground, grass, water, and other plants. Aerial photography might resolve the weeds but only if an appropriate resolution is selected.

Fig. 28 shows the same scene of a vertical view of flowering purple loosestrife at a series of simulated resolutions, differing by a factor of 2. The two lower rightmost views are enlargements of the upper left portion of the main view. The last view, at 0.5 mm resolution, shows a flower cluster, leaves, a dry seed stalk from the previous year (top) and a cattail seed head (lower left), in addition to dark views of the undergrowth. An analyst needs to select a resolution at which the presence of flowering purple loosestrife can be distinguished from other things in the view. A resolution of about 10 mm/pixel seems appropriate for presence identification but does not clearly resolve what else is in view.

Satellite resolution is fixed at specified values, such as 1 meter/pixel for panchromatic imagery from IKONOS and Orbview-3. Aerial resolution can be adjusted by the height

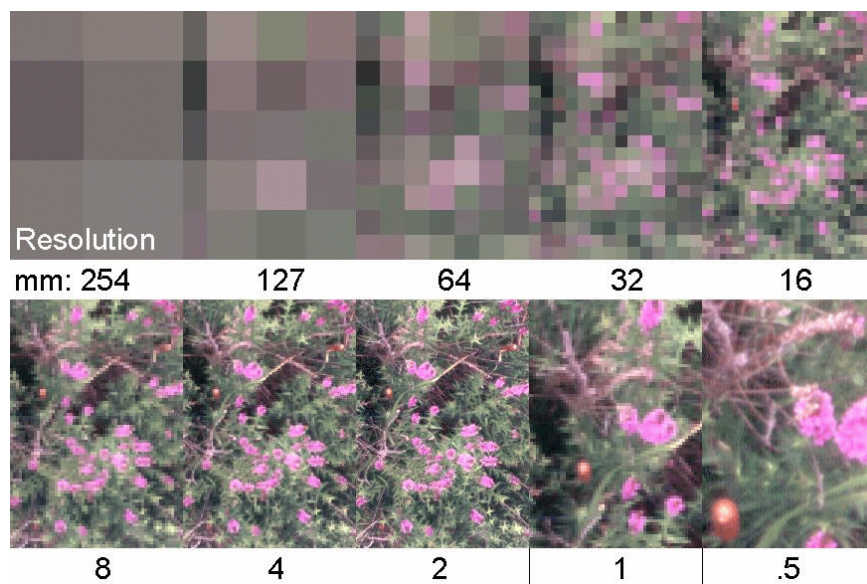


Fig. 28. A series of views of purple loosestrife flowers at different resolutions.

(altitude) of the camera above the surface, using a variation of the equation $p = h * d / f$ associated with the triangle of Fig. 26. For digital cameras the sensor resolution, d , is fixed and usually difficult to identify in the specifications. It may have to be calculated from the size of the CCD array and the number of pixels across its view. For photographic film that is scanned, the scanning resolution (usually in dpi - dots per inch = pixels per inch) is the inverse of d . Inserting the numbers into the equation then produces a need to carefully deal with the mixture of English and metric units! $(\text{dpi}) * (\text{pixel resolution}) * (\text{focal length}) = (\text{altitude})$ becomes $(\text{pixels/inch}) * (\text{meters/pixel}) * (\text{millimeters}) = (\text{feet})$ with the obvious need for conversion factors. In review, satellite resolution is fixed, aerial resolution can be adjusted by aircraft altitude, camera (digital or photographic) resolution can be adjusted by zooming or lens switch before picture acquisition, and scanned photographic film resolution can be adjusted by the scanner resolution up to the limit of film grain size. The resulting resolution is a solution of the available adjustments.

3. Data sources

Photography

Aerial imagery usually comes from photography, videography, and scanners. Traditional aerial mapping cameras use film as 9x9 inch frames and a 6 inch lens. The flight altitude in feet is then half of the scale number; 1:5000 scale imagery is flown at 2500 feet. Sometimes 35 mm photography is appropriate. Film types can be panchromatic (B&W), natural color, and CIR (false color). Photographic style can be negative (for positive prints) or positive (for transparencies). The transparencies usually have the greater resolution and color brilliance.

Film speed is important and interacts with shutter speed and diaphragm aperture for proper exposure and depth of view. Slow speed films have fine resolution while fast speed films are coarse grained. This is true for both panchromatic and color films. Therefore, using films which promote capabilities in situations with dim illumination results in a serious drawback of poorer resolution. Diaphragm apertures have settings, known as “f-stops”, that are on a logarithmic scale of powers of the square root of 2: 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32. The smaller numbers indicate wide open apertures and the larger numbers very narrow apertures. For a constant illumination, shutter speed increases by a factor of 2 must be compensated by f-stop changes to the next smaller number. The depth of field is the range of distances at which objects are in reasonable focus. As the f-stop number gets smaller, the depth of field gets narrower. Therefore, as illumination decreases and an f-stop is adjusted to compensate, the need for precise focusing becomes greater. Popular hand-held cameras rarely have such independent controls of shutter speed and f-stops. Full control of these features allow a photographer the options of having everything in focus, from nearby objects to infinity, or only a particular object in focus while things in the foreground and background are out of focus.

For aerial photography from great heights, aircraft motion has little effect. When flights are close to the ground (1:5000 or finer scales, for example) fast shutter speed or fast film speed become important. A camera with “forward motion compensation” is needed for such close-up work. Such cameras move the film during exposure at a speed that compensates for the aircraft speed. Though the image is moving within the camera, it stays at a fixed location on the moving film itself.

The new technology of digital cameras has recently become available. Imagery is recorded electronically instead of on physical film. Data are then already compatible with computer analysis. Imagery can be viewed and downloaded soon after acquisition. Resolution is not as good as film photography, but some cameras (such as about 4000 x 4000 pixels) are reasonable substitutes. Some expensive mapping cameras are becoming available which have a much greater number of pixels across the scene. The time between subsequent exposures is limited by the time to download an image to the storage device; it increases with image size. Various image compression techniques are offered with the better cameras to speed storage times and save storage space. Some digital

cameras are configured for CIR imagery. Numerous aerial imagery vendors are now offering digital imagery.

Videography

For some projects, videography offers an inexpensive RS system. Videotape is much cheaper than photographic film and can be viewed soon after acquisition. Home video cameras used to be of a quality that was inadequate for RS work. That was easily demonstrated by grabbing and viewing a single video frame. Imagery was grainy. A broadcast quality (expensive) camera is needed for most RS work. However, both cameras produce imagery of limited resolution. Though the computer might render an image as 480 x 640 pixels, the vertical part of the image is really made of roughly 350 lines. Furthermore, each frame is captured in a total of 1/30 sec, but in two halves. First, every other line is sampled in 1/60 sec. Then the camera captures the intervening lines in the next 1/60 sec. If there is forward motion of the scene, as from a camera pointing directly downward (at nadir) from a helicopter or aircraft, the movement will create offset duplication of scene features, as in a double exposure. The video capture system then needs to be instructed to capture only the first or second half (field) of the scan and duplicate it as the missing lines of the other 1/60 sec. That reduces the effective resolution even further.

Video systems in use in the USA and some other countries are in the NTSC format. Systems in Europe and many other countries use the PAL format. Though cassette tapes are physically identical, the data are so different that a PAL tape played on an NTSC machine does not produce anything visible on the display. This becomes a problem only if foreign projects are under consideration. Special equipment is required to convert between the video formats.

The half-inch video tapes common for home use are inferior to broadcast (3/4 inch) tapes in terms of image quality. The latter require special players to view. The use of the better tapes reduces the graininess of the video imagery, making it more suitable for remote sensing investigations. Recording media are rapidly improving and storage devices are becoming tiny. The image resolution and quality for the new systems have not yet been evaluated by our office.

A new technology of digital video is becoming available, promising greater quality of imagery and greater resolution, with recording onto much smaller tapes and devices. This may be the preferred system in the future. We are beginning to test the modern digital video cameras.

Scanners

A scanner views the Earth (or other scene) one to several lines at a time at an orientation perpendicular to the flight direction of the aircraft or satellite. One style of operation has

the view of the sensors mechanically moved along the line of examination, recording the variation of radiance reaching the instrument in various spectral bands. Another style is to have a linear array of detectors (“pushbroom”) that views the scene (a slit view) simultaneously. The array of detectors is interrogated sequentially for the radiance values at each location along the viewing line. Either style produces a stream of data, line by line, for recording. The forward movement of the platform provides the displacement for the perpendicular dimension in order to create 2-dimensional imagery. Scanners have been designed with variable numbers of spectral bands, from monochrome to multispectral to hyperspectral.

Satellites

Earth-observing satellites began with weather satellites in the 1960s. The AVHRR instrument on the modern NOAA weather satellites is additionally used for coarse (1 km) vegetation health mappings. The satellites were soon adapted to the Landsat series of polar orbiters in sun-synchronous, low-earth (LEO) orbits, gathering their images at about 10:30 a.m. each day at about 30 m resolution. Imaging technology grew from videography to multispectral scanners (MSS) to thematic mapper (TM, a better scanner), and subsequent enhancements. The French put up a series of SPOT satellites for land cover imagery. India then had a series, IRS, with a wide range of resolutions. Some other systems specialized in oceanic views (Orbview-2). The new trend is towards much finer resolution (4 m 4-band color, 1 m panchromatic or better) from IKONOS, QuickBird, and Orbview-3. The Terra satellite (10:30 a.m.) carries the MODIS (wide angle, coarse resolution, three dozen bands) and ASTER (14 bands, VNIR, SWIR, TIR, comparable to Landsat resolutions) instruments; the Aqua satellite (1:30 p.m.) carries another MODIS instrument.

The navigational satellites, GPS and the Russian and European equivalents, are in a middle altitude above the earth, with orbital periods of about a half day. They are not used for imagery. The geostationary imaging satellites, such as the GOES series are mainly used for weather surveillance, always viewing from the same position over the equator. Most geostationary satellites are used for communications of various types.

An important consideration is repeat coverage. The modern Landsat series images the same location every 16 days. Other satellites can be aimed off-nadir for more frequent views, such as every couple of days. Off-nadir viewing allows the creation of stereo pair imagery from which elevations can be derived. The several decades of Landsat coverage allow for change detection studies. However, that coverage will become reduced because of a component failure in Landsat-7 at the end of May 2003. Landsat-5 (launched March 1985), which still takes images well after its designed lifetime, can substitute for a limited time. There are several satellites using microwave energy. Those like Radarsat (and comparable European and Japanese satellites) and a few Shuttle flights operate(d) radar to measure surface topography and texture. They could view through clouds and operate at night. The latest Shuttle series has acquired topographic data for most of the earth. Radar is good at mapping flooded ground and oil slicks on water. Other satellites

passively measure falling rain or the water content of snow packs, though at coarse resolution.

The Civil Applications Committee is promoting use of Department of Defense satellites for government projects and studies. However, viewing of such products must be done in secure facilities and the analysts must have security clearance. More recent directives have suggested that commercial satellites be used whenever possible.

There are now dozens of past and present satellites with available data in the visible and infrared bands. Fig. 29 shows the spectral ranges and pixel resolutions of most of them. Our satellite remote sensing has traditionally used the Landsat series. The old satellites provided MSS data in 4 bands (green, red, two near-IR) with coarse pixels that were not square. The Thematic Mapper (TM) then provided 6 visible and infrared bands at 30 m resolution and a thermal band at 120 m resolution. Landsat-7 improved the thermal resolution to 60 m and provided a 15 m panchromatic band. However, Landsat

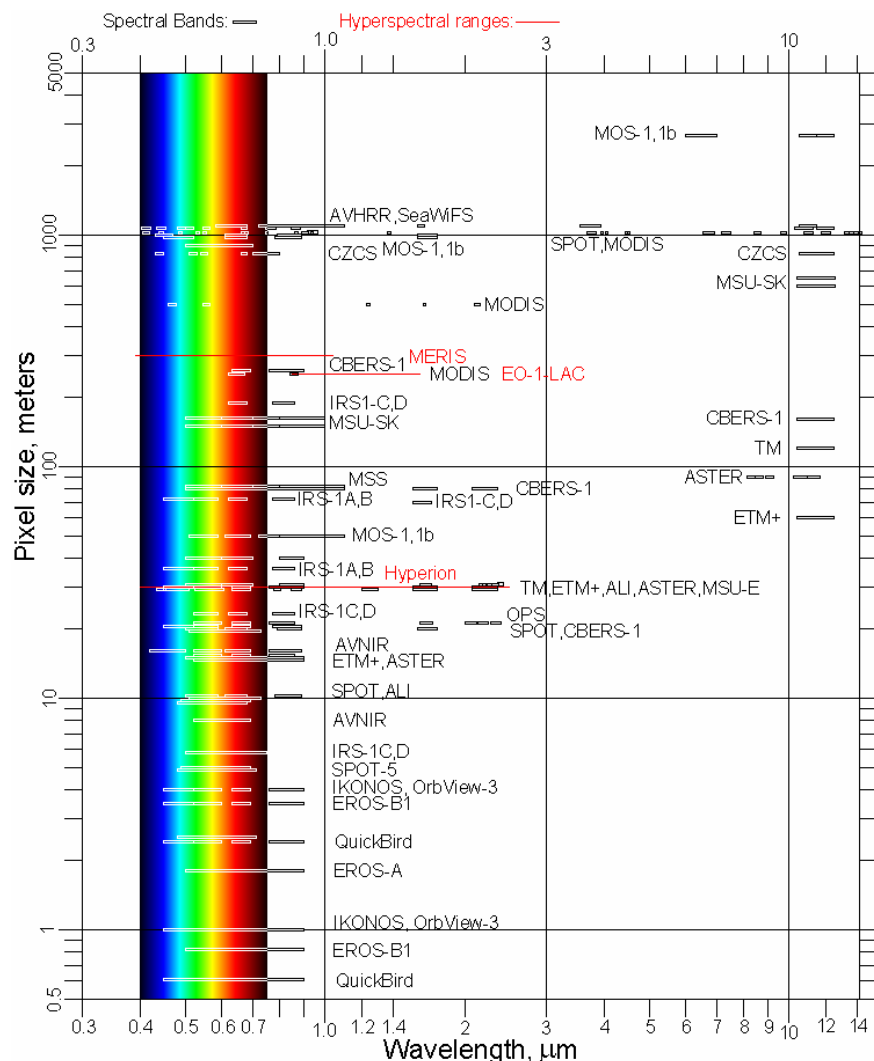


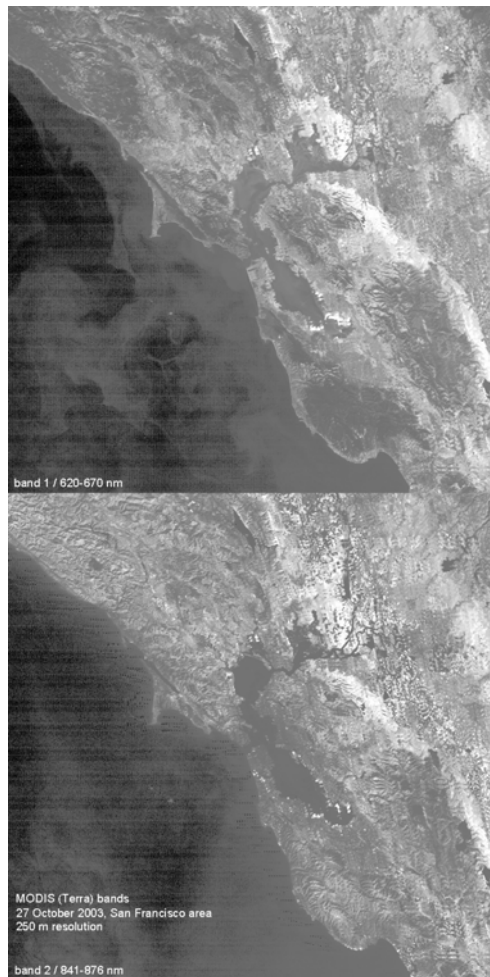
Fig. 29. A graph showing the spectral and pixel resolutions of various satellites.

data are becoming unreliable for future use. Landsat-5 is much older than design specifications. Landsat-7 has lost its scanning correction for getting its scan lines parallel with respect to the earth, creating gaps in coverage away from the orbital path. There is no good replacement when these satellites fail completely.

The EO-1 satellite, in orbit 1 minute behind Landsat-7, carries the ALI (Advanced Land Imager) camera which occupies only a quarter of the Landsat swath. It has more numerous bands in the visible to mid-IR, at much better signal-to-noise ratios than Landsat. However, there is no thermal band. The satellite also carries the Hyperion hyperspectral instrument with about 190 useful spectral channels (visible to short-wave-IR) but only a 7.5 km swath at 30 m pixel resolution.

We have made limited use of the French SPOT satellite system data. The latest SPOT-5 has a variety of resolutions from 1 km to 2.5 m in various wavelengths but no thermal imagery. The Indian IRS-1C and -1D and the new Resourcesat have resolutions near 180 m, 23 m, and 5.6 m, but without thermal imagery. Both satellites do not automatically take pictures but must be tasked for specific views.

The ASTER camera can be a good substitute for Landsat imagery, but it must be tasked for its views; it does not routinely take pictures. The 3 VNIR bands are at 15 m resolution, good for vegetation and cultural mapping. 6 SWIR bands are at 30 m resolution, possibly good for mineral mapping. 5 thermal IR bands can not only give temperature data (useful for evapotranspiration calculations) but can be manipulated to yield basic rock types: carbonate, silicate sands and shale, and igneous/metamorphic.



The MODIS camera on the Terra and Aqua satellites provides only coarse resolution of limited use to Reclamation needs. Some of the bands are designed for water penetration and are saturated over land and clouds. Some of the bands have excessive noise.

Three figures for the different resolutions are provided for viewing. The scene is of the San Francisco area on 27 October 2003, a date with extensive fires farther south. Fig. 30 shows the two bands at 250 m resolution. Fig. 31 shows the five bands at 500 m resolution. Fig. 32 shows the 29 bands at 1 km resolution. Notice the horizontal striping in the images, indicating that the elements in the sensor arrays are not

Fig 30. Two MODIS 250m band views of San Francisco area.

balanced. This striping becomes strong in some of the 1 km bands. Some of the 500 m bands show artifacts of dark ocean signatures below threshold. The top half of Fig. 32 is for reflective bands. Bands 13 and 14 are given in low and high gain versions. Bands 15 and 16 saturate on land. The lower half of Fig. 32 are emissive bands, sensing only the energy emitted by the earth's surfaces. Bands 27 and 28 do not see the ground. Band 36 seems worthless. All of the bands have georeferencing challenges that increase from the nadir (orbital path) sideways to the edge of the view.

Fig. 33 shows the Terra view of the Salton Sea, near the eastern edge of the view. The 250 m pixels are acquired in a swath of 40 pixels. The 500 m pixels are acquired in a swath of 20 pixels. The 1 km pixels are acquired in a swath of 10 pixels. When viewing near the nadir the swaths abut but do not overlap. Near the edge of the view, far from the satellite, the views expand greatly so that the swaths significantly overlap, as shown by the segmented view of the Salton Sea. This suggests that it may be better to get summarized and georeferenced data rather than the basic L1B data. In contrast, Fig. 34 shows the Aqua view of the Salton Sea 3 hours later, which was near-nadir. The Sea is larger in the figure because it is closer to the satellite. Image overlaps are difficult to detect in the Aqua view.

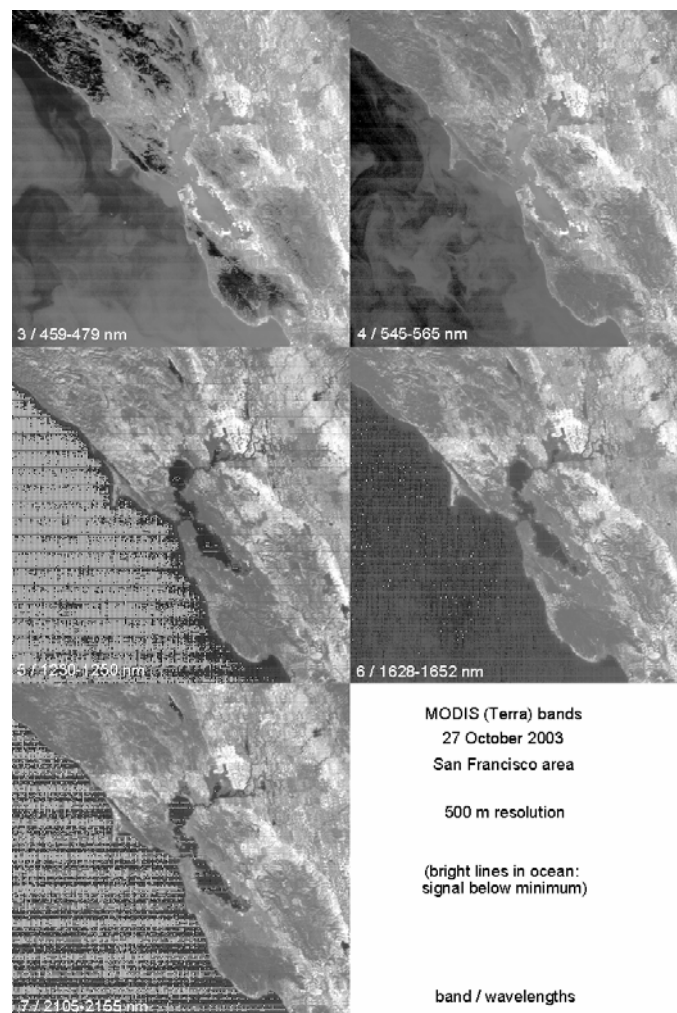


Fig. 31. The five MODIS 500m band views of the San Francisco area.

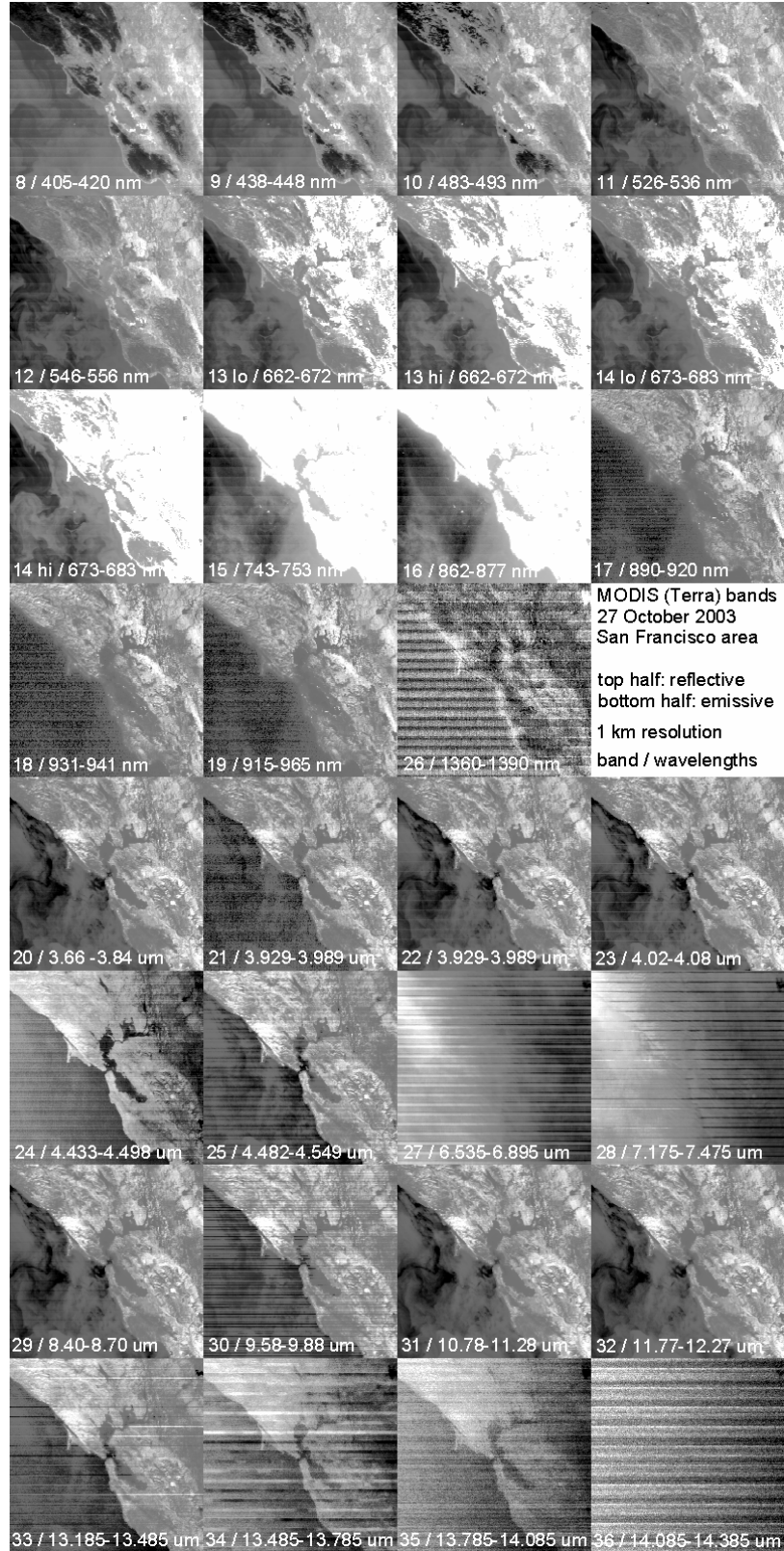


Fig. 32. The 29 MODIS KM band views of the San Francisco area.

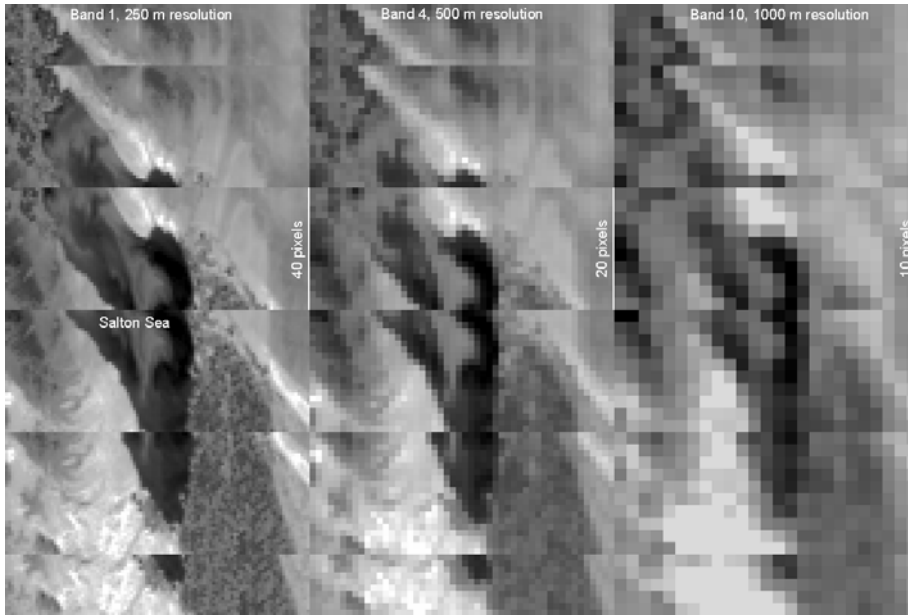


Fig. 33. The edges of the MODIS scans overlap.

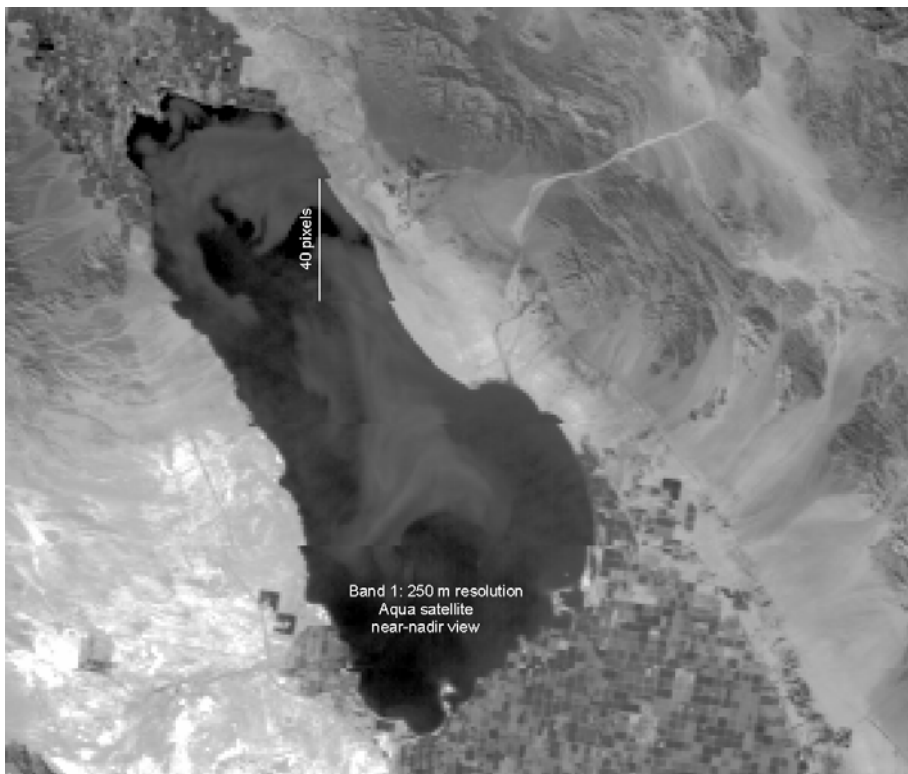


Fig 34. Objects are larger in the nadir view, with minimal scanning overlap

Radar

Radar involves illuminating a scene with pulses of radar energy. The timing of the reflection indicates the distance to objects in view. Radar beams are normally transmitted at a slant angle to the ground. Tall objects will appear closer to the radar unit than their

map position indicates. Terrain can block radar beams, causing shadows. The strength of the return signal indicates something of the nature of the surfaces. The orientations of the polarization of transmitted and returned energy give additional information about the surfaces. Mirror-like surfaces, like smooth water, return nothing. Geometric surfaces, like buildings, can act like corner reflectors, sending back a strong return pulse. Therefore there are interpretation challenges for raw radar data.

Radar has long wavelengths, compared to other parts of the electromagnetic spectrum. It therefore requires transmit and receive antennas comparable in size to the wavelengths. Larger antennas give greater focus to the radar beams, but large antennas may be too large to carry on aircraft and spacecraft. The solution is to continuously record radar data as the antenna is moved along to different locations. The technique is called Synthetic Aperture Radar (SAR), simulating a line with lots of antenna segments that, with computer processing, appear to be parts of one giant antenna. Most airborne and satellite radar systems are operated in such a mode. The Shuttle Radar Topographic Mission (SRTM) recorded elevation data for most of the earth. It has been processed to 1 arc-second (about 30 meter) resolution for continental USA and 3 arc-second resolution for the rest of the world except polar and ocean areas. Similarly, SAR data from different aerial flight lines can be used to produce digital elevation modes of the terrain.

For additional refinement, radar data can be analyzed in an interference mode. For example, data from different dates can be compared for minute differences, thereby indicating topographic changes from earthquakes and volcanoes and speeds of glacier flows.

Fig. 35 is from east of Yuma, Arizona, taken by the Radarsat-1 satellite. The brightness indicates the strength of the radar reflection. Hills in the lower right appear to lean eastward towards the satellite, as is typical for radar data. Agricultural patterns are visible near the Gila River.



Fig. 35. A Radarsat view of the hills east of Yuma, AZ degraded to Landsat resolution.

The enlargement of the river area (Fig. 36) shows more detail of roads, a railroad, the river, and fields. The hills are brightest on the east side, being illuminated from the east by the satellite.

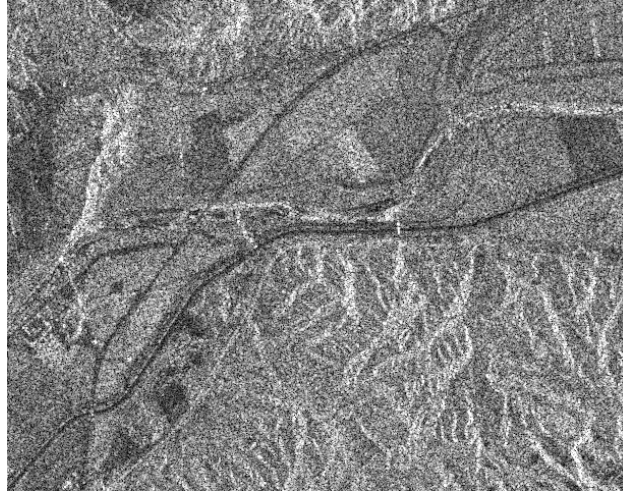


Fig. 36. A Radarsat view of the Gila River, full resolution.

The suburban area in Fig. 37 is strongly reflective, with the geometric buildings acting like corner reflectors. A limited access highway interchange is weakly visible in the center of the view. Street patterns contrast strongly with the buildings.



Fig. 37. A Radarsat view of housing east of Yuma.

Satellite radar imagery is valuable for mapping the extents of flooding. The area covered by water gives essentially no radar return, appearing black in intensity. This Fig. 38 scene is from the Red River flood, showing a region near the junction of Minnesota, North Dakota, and Manitoba. The scene is artificially colored with blue indicating the water areas. Using the section patterns of the fields indicates a flood roughly twenty miles across. Trees give a signal along the river corridor. Such evaluation of floods can be done day or night and through any kind of cloud cover. The satellite provides the illumination energy and clouds are transparent to the radar beam.

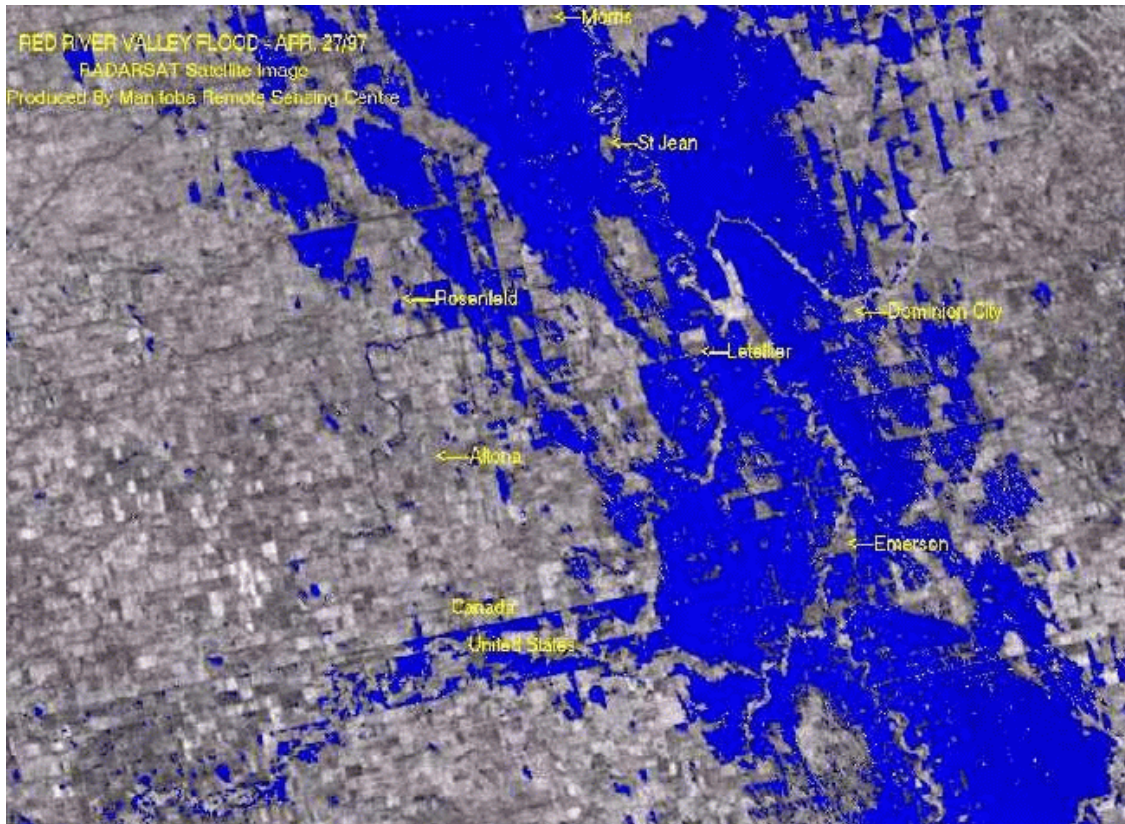


Fig. 38. A Radarsat view of the Red River floods, colorized blue.

LIDAR

Light Detection and Ranging (LIDAR) is another tool that many larger photogrammetric mapping companies have incorporated into their elevation data collection methods in recent years. LIDAR works in a similar way to radar: ranging based upon the speed of light. The beam can be focused to a more narrow point than radar. Both visible and infrared lasers are possible, but there is much atmospheric scatter for blue light. The sensors can receive back multiple reflections from a single pulse, indicating a succession of surfaces at increasing range or depth.

There are two basic types of LIDAR systems, one is used to collect topographic elevation data and the other is used for bathymetric data collection. There is even a hybrid LIDAR system that is supposed to be able to collect both topographic and bathymetric data simultaneously. Aerial use of LIDAR requires knowing precisely where the aircraft is located in 3-dimensions and its 3-axis orientation. An airborne LIDAR systems primary components are a focused infrared laser that emits laser energy pulses toward the ground by means of a scanning mirror, an interfaced inertial measurement unit (IMU), airborne GPS (global positioning system, likely differential), required hardware/software, and the expertise to make it all work properly. Quite often companies will pair a digital camera with the LIDAR system to capture digital imagery simultaneously.

LIDAR systems can capture tremendous amounts of point (x,y,z) coordinate data in a relatively short time frame. Currently many LIDAR systems can collect data at a 1-5 meter post spacing, with a horizontal point accuracy of 1-meter or less, and an expected vertical point accuracy in the range of 15-25 cm. LIDAR data can be collected in daytime or nighttime, and in overcast conditions (if the clouds are above the LIDAR system platform). However, good LIDAR data cannot be collected during adverse weather conditions such as snowstorms, rain, smoke, mist, and fog.

Laser altimetry operates with similar geometric considerations as across-track scanning. Objects away from nadir are seen increasingly from the side as the off-axis angle increases. Near nadir views can permit sometimes seeing the ground through a vegetative canopy, but that can become rare with off-nadir measurements. Bare-earth elevation data is what most Reclamation projects require. Most LIDAR contractors have developed algorithms to classify and remove vegetation, buildings, and other above ground features from the raw LIDAR data in order to produce the bare-earth elevation data. In some instances, such as vegetation/canopy height or infrastructure mapping the multiple-return LIDAR data is needed. However, keep in mind that LIDAR is not always a “silver bullet” solution to your elevation data needs. Contrary to what some contractors say LIDAR does not always penetrate vegetation cover and put the point on the ground, especially in dense vegetation conditions. In some cases the resulting bare-earth LIDAR data points may not have dense enough point spacing for applications such as hydraulic modeling. Just because you specify the LIDAR data be collected with a 2-meter post spacing, you’ll likely find the bare-earth post spacing in some places will exceed several times 2-meters. You will still end up with more data points being collected, more quickly, than with about any other method. Don’t be surprised if it falls short in some areas. Also remember that LIDAR systems collect “mass points” data, and not necessarily break line data. Your own application may require the collection of aerial photography or digital imagery, so that 3-D stereomodels can be setup on a stereoplotter or a photogrammetric workstation to collect breakline data for your elevation needs. Dense foliage adversely impacts photography and imagery; you can’t map what you can’t see.

Sample LIDAR data: All in feet, United States Plane 1983, Washington South.

Northing	Easting	Elevation(FT)
374333.5	5015936.6	1508.27
374324.3	5015935.8	1508.48
374321.9	5015934.9	1508.53
374383.3	5015860.4	1508.34
374384.0	5015856.7	1508.30
374378.8	5015852.6	1507.99
374372.2	5015855.4	1508.61
374296.8	5015864.0	1508.71
374276.2	5015879.3	1508.72
374295.3	5015862.5	1508.40
374295.3	5015861.6	1506.67
374272.5	5015879.9	1508.82

These successive records are of variable spacing, and a data set is likely to be many hundreds of megabytes in size. They can be imported as a 3-D vector set or as a surface.

The Fig. 39 orthophotograph is at Dry Falls, in central Washington state. LIDAR was used to accurately map the topography downstream for input to a model of water flows in case of dam failure. The LIDAR data in Fig. 40 were contoured at 1 foot intervals and are here overlaid on the orthophoto. Trees and buildings have been edited out of the data set.



Fig. 39. An orthophoto view of the Dam at Dry Falls.

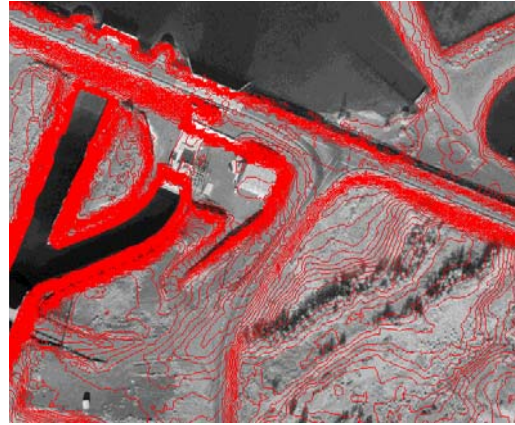


Fig. 40. LIDAR generated elevation contours at 1' resolution.

LIDAR instruments are also available for use on a tripod mounted on the ground. They can generate a fine scale array of 3D data points which can be edited to remove unwanted artifacts such as trees and other non-surface features. They also record the brightness of whatever the laser beam hits so that a B&W image of the scene can be created for reference.

The Bureau of Reclamation has also used bathymetric LIDAR. It was arranged by Robert Hildale who supplied these examples. The instrument was a Shoals 1000T manufactured by Optech. It was flown over the upper Yakima River in Washington State, where the water is very clear. Ground truth was provided by a physical probing of the river by poles, with GPS locations. In Fig. 41 the LIDAR provides many more data points (yellow) than the ground crew (blue points connected by a green line) and much more rapidly.

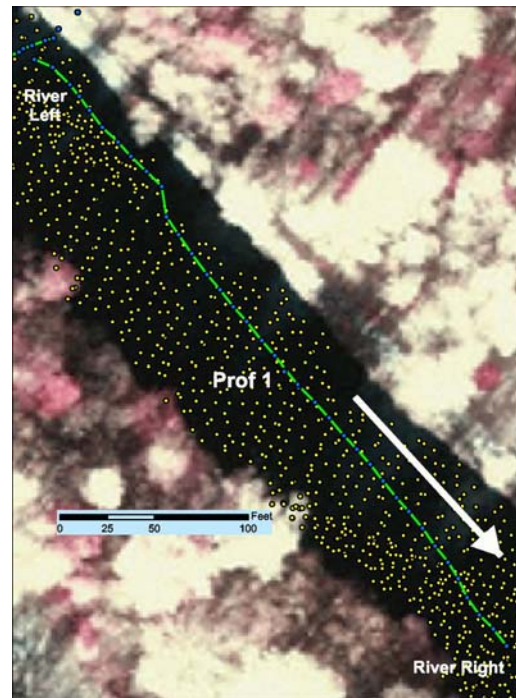


Fig. 41. The distribution of water depth measurements in Yakima River by wading survey and LIDAR.

A comparison (Fig. 42) of the two methods was made by selecting LIDAR points closest to the survey line and within a set distance. The LIDAR measurements are connected by the magenta line, the ground survey by the black line. Differences exist. An instrumental offset was discovered such that the LIDAR processing software needs some adjustments. Sometimes holes and submerged obstructions were discovered by the LIDAR but not the ground survey. It must also be remembered that the LIDAR works primarily in clear, not muddy water.

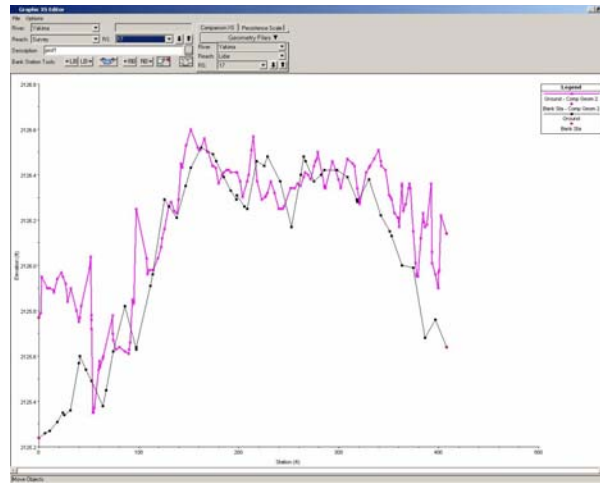


Fig. 42. The relation between hand measured water depths and LIDAR values.

Thermal

Thermal imagery is available from some airborne scanners or FLIR (Forward Looking InfraRed), and from satellites. Airborne scanner units may be of the Daedalus brand; the thermal band being just one of several wavelengths observed. FLIR instruments were developed for the military and police surveillance and produce a television format output of the thermal data, sometimes with an additional natural color video image of the same scene. Thermal images are affected by the diurnal curve. Water bodies have relatively slow and minor temperature changes as the day progresses. Soil and rocks have little thermal inertia and heat and cool rapidly. Therefore, water can be warmer than land near sunrise but strongly the reverse in the afternoon.

The Fig. 43 FLIR image from the canyon of the Little Colorado River shows the video (visual) view on the left and the thermal view on the right in the hours after sunrise. The shores of the river are dark in the thermal because the damp soil cools to the "wet bulb" temperature in addition to being cooler from overnight radiation loss. Therefore thermal remote sensing can sometimes give an indication of soil moisture. Dry rocks and soils are not as cool. Rock ledges are often visible because of differing thermal inertia from the surrounding rocks. In addition there is a flow of warmer water entering the river from a warm spring on the side, contrasting with the cool shores.

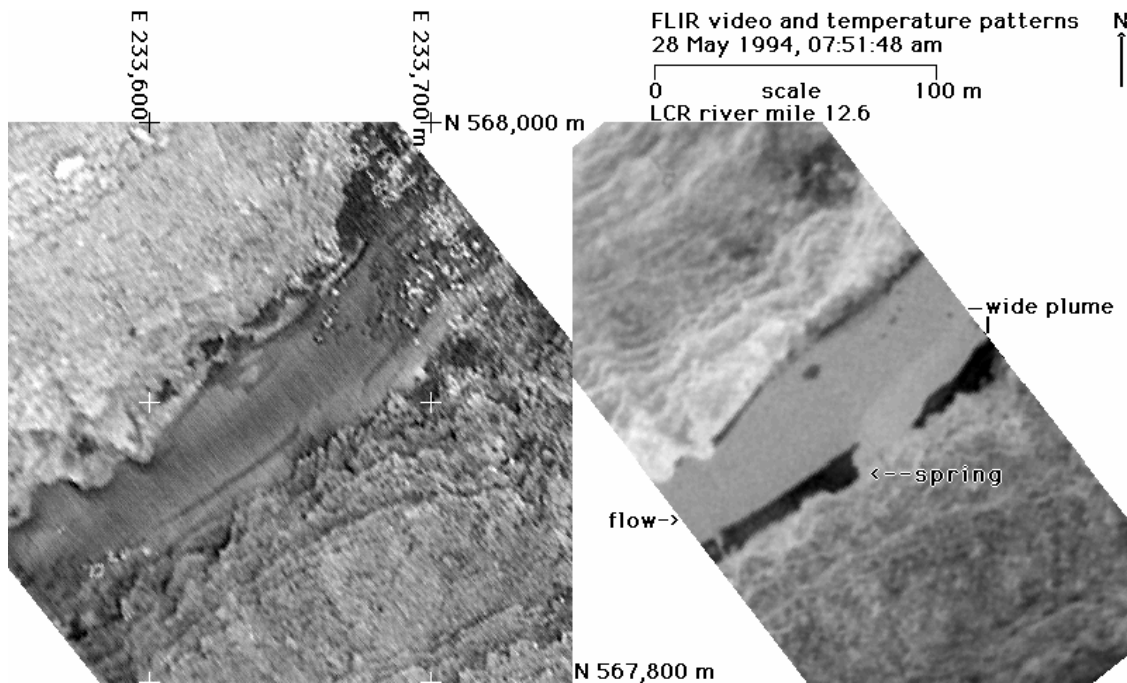


Fig. 43. An example of a hot spring in the Little Colorado River measured by FLIR in Visible and thermal wavelengths.

When properly calibrated, water temperatures can be measured to about 0.2 C precision. The Fig. 44 image is from the confluence of the Colorado River and the Little Colorado River. It was obtained with a FLIR instrument from a helicopter flight about 2500 feet above the river. The Colorado river (blues) is constantly cold, drawing its water from the bottom of Lake Powell behind the Glen Canyon Dam. The Little Colorado is about ten degrees C warmer (reds). It flows along the north edge of the sandbar, then starts to split its flow and rapidly merges into the turbulent and much colder Colorado River. The thermal pattern reveals the dynamics of the mixing waters.

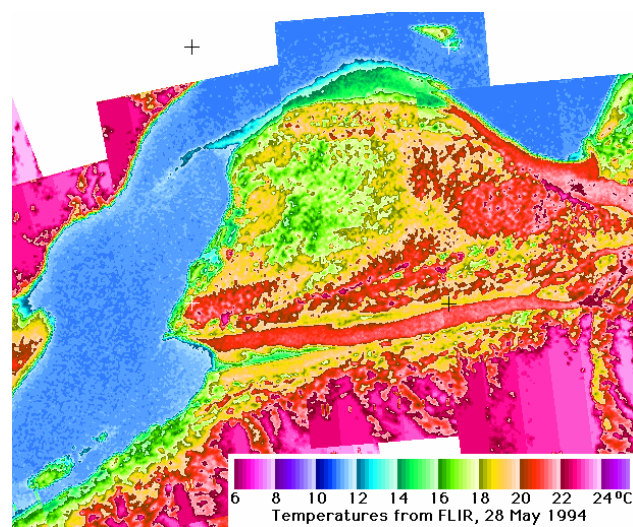


Fig. 44. FLIR thermal data colorized according to temperature.

A Daedalus scanner recorded 3 visible and 3 infrared (including thermal) bands at the confluence of the Columbia and Yakima Rivers in central Washington state. The visible scene is at the left of Fig. 45 and a colorized thermal scene is at the right. The river temperature patterns are strongly evident. The Columbia River (left) is cool (cyan) and mostly uniform. The Yakima river (bottom) is warm (green to orange), especially as it becomes shallow over mud flats near the large island. Thermal scanners can also determine the radiative temperatures of manmade objects, such as house roofs and power plants to see the thermal losses of energy or unusual emissivities. Many of the roofs in the right side of the view look unusually cool (dark blue) because emissivity.

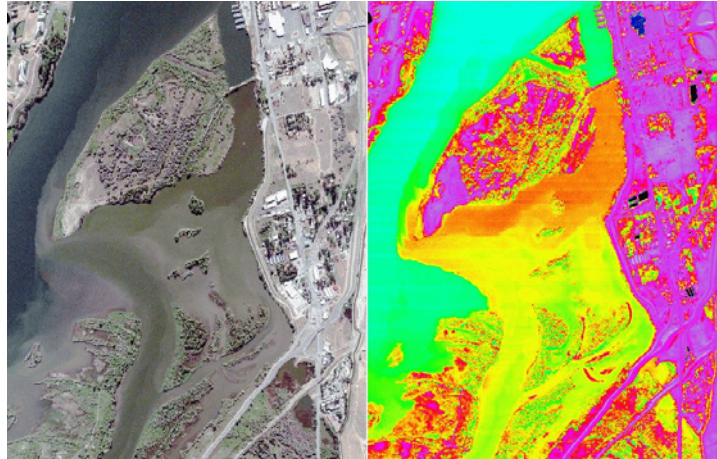


Fig. 45. The visible and thermal (colorized) views of the confluence.

Image geometry

The scale of a photograph is the ratio of the focal length of the lens to the height above ground. For example, a 6 inch lens flown at 2500 feet above ground gives a scale of 1:5000 on the film.

If the camera axis is not vertical, the center of the photograph will not be at the nadir and there will be distortions in the image, shown in Fig. 46, compared to a map view. If the off-nadir direction is parallel to one of the edges of the image, the camera will view flat terrain in the shape of a trapezoid. Otherwise the view will be a more complicated quadrilateral.

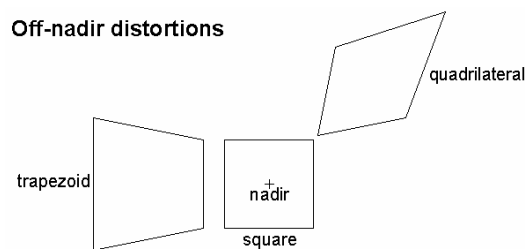


Fig. 46. Image distortions from off-nadir viewing.

Aerial photos are close to agreement with maps only if the subject is flat and the camera is pointed at the nadir. Where there are vertical displacements, the position of an object in the photograph will be displaced radially from its true position. Fig. 47 and the corner enlargements in Fig. 48 are from the Spring Creek development south of Buffalo Creek. Notice that the conifer trees are leaning back radially, with the greatest distortion at the edges. The scene also has vignetting: a darkening with distance from the center that is most severe in the corners.



Fig. 47. Radial leaning of conifer trees.

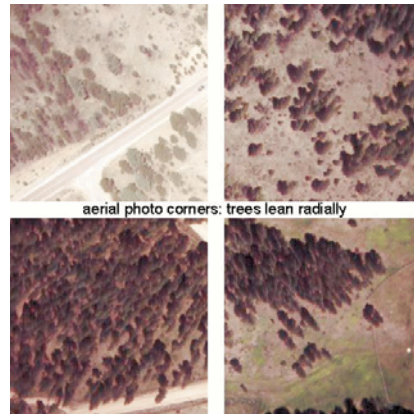


Fig. 48. Enlargements of the photo corners.

The apparent brightness of the scene varies across the view. The anti-solar point (upper left) is brightest. Some vegetation types reflect light back along the incoming path to a greater extent than in other directions. Furthermore there is a minimum of shadowing there. The maximum shadowing is seen in the opposite side (lower right, Figs. 47 and 48) of the photo; both the dark sides of the trees and their shadows contribute there.

Higher terrain causes the terrain to move radially outward on the aerial image. Lower terrain moves inward. In the Fig. 49 image of an entire section of land the roads do not form the perfect square shown in the topographic map, Fig. 50. The view is off-nadir. Furthermore, the road at the top of the image goes over a hill, making it bow outward in the photo. Outward bowing of straight lines is also a symptom of some lenses, particularly those with relatively short focal lengths which approach wide angle or fish-eye lenses.



Fig. 49. Distortion of photo caused by topography.

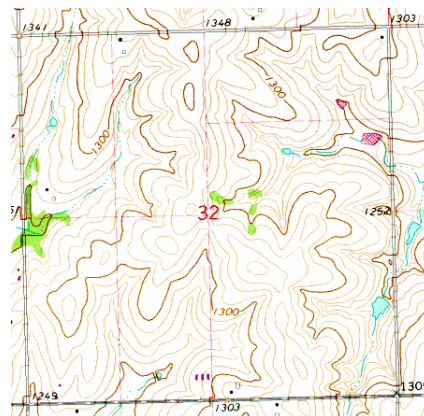


Fig. 50. Topographic map of the section.

Scanner geometry is different. As shown in Fig. 51, tall features lean back in a direction perpendicular to the flight path, away from the flight line.

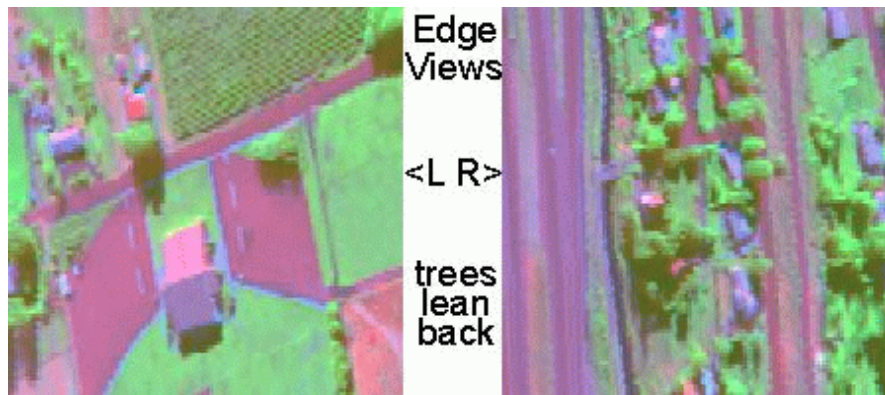


Fig. 51. High features lean away from and perpendicular to the flight track of scanners.

Platform attitude

Aerial images can be distorted by the orientation of the aerial platform. Off-nadir viewing has already been illustrated. Other effects are noticeable with scanner instruments, which put an image together by splicing successive lines of image data. The angular movement of the aerial platform, such as an aircraft, is known as "attitude".

A change in the pitch (angle of attack) of an aircraft results as the nose moves up or down with respect to the center of the aircraft. In Fig. 52, from just northwest of Golden, Colorado, the ER-2 (modified U-2) stratospheric aircraft encountered a wave in the atmosphere as the air bounced as it came over the continental divide and front range. The aircraft's pitch oscillated, causing alternate stretching and compression of the image along the flight direction. Notice that the blurring is parallel to the front range.



Fig. 52. Distortions in caused by pitch.

The roll angle of an aircraft is changed as the aircraft rotates around the flight direction, as in left or right banking. Some aerial instruments can adjust for a limited degree of roll changes by means of gyroscopic control, but the angular changes in Fig. 53 are excessive. This is scanner data. The margins are blackened where the image system could not compensate enough. Elsewhere the distortions can be seen by roads that are not straight.



Fig. 53. Distortions caused by roll.



Fig. 54. Distortions caused by yaw.

Yaw is a twisting movement as the forward orientation of the aircraft moves to the right or left. For scanner data, in Fig. 54, yaw will create compression on one side of the flight track and expansion on the other, with minimal distortion near the flight track. For aerial photography, in Fig. 55, yaw shows up in successive images that are not at the same orientation with respect to the flight track.

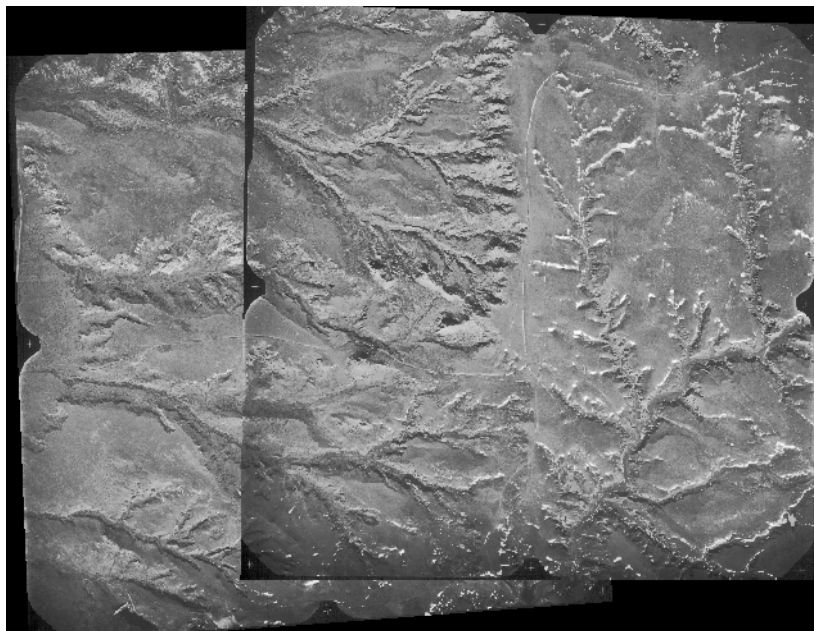


Fig. 55. Displacement in aerial photos caused by yaw.

4. Datum and Projections

The Earth is not a perfect sphere nor a perfect ellipsoid. Therefore there are mathematical models that attempt to describe the Earth. A key word is Datum, which is the name of the model being used. North America topographic maps have traditionally used the North American Datum - 1927 (NAD27) that uses the Clark Ellipsoid of 1866. An update is a 1983 version, NAD83, that uses the GRS 1980 ellipsoid. This is similar to the World Geodetic System 1984, WGS 1984, for acronym and ellipsoid, that is the default system for GPS use worldwide. There are hundreds of local and regional datums in existence. Differences between them can be significant, especially when using location measurements at centimeter scales.

The Earth has a generally curved ellipsoidal surface. Maps are usually flat planar surfaces. Therefore projections are used to convert Earth positions onto planar maps. The USGS offers a paper poster about map projections. Numerous projections are described and illustrated. The latitude/longitude coordinate system is not a projection. Those coordinates can be converted into a true projection by appropriate mathematical formulas. One of the projections typically used for Reclamation work is Universal Transverse Mercator (UTM), which divides the earth into 60 narrow zones that are 6 degrees of longitude wide; knowing the appropriate zone is important. The Space Oblique Mercator can be used for Landsat satellite images. Conic projections are common, such as the Lambert Conformal Conic and the Albers Equal Area Conic. The State Plane, which can divide a state into 1 to 6 (10 for Alaska) zones, is a variation of the Lambert Conformal Conic. Map products should always indicate the projection being used, especially if the area extent is large enough that Earth curvature is significant.

For a random example of the importance of Datum and Projections, consider a GPS measurement (WGS 1984) location at N 40°, W 105°, elevation 5000 feet (1524 meters), which is northwest of Denver, Colorado, but not necessarily at the ground surface. Using the NAD83 Datum gives the same values. Converting to the NAD27 Datum gives the same elevation, but a position of N 40° 00' 00.055", W 104° 59' 58.073". The UTM position needs Zone 13; using WGS 1984 gives coordinates of northing 4,427,757.219 meters, easting 500,000.000 meters and the same elevation. Switching to NAD27 gives coordinates of northing 4,427,548.876 meters, easting 500,045.692 meters and the same elevation. The northing difference is 208.343 meters and the easting difference is 45.692 meters, for a total (diagonal) difference of 213.295 meters. That is a large difference compared to typical GPS precision. State Plane for Colorado North (NAD83) has coordinates of northing 378,940.842 meters, easting 957,097.095 meters and the same elevation. Switching to Colorado Central (NAD83) results in northing 545,448.335 meters, easting 957,101.063 meters. There are some Datum changes (I was comparing values in Ecuador) which change the elevation values because of ellipsoid differences.

5. Global Positioning Systems

The Defense Department operates a constellation of at least 24 satellites as part of a Global Positioning System (GPS). The satellites have orbital periods of about 12 hours and are distributed in 6 orbital planes so that at least 4 satellites are usually visible in the sky at any given point on the Earth. Receiver stations (many brands - such as Garmin and Magellan - and various qualities, mostly portable) measure the distances to the satellites and triangulate the geographic position of the receiver antenna. Vertical accuracy is less than horizontal accuracy.

In addition, the Russians operate their own network of satellites (GLONASS) and the Europeans are planning a system (Galileo). The systems have two or three levels of accuracy. As originally configured, the American system had a condition known as selective availability. The GPS signals were intentionally degraded to about 100 m accuracy. That option is not presently activated, giving typical hand-held GPS receivers about 5 m accuracy. Military grade receivers, known as PLGR, are available on a restricted basis. They are not subject to the selective availability, even if that degradation option is being applied.

A more accurate mode of operation is known as Differential GPS (DGPS). It depends on a GPS receiver at a fixed location (base station) that determines the error in the signal. That error can be applied to GPS data recorded by a roving receiver within about 300 km of the base station and sub-meter accuracy can be achieved. The corrections can be made in post-processing mode with the recorded data. Some base stations broadcast the error correction in real time. Suitably equipped receivers can use the WAAS correction signal to achieve the greater accuracy.

A survey grade GPS uses a different signal type to achieve centimeter accuracy, but such units cost tens of thousands of dollars and need to be at a fixed location for hours of integration.

The GPS signal is not receivable within most buildings. Tree canopies and cliffs can block the signal, limiting the number of satellites in view. Tall buildings can deflect the signal, causing inaccuracies. It is best to operate with an open sky. That may mean placing a receiving antenna on the roof of a vehicle to get an unobstructed view of the GPS satellites while traveling. GPS receivers can be carried by hand around places of interest, erected on fixed tripods, and attached to vehicles roving an area. They can be attached to aircraft to record the positions at which imagery was gathered. Fig. 56 illustrates a GPS track (red) from a PLGR with roof antenna while traveling on roads shown in an IKONOS image near the intersection of Dodson Road and Frenchman's Creek Road, southwest of Moses Lake, Washington. Only slight deviations from the road are present because of the clear view of the GPS satellites.



Fig. 56. GPS Track in central Washington state.

In contrast is the track shown in Fig. 57 of a Garmin GPS-12 unit carried in a side pack through the Forbidden City of Beijing, China, shown on a QuickBird satellite image (0.6 m resolution). The image has been split so that the upper left matches the lower right. North is at the right. The red line is the GPS track and the cyan line closely approximates the actual route walked. There was loss of signal when passing through buildings. There may have been distortion of signal from reflections from buildings and absorptions by the human body beside the GPS unit. Significant positional errors were therefore caused by having blockages of at least parts of the sky and by reflections of signal. Similar effects should happen with a GPS unit used within a canyon with steep walls.

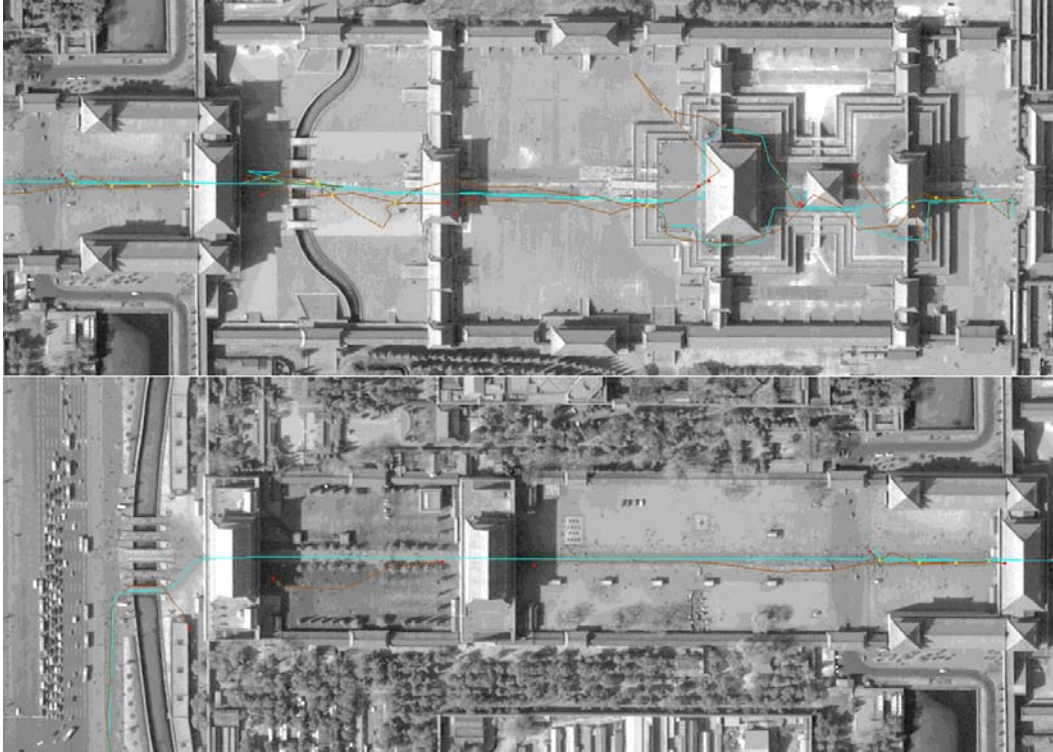


Fig. 57. Distortions and dropouts in GPS track caused by buildings.

6. Image Processing

Adjusting Contrast

Imagery on the computer display (or sent to a printer) can be adjusted for better visibility or for special effects. For illustration the sample scene will be a close-up image of embryo ice crystals formed in a super cooled cloud by a cloud seeding technique of chilling some air colder than -40° . The event took place in a chest freezer in the late 1940s with a black velvet background. Some contrast adjustments may have already taken place as a B&W photo was scanned to form this image. A variety of adjustments will be shown, using graphics captured from TNTmips software displays.

The figures are in pairs, with graphics first and then the resulting output image. The graphics has three parts. The large square in the center to lower right is a graph showing the relation between input pixel numerical values (vertical axis) and output pixel numerical values (horizontal axis). To the left is a histogram, showing the distribution (horizontal axis) of input numerical values (vertical axis). At the top is a similar histogram, showing the distribution (vertical axis) of output numerical values (horizontal axis).

First will be a version “as is” as it comes from the 8-bit grayscale file image using a linear contrast scale from 0 to 255. The left side of Fig. 58 (and similar graphical figures) shows the histogram of the digital numbers in the image. Most pixels have small values, as shown by the bimodal distribution at the left, but there are a few pixels that are bright, as shown by the trailing tail at the upper part of the distribution. Scanned photography will often have such a distribution. The output histogram, displayed across the top of the graphics, has the same shape as the input histogram. The relationship between the input and output images is shown by the diagonal line across the large square. The type of contrast relationship (Linear) is displayed near the bottom, as are the ranges for the input and output numbers. Fig. 59 shows the scene with this linear contrast.

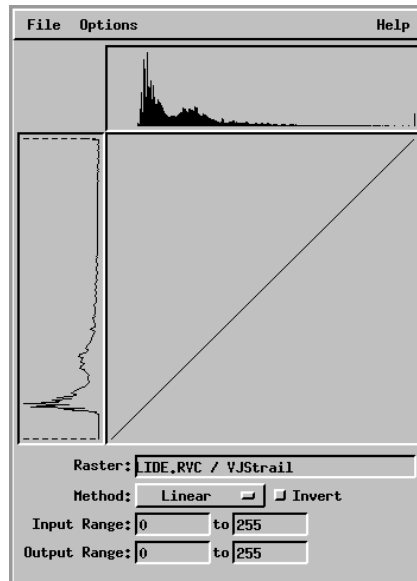


Fig. 58. Graphical representation of full linear contrast.

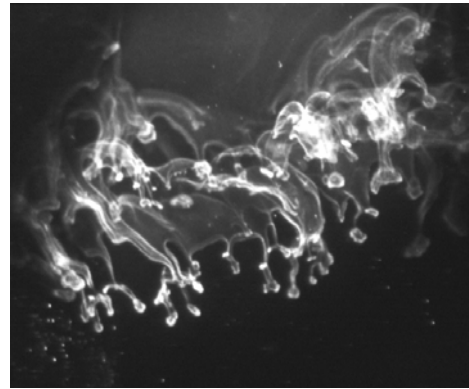


Fig. 59. Snow crystal embryos with full linear contrast.

This software lets the input range be adjusted by sliding the dashed lines in Fig. 60 to different positions. I have selected a lower limit of 17 and an upper limit of 90 in order to isolate the black velvet background and the cloudy air, ignoring the brighter snow particles. Alternatively, I could have simply typed those values in the Input Range boxes. The resulting display in Fig. 61 shows saturated snow but the cloud is more visible. The graph in the large square shows a diagonal line stretching between the limits indicated in the range boxes at the bottom. When adjusting for atmospheric haze, it is useful to place the lower limit at the darkest feature in the scene, such as a lake.

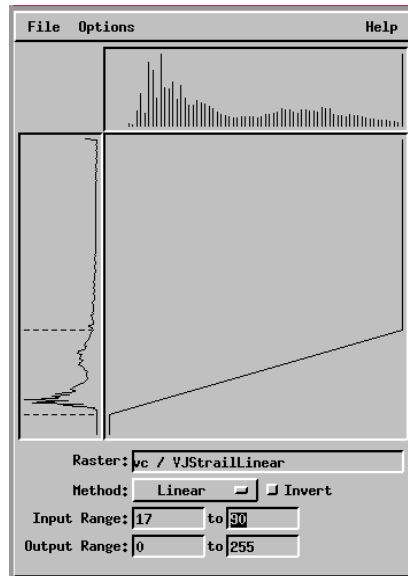


Fig. 60. Graphical representation of partial linear contrast.

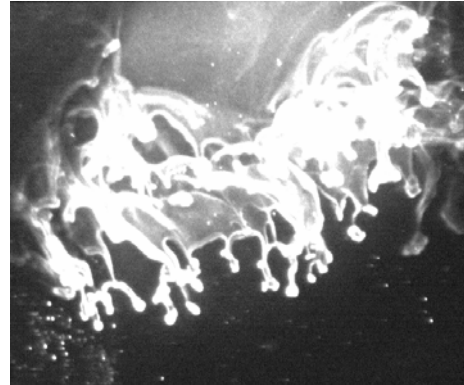


Fig. 61. Snow crystal embryos with partial linear contrast.

Then displaying an image with an initially unknown histogram, the “Normalize” contrast method . The histogram of the input image is resampled, so that its output distribution somewhat resembles a normal curve (as defined in probability and statistics). In this case the bimodal distribution prevents a near-perfect fit to the normal curve (Fig. 62), but the result (Fig. 63) is a pleasing rendition that shows all image features: black velvet, cloud, and ice crystals. The normalize process also found that the darkest pixel had a value of 17 and therefore started its distribution at that number. Notice the wavy line in the large square box. The logarithmic contrast method will greatly brighten the dark values while keeping the bright pixels from saturating. The curve in the large square box of Fig. 64 has a shallow slope initially but then a smooth transition to a steep slope. The image in Fig. 65 has a gray background as a result.

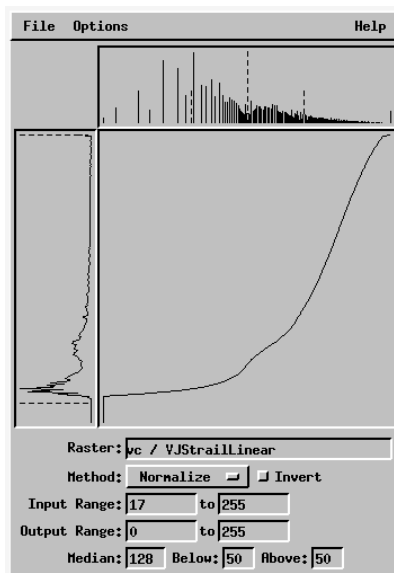


Fig. 62. Normalized contrast



Fig. 63. Snow crystal embryos with normalized contrast.

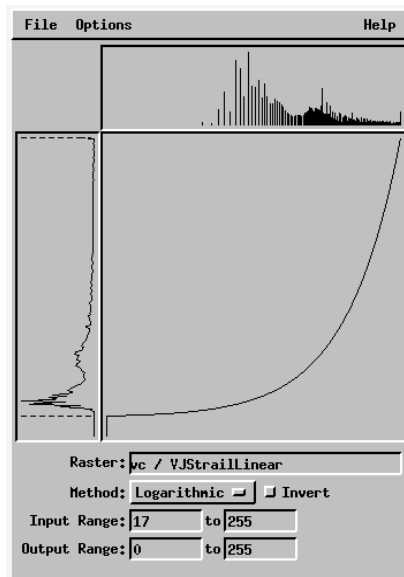


Fig. 64. Logarithmic contrast.

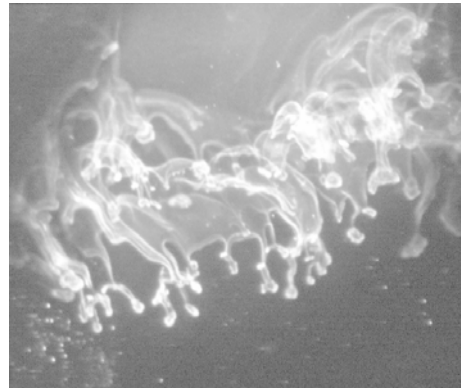


Fig. 65. Snow crystal embryos with logarithmic contrast.

The exponential contrast method gives the analyst much control over the appearance of the output. An exponent of 1.00 (default) is the same as a linear contrast method. An exponent of 0.50, shown in Fig. 66, lies between a linear and a logarithmic relationship. The exponent number may be typed into the box at the bottom or the cursor can drag the curve to its new position (in this software, if not in the others), yielding exponents ranging in hundredths from 0.01 to 100.00. The result in Fig. 67 is a generally pleasing view without saturations.

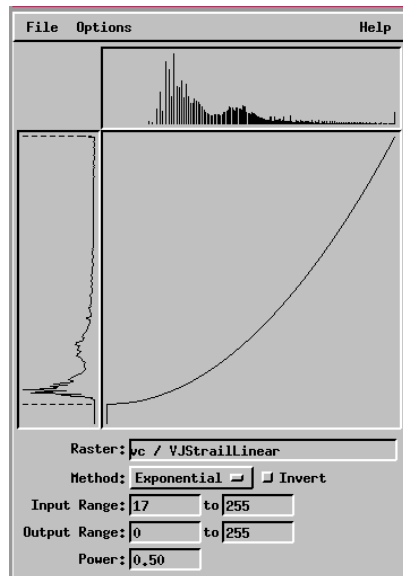


Fig. 66. Exponential contrast with power 0.5.

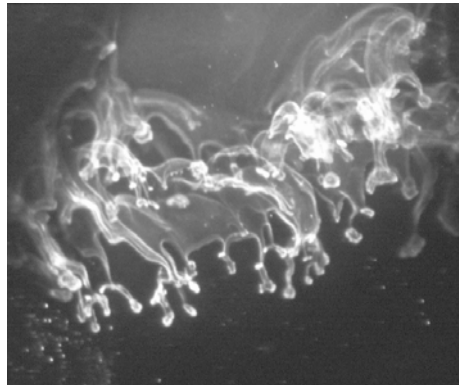


Fig. 67. Snow crystal embryos with exponential contrast with power 0.5.

If the exponent is greater than 1.00, the bright values are enhanced and the darks are made darker. In Figs. 68 and 69 a value of 2.00 effectively eliminates the black velvet and the cloud, leaving only the higher concentrations of ice crystals.

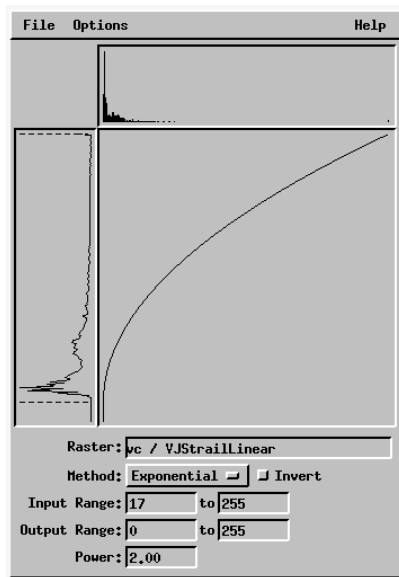


Fig. 68. Exponential contrast with power 2.0.



Fig. 69. Snow crystal embryos with exponential contrast with power 2.0.

Sometimes the input image may be a negative and the contrast needs to be inverted, as shown in Fig. 70. This produces in Fig. 71 black ice crystals on a bright background, much like astronomers often display pictures of stars.

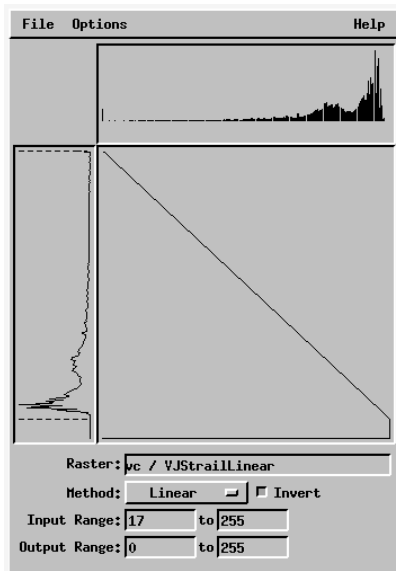


Fig. 70. Inverse linear contrast.

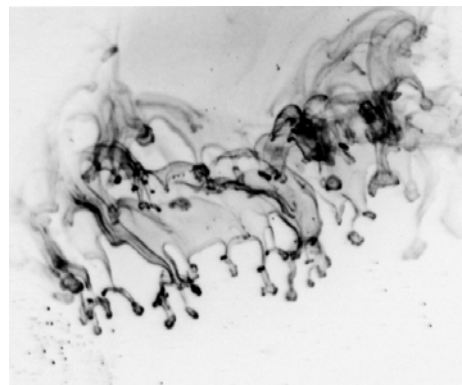


Fig. 71. Snow crystal embryos with inverse linear contrast.

These illustrations have been with single band monochrome images. When a color image is displayed as Red-Green-Blue, each band may be individually enhanced with possibly a

different contrast method. However, it is usually good to keep the contrast method the same but possibly vary the Range limits. Similarly to the last illustration, color negatives can be inverted to get positive images.

Gray scale imagery that is 8-bit can be artificially colorized. In the color look-up table of Fig. 72 the values of 96 to 254 have been given a spread from Blue through Red to purple, enhancing the ice crystals. The values saturated at 255 have been left as white and all dark values remain the same. Random colors could also be assigned. The colors highlight regions of the scene in Fig. 73.

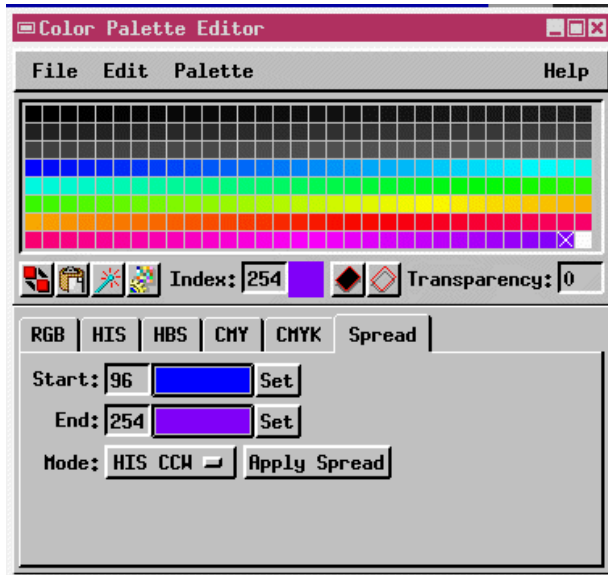


Fig. 72. Color table used to colorize snow crystal embryos.

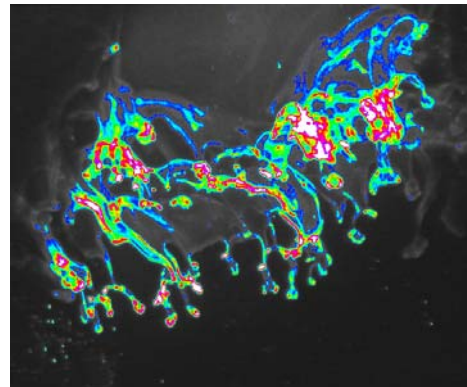


Fig. 73. Colorized snow crystal embryos.

Displaying Color

In Fig. 74 I have selected a portion (300x300 pixels at 15 meter resolution) of a scene from the North Rim of the Grand Canyon, as seen by the ASTER camera on the Terra satellite. The actual color bands are green, red, and NIR, which display to the standard false-color infrared rendition (healthy vegetation is red). At the bottom of the view are the headwaters of Bright Angel Creek. The image was converted from R,G,B separate bands to 24-bit, 16-bit, and 8-bit composite color images. Within the scene, slightly lower than center, a region of individual pixels was selected about the pixel at line 215 and column (row) 169, as shown in the image extract with the cross-hair symbol in Fig. 75.

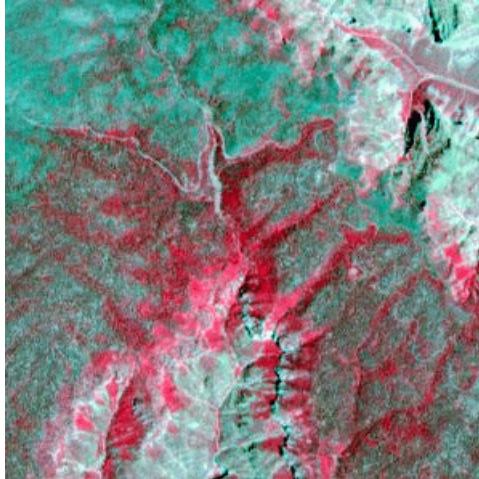


Fig. 74. ASTER view of part of the Grand Canyon

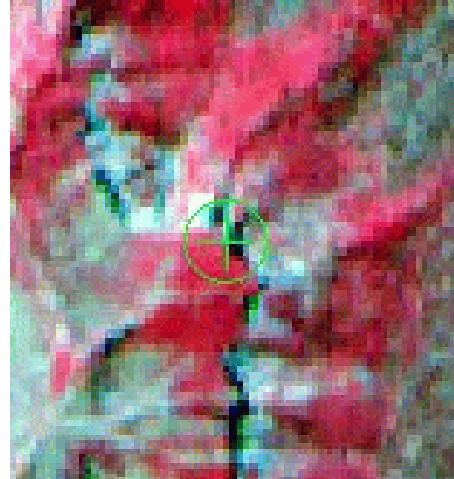


Fig. 75. Subset of the ASTER view, marking a particular pixel.

The pixels in a 24-bit composite image are made of 24-bit integers (3 bytes). Each of the 3 bytes represents an 8-bit Intensity, ranging from 0 to 255. The byte order may be RGB or BGR. The TNTmips software allows the examination (and direct modification) of nominated pixel values. The first illustration, Fig. 76, of the table of pixel values has a box around the pixel at (215,169). Within the brackets are the numbers 109, 84, and 153. Therefore Red has a value of 109 out of 255, Green a value of 84, and Blue a value of 153. To the right is a pixel with values [0 0 0], indicating pure black. To the lower left are many pixels with greater amounts of red. Two and three pixels above the target pixel are values of 255 for both blue and green. This software allows direct editing of individual pixels; any other numbers can be typed into the “Raster Value” boxes to permanently change them in the image.

The 16-bit images have 5 bits per color. Notice in the Fig. 77 table that the color values range from 0 to 31.

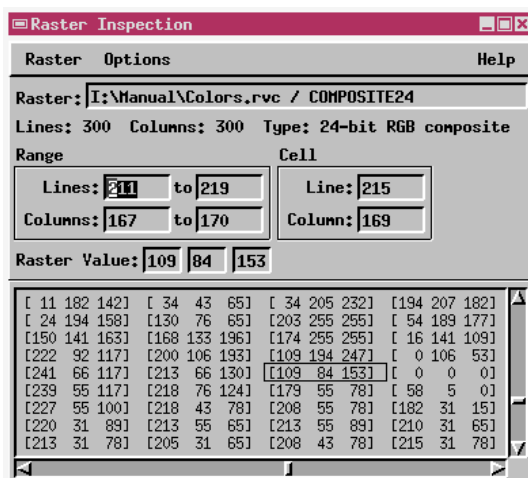


Fig. 76. Pixel values for a 24-bit color composite image.

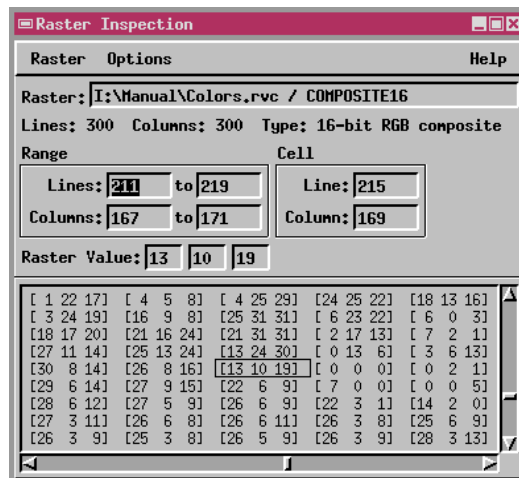


Fig. 77. Pixel values for a 16-bit color composite image.

The 8-bit images have a very different structure. The numbers 0 to 255 are assigned randomly to a look-up table of the various colors in the image. (In conversion from 24 or 16-bit color to 8-bit color, the closest of the 255 possible colors is used.) In this software, the most frequent colors are assigned to the smallest integer values and the rare colors to the largest values. Notice in the illustrated Fig. 78 table for the 8-bit image that the numbers seem quite random, unrelated to the scene. The color look-up table is displayed in Fig. 79 for reference.

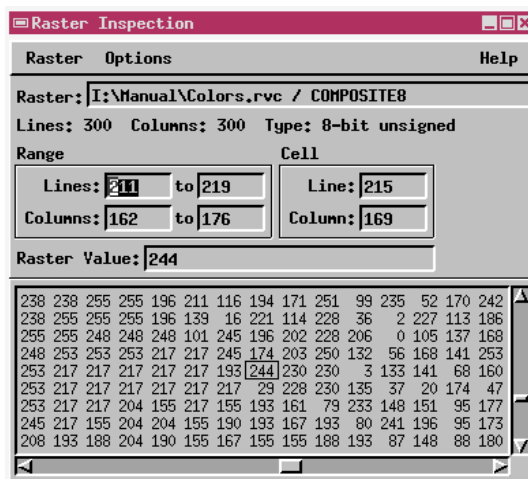


Fig. 78. Pixel values for an 8-bit color composite image.

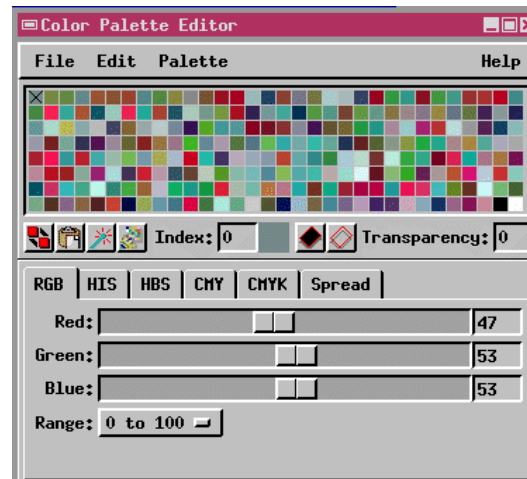
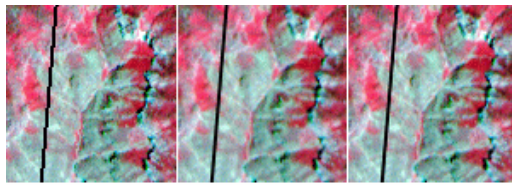


Fig. 79. The 8-bit map for the ASTER image.

Resampling Styles

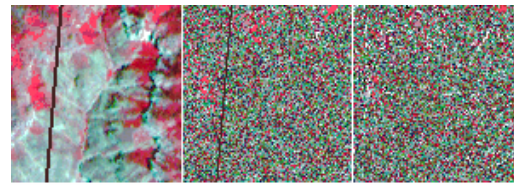
Resampling of images to change sizes, orientation, or projection gives the analyst three choices: (1) nearest neighbor (NN), (2) bilinear interpolation (BL), and (3) cubic convolution (CC). NN selects the pixel of the former image that is closest to the target position in the newer image, simply copying its value or color assignment. BL takes the four former-image pixels surrounding the target position and combines the linear interpolation between the opposite pairs of pixels. The resulting value will be somewhere within the range of the values of the 4 pixels. CC uses 16 former-image pixels about the target location for a more precise selection of a new pixel value. Where a linear feature is in the image that is not parallel to the lines or columns of the image, the NN process will usually cause a slight offset in the line in various places. The BL and CC processes will have smoother transitions.

It is very important to understand the color style when selecting a resampling style. There is a trap! If a 24-bit or 16-bit color image is resampled, there will not be a problem. For example, the ASTER image of the Grand Canyon was edited to make a vertical black line 2 pixels wide. The image was then rotated 5 degrees clockwise using the 3 resampling styles. A 100x100 subset of the result was extracted for each style and shown in Fig. 80. The edited 24-bit image was also converted to an 8-bit image and the 8-bit image was rotated 5 degrees using the 3 resampling styles. The same subset was extracted from the 8-bit rotations and shown in Fig. 81.



24-bit: NN BL CC

Fig. 80. A 24-bit sample ASTER image



8-bit: NN BL CC

Fig. 81. An 8-bit sample ASTER image

The 24-bit NN style shows a segmented black line. The BL and CC styles have a smoother line, with the CC having a slightly better image. The 8-bit NN style looks like the 24-bit NN rotation. However the BL and CC images do not resemble the scene! That is because the resampling by the BL and CC methods interpolate the digital numbers and assign a new one to the result. But the color table remains the same and the pixel gets a random color assignment. For this reason, 8-bit color images must use the NN resampling method. If the 8-bit image is only a monochrome, gray-scale image, then the other methods may be used. Similarly, when resampling an image in which the numbers represent classifications, NN must be used to avoid having pixels reclassified to something else.

Filters

Imagery can be cleaned up of artifacts and filtered. Many filter types are available and the choice depends upon the particular need. The first example is an image with much dust on it. A 35 mm slide view of the north end of the Dead Sea was copied commercially to a duplicate slide, but unfortunately the original had dust on it that was not removed. The duplicate slide was scanned to produce the initial image (Fig. 82). (The dust may not show at this enlargement scale.)



Fig. 82. The Dead Sea with dust on original slide photo.

An efficient way to clean up the image is to convert to HIS and then work with the Intensity image. A subset of the initial dusty image is shown at the left of the triple series in Fig. 83; all three are shown with Normalized contrast to make the dust more visible. A simple 3x3 Low Pass Filter was applied for the middle view. Unfortunately, it is just a simple average of the nine pixels centered on the output pixel; extreme values affect such an average. The dust is blurred but is still visible. For the right view the initial Intensity image was hand edited at the large dust spots, manually typing in replacement numbers that were similar to the pixels adjacent to the dust; perfection was not attempted. Next a 3x3 Median Filter was applied. It takes the median value of the nine pixels around the output pixel and assigns that median to the output. Extreme values are thereby ignored. The dust and other noise in the image was removed. An exponential

contrast, with power 0.50, was applied to the result to make the dark foreground more visible.

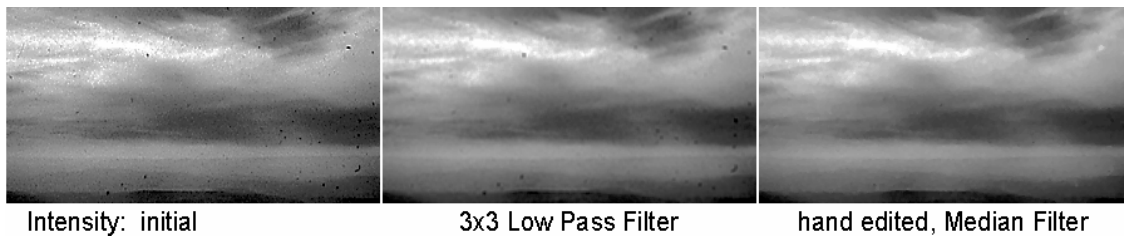


Fig. 83. The raw and filtered intensity portion of the dirty image.

The former Hue and Saturation (which still contained some residual dust signatures) were combined with the median-filtered Intensity to produce a revised color image, which is shown as Fig. 84. However, what if the dusty and other features need to be made more visible? There are other filters available. Three are shown as examples in Fig. 85. The general advice is simply “try it and see.”

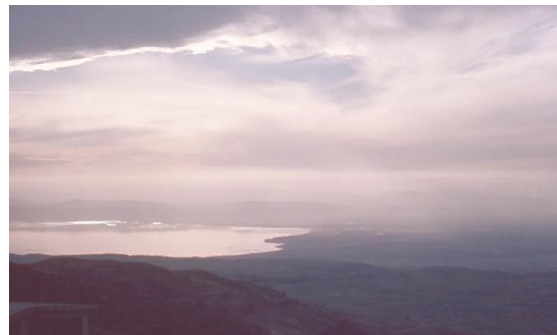


Fig. 84. The cleaned and brightened version, Dead Sea.

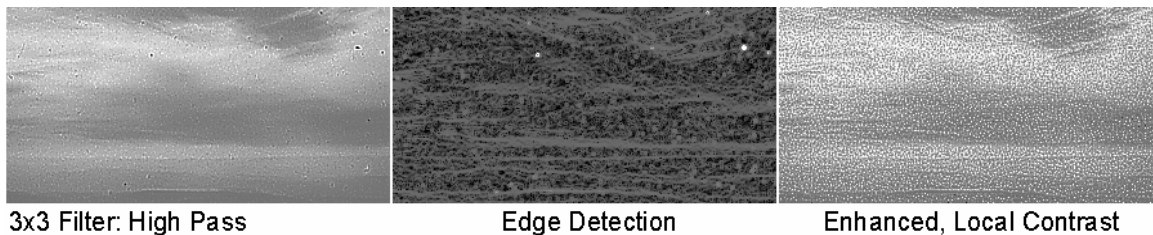


Fig. 85. Three enhancement filtered images.

Fast Fourier Transform Filters

Sometimes instrumental noise creates banded or repetitive patterns in an image. That could be from a 60 Hz hum or other special frequencies. An example here is an image from a FLIR (Forward Looking InfraRed) instrument taken in the early 1990s. The image was written to NTSC television format, scanned in pairs of lines. There are two sensors that may differ in calibration, as is the case here. Their line order alternates: 1,2,2,1,1,2,2,1,... Therefore it is similar to a scanning sensor with 4 detectors per sweep. A full scene (omitting the numerical data below the image) is shown as the example in Fig. 86, with a portion from the middle right enlarged by a factor of 4 in Fig. 87.

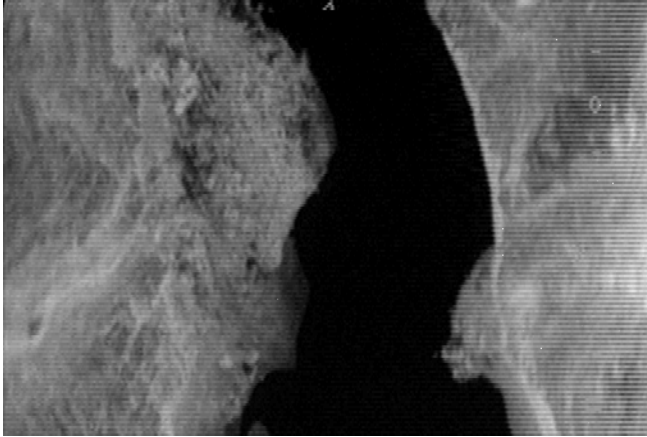


Fig. 86. A raw FLIR image of the Colorado River.

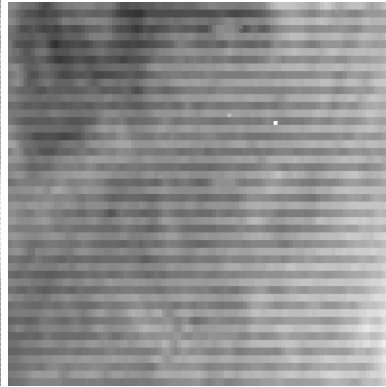


Fig. 87. An Enlargement of the FLIR.

The original image is then transformed by a Forward Fast Fourier Transform (FFT) to a complex raster image, Fig. 88, with magnitude and phase information. It looks like a scatter diagram with some prominent clustering of points along particular lines. This figure pictures the series of sinusoidal waves that can express the data in the original image. It seems to have no relationship to the scene in the original picture. (It is like a hologram which seems to contain meaningless patterns but through which a 3D image can be viewed.)

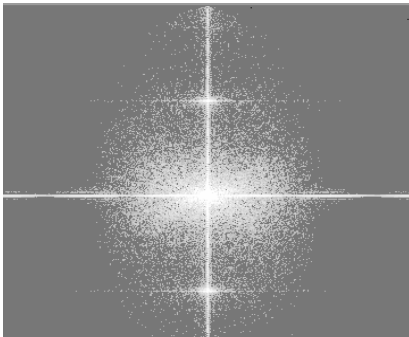


Fig. 88. Fourier transform of the FLIR image.

A special editor is then used to cut out portions of the FFT image, particularly pieces of the preferred lines. In this case, the upper and lower crossbars were removed and the upper and lower 3/4 of the vertical axis. (Trial and error may be the best method for discovering what works best.) The software then used the remainder of the FFT image to do the Reverse FFT process and recreate in Fig. 89 the original image, minus the banding. The same subset of the right side of the image is again enlarged by a factor of 4 in Fig. 90.

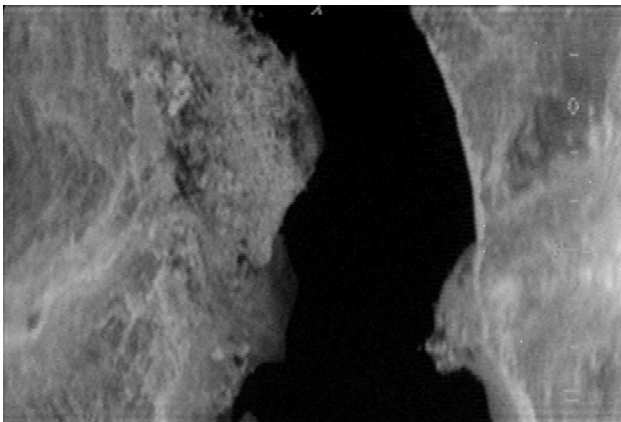


Fig. 89. The FLIR image cleaned by the FFT process.



Fig. 90. Enlargement of the FLIR image.

During the original analysis of these FLIR images the banding was removed by using a low pass spatial filter of size 4 lines by 1 column. That preserved horizontal resolution and blurred the vertical resolution, but the result got rid of the banding problem. A temperature analysis was then performed on the Colorado River portion of this image from the Grand Canyon.

Band Combinations

Spectral bands can be assigned in any order to the RGB components of a display, often producing a false color combination. For example, the ASTER thermal IR view of the Grand Canyon was chosen. There are 5 narrow thermal bands named 10, 11, 12, 13, 14, all at 90 meter resolution as 16-bit integer data. Fig. 91 shows a 13, 12, 10 assignment as RGB with linear contrast. The South Rim is at the bottom of the view and the North Rim at the top. The Bright Angel Fault follows the diagonal valley. The Colorado River is the dark curved line. The sun angle from the lower right creates shadows in this topography. There are subtle color changes with rock types. Band ratios are typically used to reduce shadowing effects. (A special ratio, called the normalized difference, will be presented later.) In this thermal data set, band 14 was brightest. The other bands were divided by band 14 and the result was multiplied by 255. The ratioed bands 13, 12, and 10 were combined with normalized contrast to form Fig. 92. Instrumental noise, shown by the dotted lines running diagonally through the image, become more visible. Notice that the shadowing is indeed reduced. Furthermore, there is a greater contrast among the colors. The light and medium greens are the limestone layers. The reds are shale and sandstones. The inner gorge by the river, predominately of igneous and metamorphic rocks of granite and schist, is bluish.



Fig. 91. Linear contrast for ASTER thermal bands viewing the Grand Canyon.

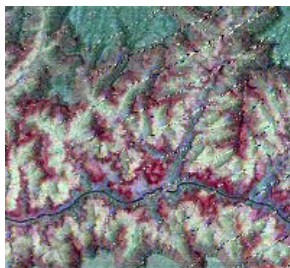


Fig. 92. Band ratios with normalized contrast for ASTER thermal bands, Grand Canyon

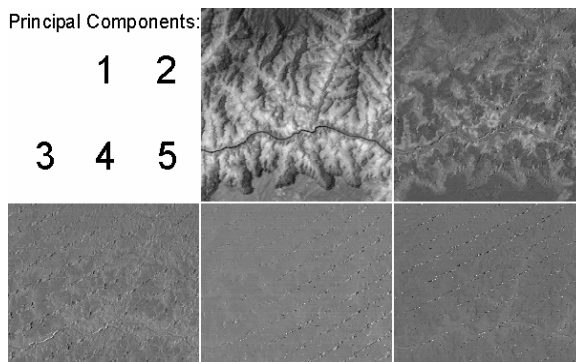


Fig. 93. Five principal components for ASTER thermal scene, Grand Canyon.

All five thermal IR bands (any number of bands can be used) were converted to principal components (PC), whereby an artificial set of bands is produced that are mathematically orthogonal. That shows the maximum variability in the data but may leave the analyst wondering what the differences really mean. The results are shown in Fig. 93. PC-1 always shows the dominant brightness patterns in the data, in this case the basic brightness from albedo, topographic and shading effects. PC-2 gives rock type information for this data

set. The remaining PC's show decreasing signal and increasing noise, including the instrumental noise.

Similarly, a decorrelation stretch version can be produced from any number of bands. It

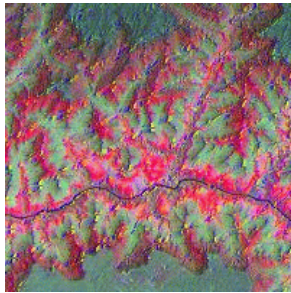


Fig. 94. Decorrelation stretch of the ASTER thermal scene, Grand Canyon.

uses a principal components routine to remove the correlation between spectral bands and show only the significant differences within the original spectral bands. The decorrelation stretch bands 13, 12, and 10 are shown in RGB order in Fig. 94. The process maximizes the differences between the bands, producing much bolder color patterns. The color interpretation for basic rock types is the same as for the band ratio image.

Image bands can also be combined by means of arithmetic functions (add, subtract, multiply, divide, ratio, rescale). They can be thresholded, to convert bands to a simple

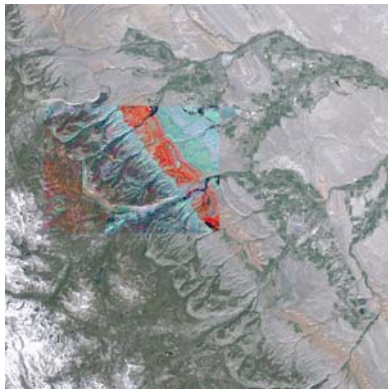


Fig. 95. Decorrelation stretch inset of visible Landsat bands; Lander, Wyoming.

binary relationship indicating imagery parts greater than or less than the threshold value. Artificially colorizing a narrow range of digital numbers in a single band can help isolate an appropriate threshold value. As a further illustration of the power of principal components and decorrelation stretch, a Landsat scene of a region near Lander, Wyoming, has been chosen. Fig. 95 shows the Landsat scene in approximate natural color. There are agricultural regions to the upper right and forested regions to the lower left. In the lower left corner snow still covers the tops of the Wind River Mountain Range in this scene from early July. The geology is that of multiple strata dipping towards the northeast. They are eroded to sawtooth forms by the streams draining the highlands. The inset is the decorrelation stretch (a subset from the entire scene) of the same bands, showing stronger colors, particularly of the Triassic Red Beds. Other shales became bluish.

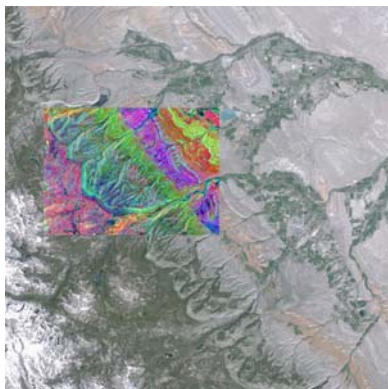


Fig. 96. Principal component inset for Landsat bands; Lander, Wyoming.

Fig. 96 of the same area has the inset from a principal components analysis. Components 2, 3, and 4 are shown as R,G,B. The area of analysis was restricted to only the area of the inset, avoiding lakes, snow, and the agricultural areas. (Including the entire scene decreased the color contrast.) The Red Beds are now purple. Other strata become more distinct, showing three types to the left and at least two to the right of the purple band. Using components 3, 4, and 5 also separate these strata well. However, they were not as separable when the entire

scene was included in the analysis because more of the computational power was devoted to the snow, lakes, and agricultural areas.

A pair of rasters can be used to create a 2-dimensional histogram (scatter diagram) in which the brightness or color at each pixel (picture element) represents the number of

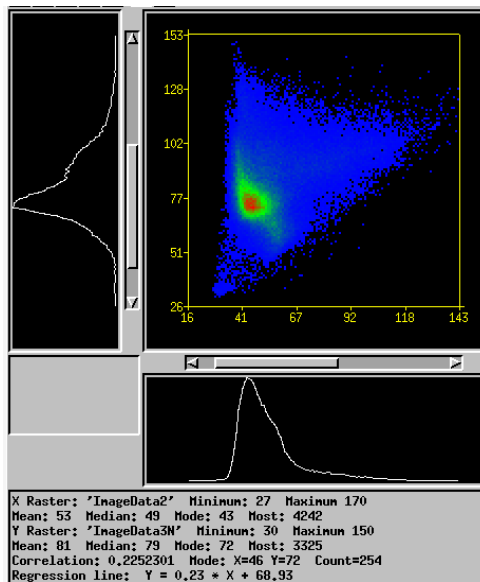


Fig. 97. 2-D histogram for the red (X-axis) and NIR (Y-axis) for ASTER view, Grand Canyon

pixels in the original two bands that have the same particular numerical values. The ASTER scene of the North Rim of the Grand Canyon, shown in the Displaying Color section, was chosen as an example. The X-axis in Fig. 97 shows the distribution (histogram) for band 2 (actual red) and the Y-axis shows that for the band 3N (actual near-infrared). The red area of the scatter diagram shows the brightness combinations with the maximum frequency in the scene. In presenting such a 2-D diagram, some software types also put in a scatter of white points (called “dancing pixels” in the ENVI software) that give the pixel values near the cursor when it is placed over the original image. That helps the analyst know what parts of the diagram apply to particular land cover types.

The data represented by such diagrams can be partitioned to provide a basis for a classification (such as water, bare land, growing vegetation, fallow land, clouds, etc.). For this band combination, pixels representing water and black parts of the scene are plotted in the lower left. Pixels with healthy vegetation (dark in red, bright in NIR) are plotted in the upper left. Barren soil and rock typically plot along the main diagonal. Sometimes the scatter diagram for this band combination is called the “tasseled cap”.

That classification can be applied to the original imagery to describe a landscape. There are many supervised and unsupervised classification systems that can take data from any number of spectral bands. Classified imagery can be summarized by pixel counts converted to area units, or by converting the data to vector polygons for GIS analysis.



Fig 98. Normalized difference vegetative index version of Bright Angel ASTER scene.

A particularly useful 2-band combination is called the normalized difference (ND). For bands A and B, $ND = (B - A) / (B + A)$. This is like a band ratio, but it gives a stronger signal. Fig. 98 sets A = band 2 and B = band 3 for the ASTER scene of the North Rim of the Grand Canyon. This makes the ND a vegetative index, with the normal acronym NDVI. Notice that the healthy vegetation is bright white. The dark area in the upper left should have been bright, but is part of a fire swath, hence dead vegetation. Barren soil and rock, as well as water, are also dark. NDVI is typically used for the red and NIR

bands of several satellites (like AVHRR, MODIS, SPOT, IRS) to measure the health of vegetation globally on a weekly basis. There is also a “greenness” and a “wetness” index.

Any number of spectral bands can be combined in a linear regression analysis, showing the correlation between the bands. Pieces of different habitats in the western U.S.A., as seen by the Landsat satellites, were mosaicked together for a linear regression analysis. The resulting table of numbers showed that band 1 (B) was related to bands 2 (G), 3(R), and 4 (NIR) by a particular formula:

$$B = 14.9358 + 1.0784 * G - 0.1443 * R - 0.1143 * NIR.$$

Though the constants may vary with a different selection of scenes, this equation can be useful for predicting a blue image for satellites that do not record it (SPOT, ASTER) or when the blue image is contaminated with too much haze. A blue band was thereby predicted for the North Rim scene. It was combined with ASTER bands 1 (G) and 2 (R) to give a natural color version of the scene in Fig. 99. Unburned trees are green, burned areas are gray, and there are pink rocks where expected.



Fig. 99. Simulated natural color version of the Bright Angel ASTER scene.

Automatic classifications

Caution needs to be used when working with automatic classifications of scenes. For an example I have chosen an IKONOS satellite view of the intersection of the Winchester Wasteway in Washington and Interstate-90, taken 18 August 2000. The 4-band multispectral imagery was at 4 meter resolution, but was reduced to 8 meters for these examples. Fig. 100 shows the natural color view and Fig. 101 shows the color-infrared (CIR) view, both with normalized contrast stretching. Fig. 102 shows a manual classification done with the original 4 meter imagery. It started with threshold partitioning for water (NIR <171), highways (170 < NIR < 360 and 214 < red < 341), and roofs (and some hay stacks and a dried pond) (204 < red). Thereafter hand analysis drew boundaries around fields showing a healthy crop, medium crop, freshly sprouting crop, and plowed fields; wetlands; sand dunes; and other; giving 10 classes.

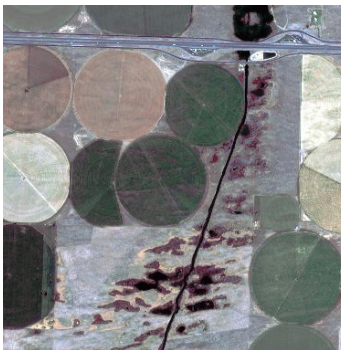


Fig. 100. IKONOS natural color.

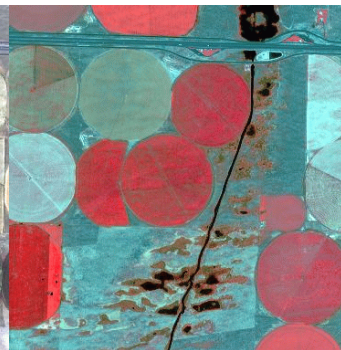


Fig. 101. IKONOS CIR.

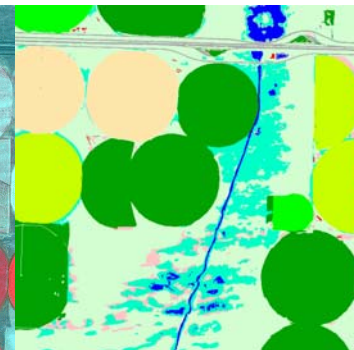


Fig. 102. Hand classified.

Automatic classification was done using the indicated routines, all 4 spectral bands, partitioning into 10 classes and using the same default values for any other parameters. Fig. 103 for Simple One-Pass Clustering. Fig. 104 is for K-Means. Fig. 105 is for Fuzzy

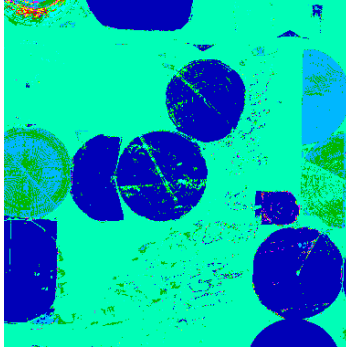


Fig. 103. One-Pass Clustering.

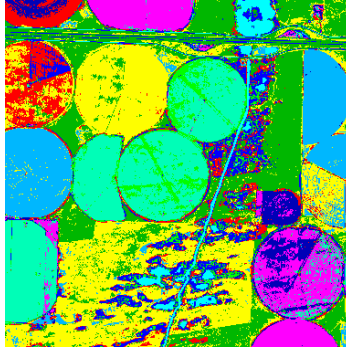


Fig. 104. K-Means.

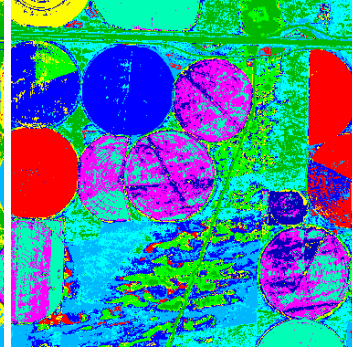


Fig. 105. Fuzzy C Means.

C Means. Fig. 106 is for Minimum Distribution Angle. Fig. 107 is for ISODATA Classification. Fig. 108 is for Self Organization. The processes produce a “distance” raster, whereby small values (black) indicate a close match to the spectral center of a class and large values (white) indicate a more doubtful match. Fig. 110 shows the distance raster for the Fuzzy C Means, using normalized contrast spreading. The same colors are used for the automatic classifications, though they are seemingly randomly assigned to the various classes.

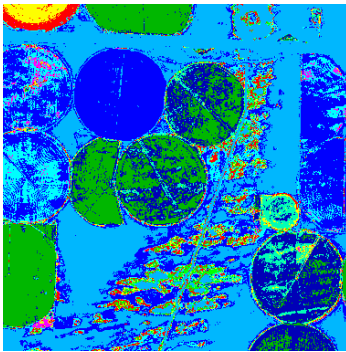


Fig. 106. Minimum distribution angle.

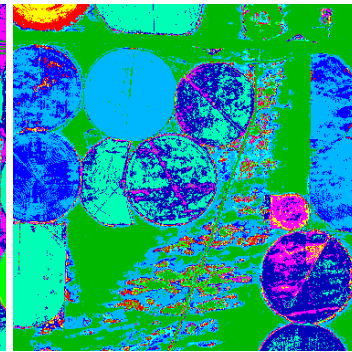
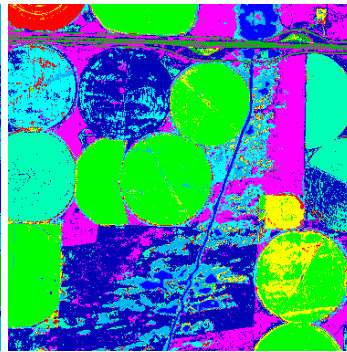


Fig. 108. Self organization.

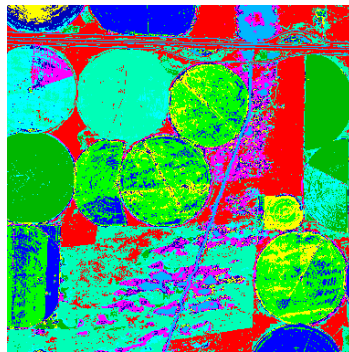


Fig. 109. Adaptive resonance.

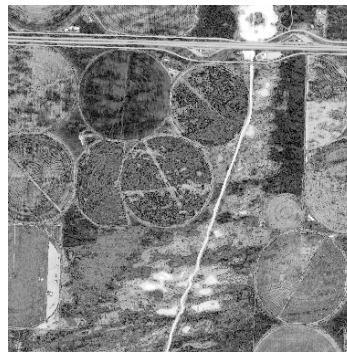


Fig. 110. Distance raster for fuzzy C means.

The Simple One-Pass Clustering seems to use up most of its classes doing fine detail in the field of the upper left corner, making the rest of the scene crudely classified. Four of the seven techniques do not discriminate between water and road. Some of the techniques highlight irrigation within a field. Some of the techniques could be useful for precision farming analyses that seek to understand variations in plant health within a field. In general, the automatic classifications may not match a more laborious hand classification that stresses logical and useful classes for specific purposes.

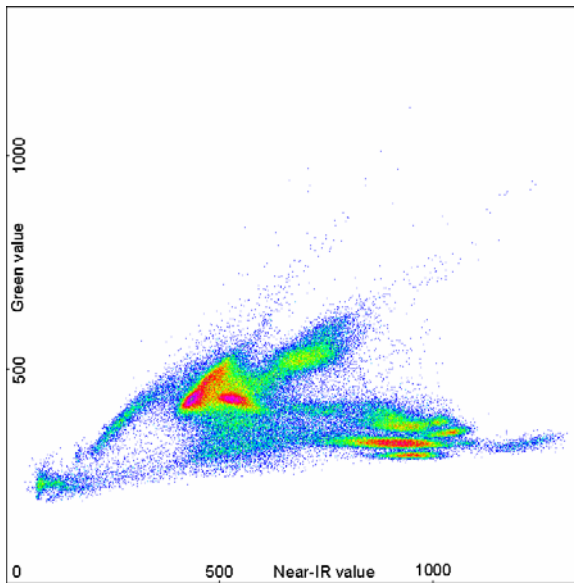


Fig. 111. The NIR-Green histogram of IKONOS scene.

Other classification strategies are possible. A 2D histogram can be created from two of the color bands. For this scene the Near-IR and green bands provide the greatest separation of features, shown in Fig. 111. This was specially prepared using axes of 1350 for the digital range of pixel values rather than a default rescaling to a 0 to 255 range. The colors in the figure indicate frequency of pixels having particular pairs of values.

The lower left cluster is water. The diagonal band on the left is the highway. The main central patch of red and green represents the barren fields and sparse vegetation areas. The upper central green patch is for the very light green fields.

The weak patch in the bottom center is for the wetlands. The various patches on the lower right represent the numerous agricultural fields with some form of crop present. It is possible to partition this diagram into rectangular or triangular areas and express various thresholds for the possible classifications. A patch might be represented by a combination of rectangles in a process named parallelepiped classification.

It is also possible to use such a histogram as a guide to make a lookup table made with polygons partitioning the histogram. Fig. 112 shows a possible partition that carefully separates 27 peaks in the distribution. Fig. 113 combines those into ten classes resembling the hand analysis of Fig. 102. Using the 10 partitions the region was classified according to the pattern shown in Fig. 114. It shows more detail than the hand classification, including the location of the central pivot irrigation line in the upper left field. The sand dune areas (tan around wetlands) received the same class as the light green and white fields. The fields with a thick crop have different separations from the hand analysis. Fig. 115 shows the results of using all 27 classes of Fig. 112. Details of the fields and water bodies are evident.

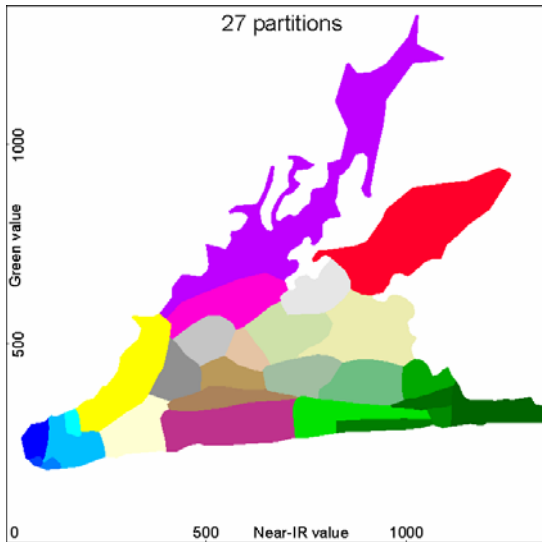


Fig. 112. The histogram in 27 partitions.

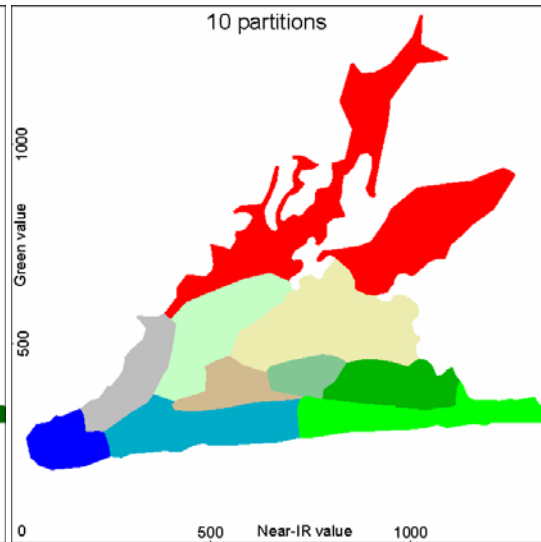


Fig. 113. The histogram in 10 partitions.

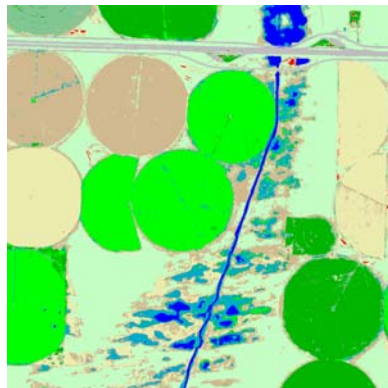


Fig. 114. Classified with 10 partitions.

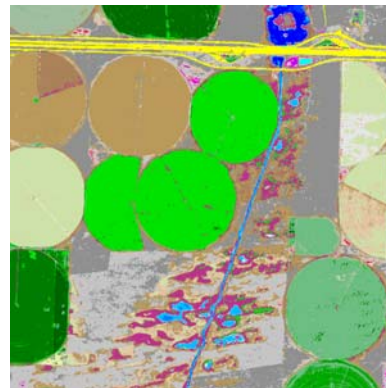


Fig. 115. Classified with 27 partitions.

Water Studies

The Landsat series can and has been used for studies of some of the properties of water bodies. For illustration purposes, portions of a scene from 2 July 1989, near the Wind River Range in Wyoming, is shown. The bands are not surface calibrated but serve as proxies for the properties. There are several lakes on the southwestern side of the range that receive meltwater from the snow-capped mountains. TM band 6 gives the surface temperature of the scene; dark is cold and bright is warm. Fig. 116 has been colorized over the narrow temperature range of the lakes such that each digital number has a different color, with blue being coldest, red being warmer and magenta and then purple

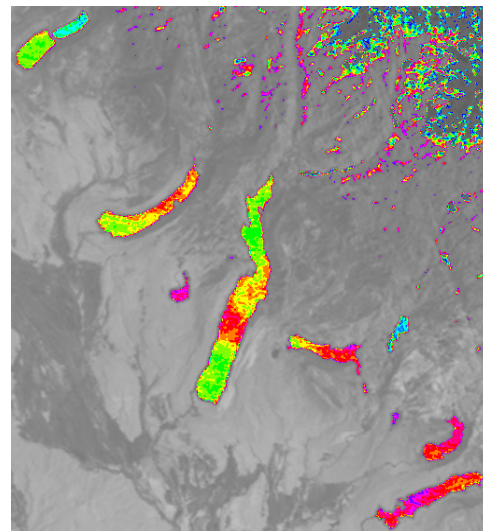


Fig. 116. Colorized according to surface temperature.

being warmest. The land areas are warmer than the water. The snow pack is in the upper right and is much darker but with colored edges, indicating that the colored temperatures are close to the melting value. Each lake has a different pattern. The two at higher elevations are cold (light blue). Two have significant temperature patterns within the lake. Notice also that the irrigated agricultural fields in the lower left are cooler (darker) than the barren land.

Another area, to the northeast of the Wind River Range was selected. The main feature is Ocean Lake, surrounded by an agricultural area with water distribution canals. The scene is northwest of Riverton, WY. The natural color version of Fig. 117 shows a lightly blue colored lake, suggesting fine sediments from a glacial source in the mountains. This scene is used as a base map for the next views, in which water bodies are colorized to show other water properties.

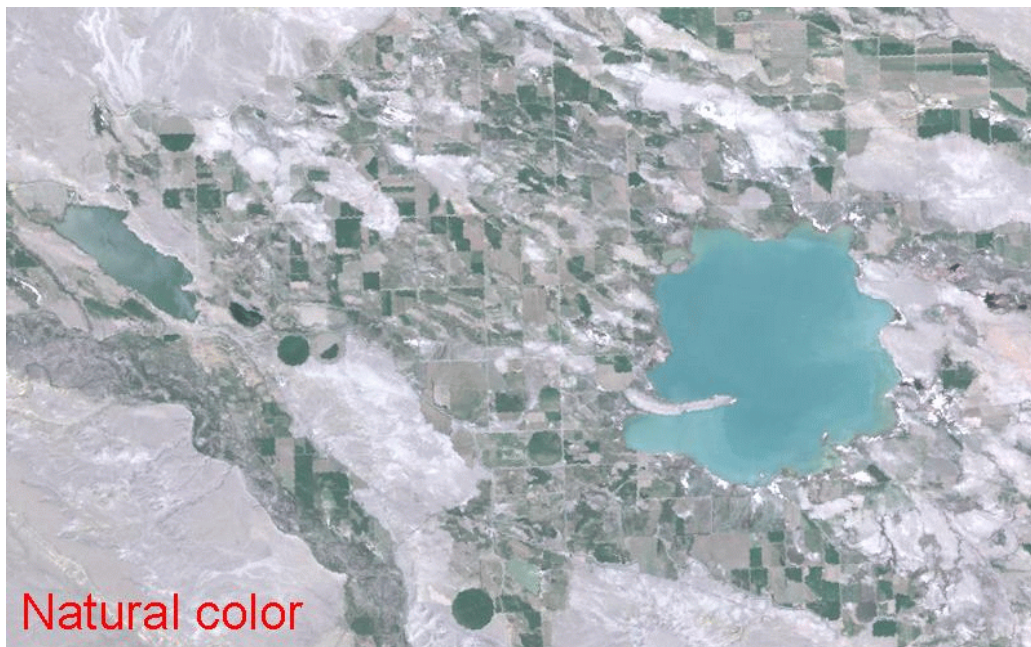


Fig. 117. A natural color version of the Ocean Lake, WY region.

The uncalibrated temperature patterns (TM band 6) show little variation across the lakes in Fig. 118. The western lake is the coldest. The two largest lakes show warmer (greenish) shorelines, probably because the shallow water lets the satellite see to the bottom sediments which are easily warmed by the sun. Along the upper left is a canal with very warm (red) water. The river in the lower left is cooler (green).

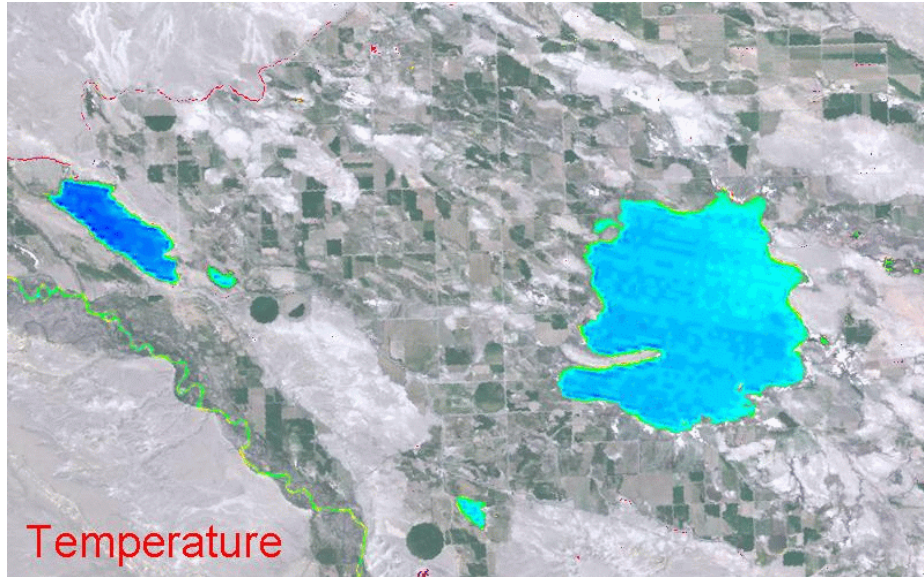


Fig. 118. The Ocean Lake scene with water colorized by temperature.

Band 1 (blue) was chosen as a proxy for turbidity. The large Ocean Lake shows strong patterns in Fig. 119 with red indicating the greatest mud content. There is a small pond at the left that has the cleanest (blue) water. The upper left canal is muddy (reds and oranges) and the lower left river is intermediate (greens). A proper calibration would require field observations of secchi depths - the depth to which a white disc can be seen in the water.

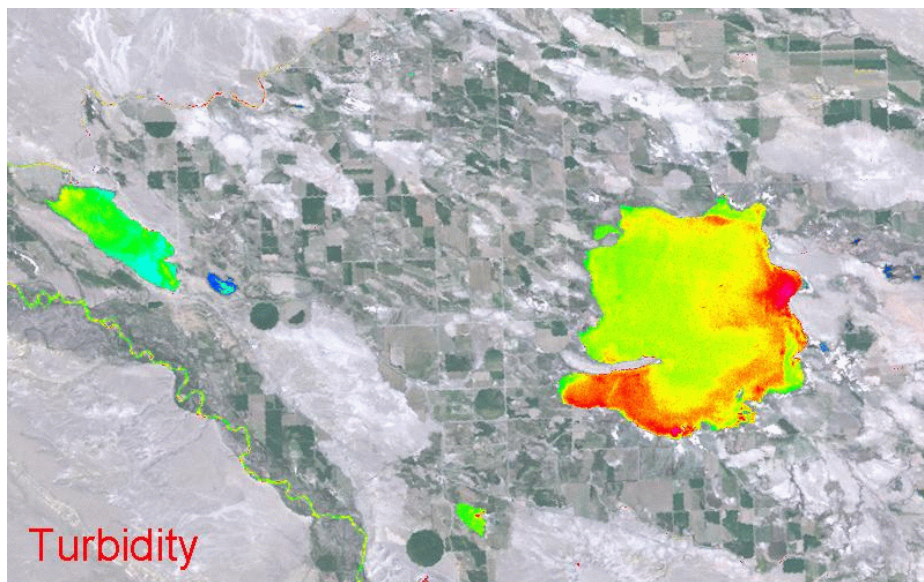


Fig. 119. The Ocean Lake scene with water colorized by turbidity.

Bands 4 (near-IR) and 3 (red) were combined as a normalized difference vegetative index. This index is greatest for growing vegetation. Though darkened by the water, it serves in Fig. 120 as a proxy for chlorophyll content. Reds (small western pond, lower

left river) indicate the greater amounts of growth while greens indicate lesser amounts. A proper calibration for chlorophyll makes a regression analysis among the TM bands.

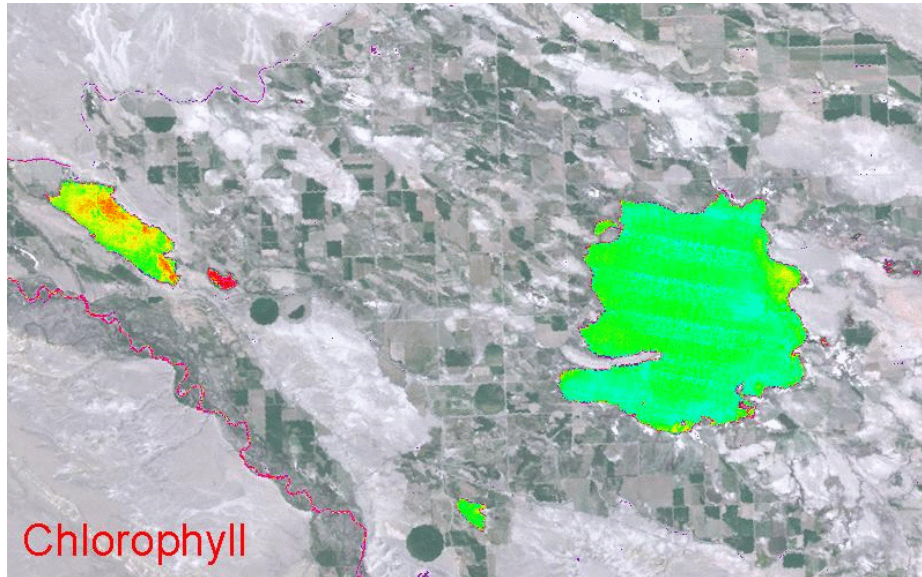


Fig. 120. The Ocean Lake scene with water colored by chlorophyll content.

All six reflective TM bands (not band 6) can be combined in a “tasseled cap” analysis to create three mathematically orthogonal bands labeled Brightness, Greenness, and Wetness. For this Ocean Lake scene in Fig. 121 these products are displayed as R, G, and B, respectively. Only a few fields showed a wetness signal. Growing vegetation had variable greenness. Barren areas had the strongest brightness.

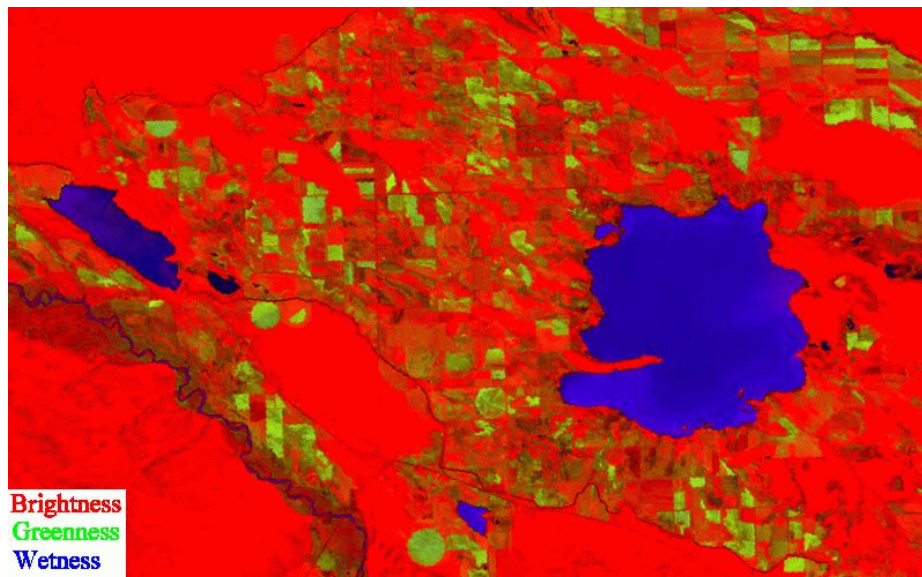


Fig. 121. The Ocean Lake scene with false color rendition of brightness, greenness, and wetness.

Pan-sharpening

Panchromatic systems, rendering a scene as a single band (B&W), can achieve a finer resolution because there are more photons available to the instrument in the broad panchromatic band than in the individual color bands. Satellites like SPOT and Landsat-7 have panchromatic bands with resolution at half the size of the multispectral bands. The IKONOS, QuickBird, and Orbview-3 satellites have panchromatic resolution of 1/4 that of the multispectral bands. For illustration, an IKONOS scene was selected, showing the intersection of Dodson Road and Frenchmans Creek Road, south of the Winchester Wasteway and southwest of Moses Lake, Washington. The individual bands (Fig. 122), natural color (Fig. 123) and CIR (Fig. 124) versions are shown at 4 m resolution, as is the 1 m panchromatic version which has more detail than shown in Fig. 125.

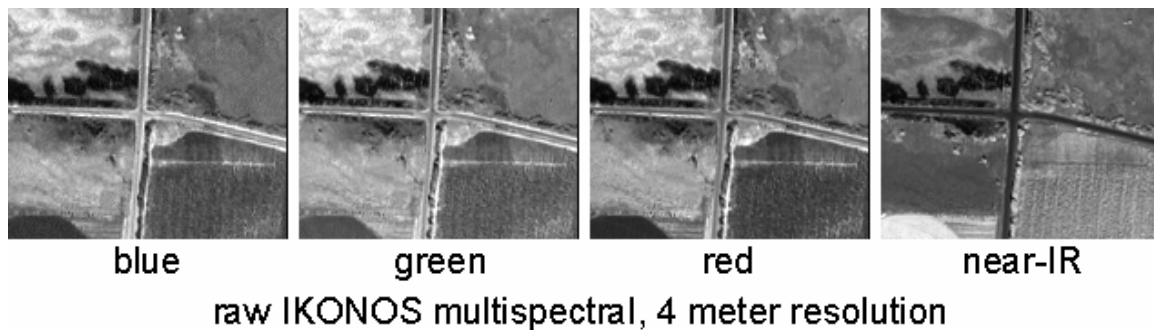


Fig. 122. The 4 IKONOS multispectral bands of the road intersection.

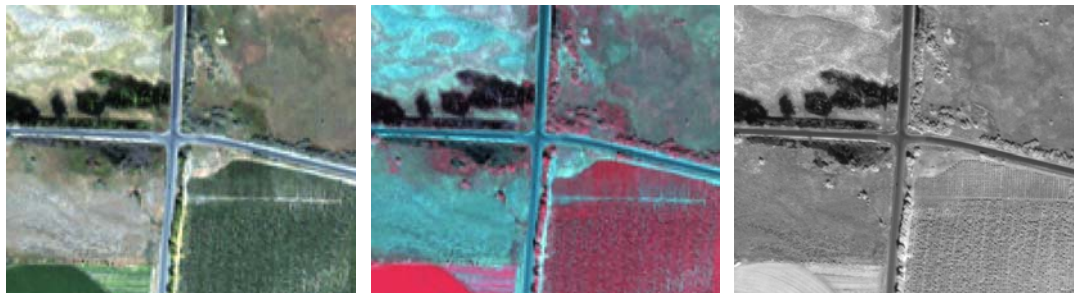


Fig. 123. Natural color.

Fig. 124. CIR version.

Fig. 125. Panchromatic version.

Pan-sharpening (pan-fusion) first involves subsampling the multispectral images to the fine resolution of the panchromatic images. One technique then transforms 3 multispectral bands as RGB into HIS, substituting the panchromatic image for the Intensity image, and transforming back into 3 bands to be displayed as RGB. The other technique transforms any number of bands into principal components, substitutes the panchromatic image for the first principal component, and then reversing the transformation back into the original bands. However, there is a problem of spectral matching that can severely affect the result. The SPOT panchromatic band spectral range overlaps that of the G-R-NIR multispectral bands, avoiding this problem. However, other satellites have the panchromatic spectral range overlapping four multispectral bands (B-G-R-NIR). If one wants a natural color version of pan-sharpening, the NIR

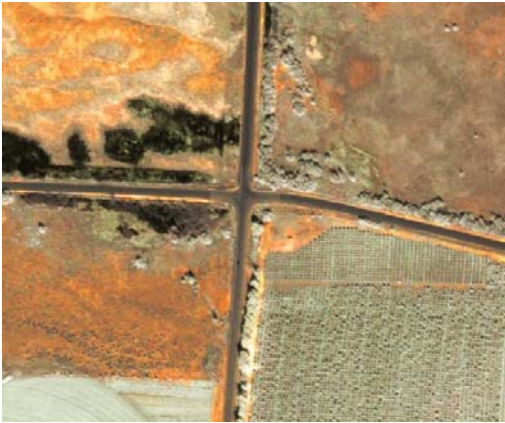


Fig. 126. Pan sharpened version, using a simple HIS substitution routine.



Fig. 127. Visible band panchromatic image from the 4-meter bands

component will greatly brighten the panchromatic image where there is growing vegetation, resulting in abnormally bright vegetation in the resulting pan-sharpened image or distorted colors as shown by the orange tones in Fig. 126.

One way of working around this problem is to create an apparent visible band panchromatic image (Fig. 127) by averaging the subsampled B,G,R components. A regression equation is then created relating the visible band panchromatic to the subsampled NIR and original panchromatic image. That relationship is then used with the subsampled NIR and original panchromatic image to calculate a better (finer resolution) visible band panchromatic image (Fig. 128). It is that calculated image that is used to substitute for the Intensity image in the HIS transformation or the first principal component before reversing the transformation. The resulting pan-sharpened image in Fig. 129 is much closer to natural color and has superb resolution. Texture is now visible in the crop in the lower right, showing the rows more prominently. There are details within the ponds in the upper left that are missed in the 4-meter multispectral bands. Shadowing is now visible beside the trees in the lower right and elsewhere, allowing an interpretation that considers plant height.



Fig. 128. Simulated visible band panchromatic.

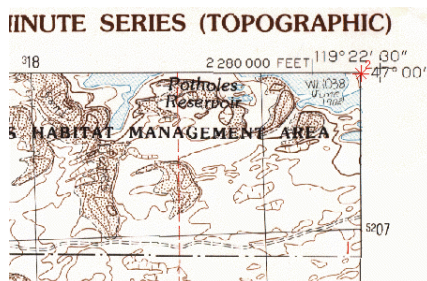


Fig. 129. Pan-sharpened version.

Georegistration

In order to be useful in a Geographic Information System, each raster (image) needs to be georegistered. It is best to assume that all physical materials used to generate raster and vector data are not perfectly scaled. Paper (and similar media) products can contain wrinkles and tears. They may change size with temperature and humidity. Scanned products and Xerox copies will usually have subtle scale differences between the x and y coordinates because the optical scales are not perfectly matched to the scanner movement scale. It is therefore imperative that all such products are individually georeferenced to re-establish the correct scale factors. That means that a sufficient number of control points are identified with respect to some geographic coordinate system.

The georegistration of topographic maps and orthophotoquads can be accomplished by telling the software the location of coordinate tic marks (+ signs) on a map. The initial setup for georegistration is important. The proper coordinate system needs to be specified, though it may be possible, for example, to enter coordinates (and view them in a table) in the latitude/longitude system but save them in the UTM system. The proper Datum and Geoid need to be specified. Topographic quadrangles are typically in the NAD1927 Datum with Clark 1866 Geoid. Properly made maps should have such information in the margins. There are display projection choices with various mathematical complexities: affine, plane projective, bilinear, polynomial, and piecewise versions. They dictate how an image is warped. The cursor is typically used to place a cross hair at a tic mark, with fine adjustments being made by keyboard arrow keys until the overlap is nearly perfect. In Fig. 130 the location is marked with a red symbol and labeled with a number. In the accompanying table in Fig. 131 is a list of the 16 coordinates of the tic marks.



##	Column	Line	Latitude	Longitude	Residual	(n)
1	172.12	162.50	N 47 00 00.0	W 119 30 00.0	5.926	
2	2508.63	153.58	N 47 00 00.0	W 119 22 30.0	2.802	
3	2524.14	3558.49	N 46 52 30.0	W 119 22 30.0	4.064	
4	182.40	3568.43	N 46 52 30.0	W 119 30 00.0	3.876	
5	1743.38	3562.14	N 46 52 30.0	W 119 25 00.0	1.722	
6	963.49	3565.61	N 46 52 30.0	W 119 27 30.0	2.750	
7	2518.60	2423.46	N 46 55 00.0	W 119 22 30.0	1.194	
8	1738.51	2427.08	N 46 55 00.0	W 119 25 00.0	2.595	
9	958.50	2430.55	N 46 55 00.0	W 119 27 30.0	3.242	
10	177.52	2433.47	N 46 55 00.0	W 119 30 00.0	4.772	
11	2513.54	1288.49	N 46 57 30.0	W 119 22 30.0	1.468	
12	1733.61	1292.34	N 46 57 30.0	W 119 25 00.0	4.672	
13	954.54	1295.51	N 46 57 30.0	W 119 27 30.0	3.720	
14	174.48	1298.57	N 46 57 30.0	W 119 30 00.0	3.431	
15	1729.53	156.61	N 47 00 00.0	W 119 25 00.0	2.897	
16	951.39	159.96	N 47 00 00.0	W 119 27 30.0	4.027	

Fig. 130. Georegistration of a topo at tic marks. Fig. 131. A table of Georegistration numbers for a full quad.

The right column contains a list of residuals. That shows the calculated error associated with each location. Such errors should be minimized. Sometimes that can be done by choosing a different display projection choice. In this case, switching from the plane projective system to one of the polynomial powers can reduce these residuals to mostly less than 1 meter. Otherwise each point can be checked and adjusted, starting with the one with the largest error. The example used latitude/longitude tic marks. Alternatively

the UTM grid intersections on the topographic map could have been used, such as that in the lower left corner of the Fig. 130 example.

For fine resolution work a topographic map seldom has enough features that can be used as control points for an aerial photo or video image. Sometimes a coarse resolution aerial photo needs to be used as an intermediate georeference standard. Points in common between the aerial photo (left side, Fig. 132) are paired with the same features in the topographic map (right side, Fig. 132). After the residuals are minimized by appropriate adjustments or deletions of bad points, the software creates the proper georeference for the intermediate aerial photo. Ideally, a digital orthophoto quarterquad will be available, with 1 meter pixels, to serve as a reference image. Its georeference will be provided, eliminating the need for the previous two steps and providing a superior resolution. Then common objects like trees, rocks, road intersections, buildings, etc., can serve as georeference points, as illustrated in Fig. 133 (colored aerial photo on left, older B&W digital orthophoto on right). In addition to providing the locations of all positions in an image, the georeference process establishes the scales (meters per pixel) in the x and y (or column and line) directions for the image. Those scales may differ, particularly in rugged terrain.

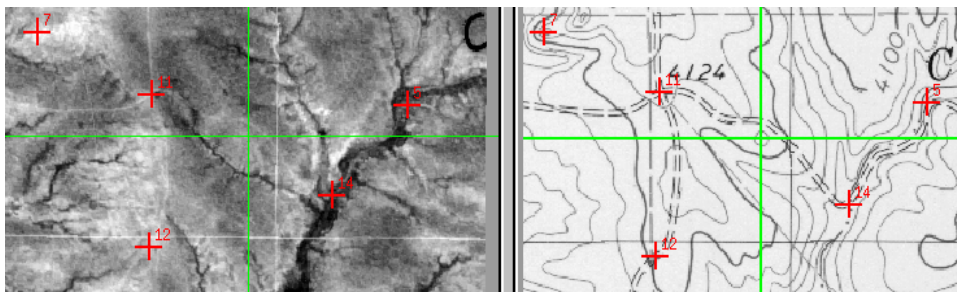


Fig. 132. Tie points used to georeference an aerial image, using a topographic map as reference.

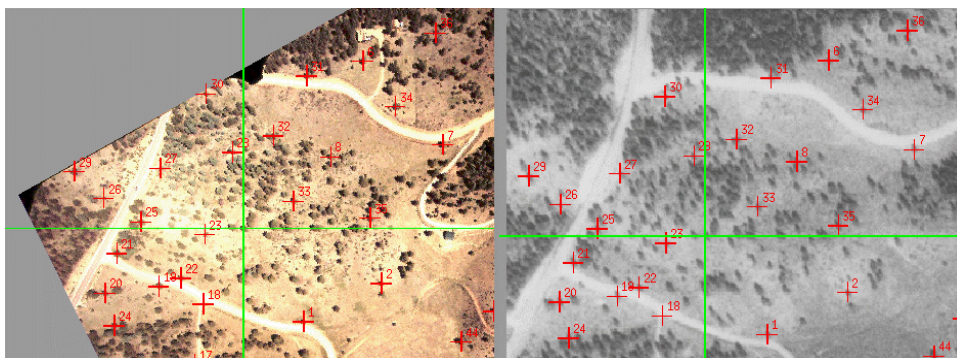


Fig. 133. Tie points used to georeference an aerial image, using an orthophoto as reference.

7. Photogrammetry

Photogrammetry, as defined by the American Society for Photogrammetry and Remote Sensing (ASPRS), is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring,

and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena.

Originally the science was applied to analyzing photographs, either ground based or obtained using an airborne platform such as a balloon, blimp or piloted aircraft. In recent years photogrammetric methods and analysis have extended into fields such as Light Detection and Ranging (LIDAR) and digital imagery, and the airborne platforms now include un-manned aerial vehicles (UAV's) and satellites. However, the principal data source for photogrammetric analysis continues to be film based photographs.

Reclamation primarily uses photogrammetric methods, analysis, and products in the forms of aerial photography, orthophotography, digital elevation data (DEM, DTM, TIN, contours, cross-sections, etc.), topographic maps, and photographic interpretation (PI). Aerial photography, taken with a calibrated large-format (9"x9"), metric aerial survey mapping camera is usually of primary data source. In the past couple of years, larger format digital aerial cameras/sensors (Z/I DMC, Leica ADS40) have been developed, purchased, and are in use by several large North American mapping companies. On occasion Reclamation has a need to use ground based terrestrial or close-range photogrammetric methods to meet special project requirements. Close-range photogrammetry, defined as having a 300-meters or less object-to-camera distance, is based on the same scientific principles and similar data needs as the more familiar aerial based photogrammetry.

Aerial photography and photogrammetric methods have many applications within Reclamation, including compilation and production of many types of maps and digital data; crop maps, wetland maps, land use and management, infrastructure, vegetation, irrigation components/networks, riparian vegetation, geologic studies, geomorphology/sediment transport, hydraulic models, wildlife and aquatic habitat, change detection, trespass, and trend analysis.

Photographs are taken from essentially a point location, using a lens that may add some radial distortion (more obviously seen in a fish-eye lens) with respect to the center of the image. Perspective from that point location makes objects that are vertically near the camera appear at a radially greater distance from the center of the photograph than objects farther away. A vertical object, such as a building, tree or pole, as viewed in aerial photography, will appear to lean back radially from the image center. The same applies to topographic differences; hilltops will similarly lean away from the image center. Therefore aerial photographs will not have its viewed objects in exactly the same relative positions as should appear on a map. A computationally intensive process is used to correct for the lens and terrain distortions to produce a special type of image known as an orthophotograph.

In the past stereo analysis of aerial photography required large manual machines and manual operation by the person viewing the imagery. Perhaps fifteen years ago software was written for mainframe computers to semi-automate the process. More recently, some PC and workstation software packages allow the semi-automated analysis of a pair of

stereo images. Sometimes the phrase “soft copy photogrammetry” is used. After some initial definitions for scale, orientation, geographic registrations, elevation ranges, and an assortment of tie points (same physical object in both images), the software generates a pair of “epipolar” images in which all elevation displacements are along an axis parallel to the line between the photo centers. Additional tie points are then added, especially along ridges, depressions, and slope changes. The software then uses an autocorrelation

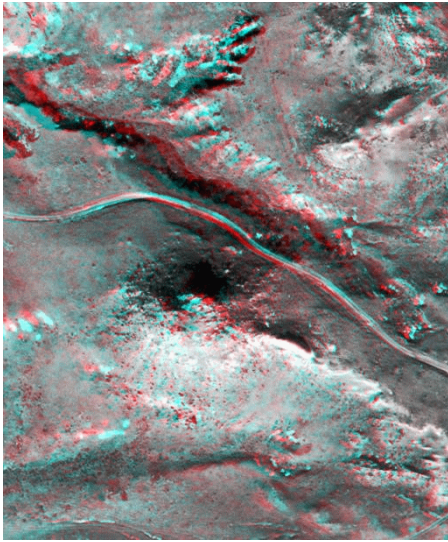


Fig. 135. A hill and valley stereo pair as left = red, right = cyan.

technique to identify other points that are the same object in both images, then convert their positional differences (parallax), parallel to the line between the centers of the two images, into elevation values. The result is a digital elevation model (DEM), expressing the elevation everywhere across a scene within the overlap of the two stereo images. The elevation data can be contoured to provide a map representation. In a related process, if the digital elevation data are known, the picture can be warped to remove distortions caused by elevational differences. The resulting product is known as a digital orthophoto. Quadrangle versions are known as DOQ and DOQQ. They are excellent products for georeferencing aerial and satellite imagery. As an example, Fig. 134 shows a small stereo pair of a badland hilltop and adjacent stream valley with the left image on the left and right while the right image is in the center. The left and center views can be

used with a stereoscope or viewed directly by people who can see straight-on stereo. The center and right views are for people who can do cross-eyed stereo viewing. Another version in Fig. 135 shows a superimposed, colored version with red for the left image and cyan for the right. When viewed through anaglyph glasses with red over the left eye and cyan over the right, the topography will appear in 3-dimensions. However, if the colored lenses are reversed, hills will appear as pits and valleys as ridges.

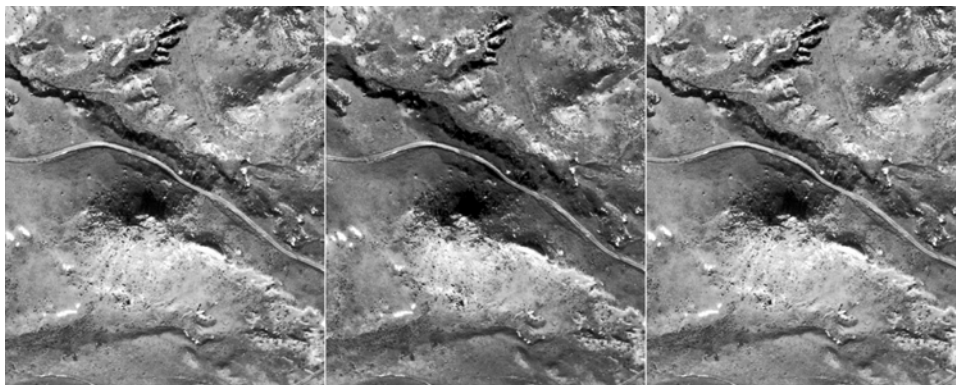


Fig. 134. A hill and valley stereo pair as left-right-left.

After the DEM has been generated by the software, it is usually good to run a median filter over the result to remove some of the noise and small blemishes. For comparison, the topographic map, with 20 foot contours was resampled as Fig. 136 to the extents of the stereo view. The DEM derived from the stereo pair is colorized in Fig. 137 at 1 meter vertical resolution, with the dark bands at 5 meter intervals. There is much more detail in the stereo-derived DEM, much from rocks and grass tufts, but there are also some blemishes caused by shadows and other things that confused the autocorrelation process.

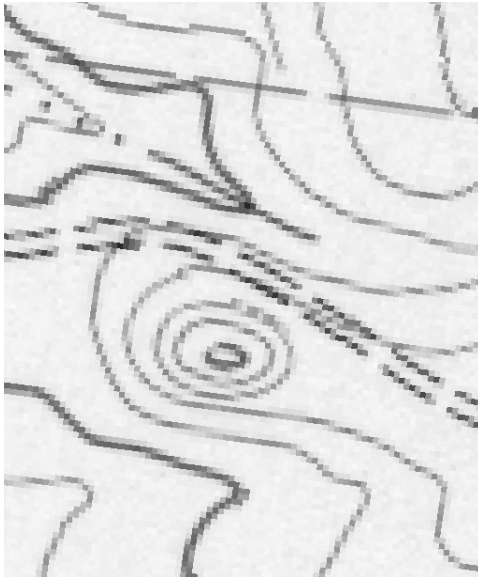


Fig. 136. Topographic map with 20' contours.

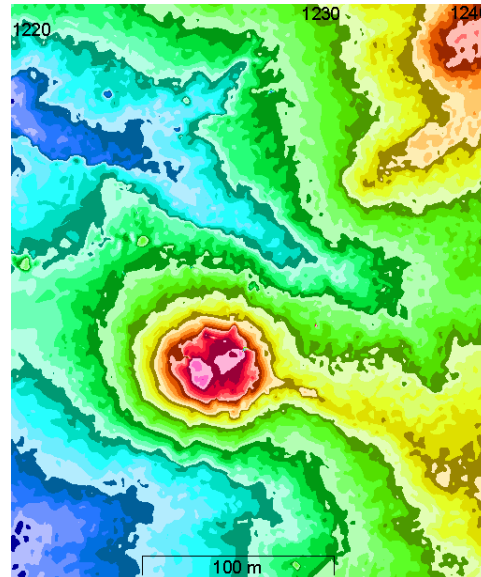


Fig. 137. Colorized DEM derived from stereo pair.

An example of the value of orthophotographic rectification is shown by a view of the Interstate-70 cut through the hogback west of Denver. The aerial photograph was taken

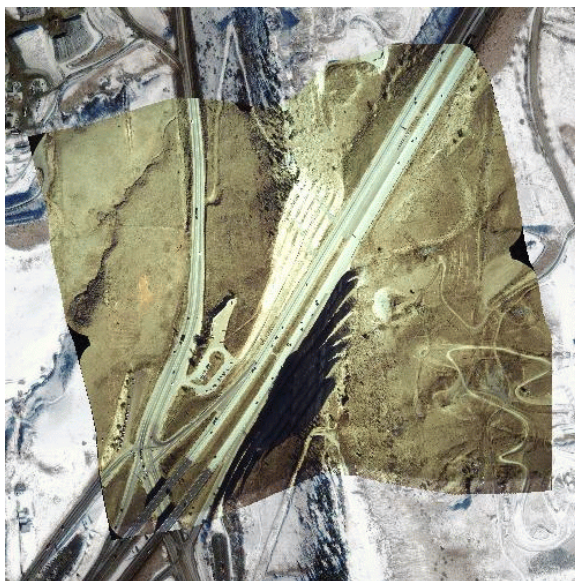


Fig. 138. Aerial photo of I-70 warped to an orthophoto.

at a relatively low altitude and therefore experienced strong radial displacements of high topography. The scene was georeferenced to an orthophoto produced by a combination of IFSAR (interference synthetic aperture radar) derived topography and an IKONOS satellite image. The aerial photo was then warped by software designed to produce an orthophoto from an aerial photograph and a DEM (digital elevation model). The result was superimposed on top of the IKONOS image. It is useful to watch for mis-matches along the edges of the warped photograph. They indicate the quality of the software adjustments. It is seen in Fig. 138 that the picture edges are

greatly distorted by a reversal of the radial stretching in the original view. The amount of change in this image of rugged topography shows the need for orthophotographic corrections of an aerial image.

A scanner uses the forward motion of the aerial or satellite platform to assemble a series of cross-track image lines into a 2-dimensional picture. The instantaneous view is only along a narrow slit perpendicular to the flight direction. All elevation distortions are perpendicular to the flight line. Higher things lean back away from the flight line. Elevations can be derived only from parallel passes, not imagery from a single pass, and then from a more specialized software algorithm.

Some satellites are able to take off-nadir views intentionally. Such images can be used as stereo pairs to derive elevations of the landscape. The early SPOT satellites took their off-nadir views perpendicular to the orbital path, requiring that the pairs were taken on different orbits and days. The ASTER camera on the Terra satellite routinely takes a nadir view and a backwards view (along orbital path) in the NIR band 3, designated 3N (nadir) and 3B (backwards). The newest generation of high-resolution satellites, IKONOS (Space Imaging), Orbview-3 (OrbImage), and QuickBird (Digital Globe) have the capability to obtain 1-meter or better spatial resolution images in the panchromatic wavelength band. These images, properly manipulated, are suitable for many applications including orthophotography and digital elevation data extraction. They can acquire imagery at any angle with respect to the vertical and orbital path. Off-nadir and scanner geometries require special software algorithms for deriving elevation models.

Reclamation currently has three aerial photography and mapping services IDIQ contracts in place; UC-Salt Lake City (Bureau wide), GP-Billings, and MP-Sacramento. You must be able to effectively communicate your data requirements to the Reclamation Contracting Officers Representative (COR/COTR) and in turn the photogrammetric mapping contractor to ensure success for your mapping project. Reclamation offices in Denver, Phoenix, and Sacramento also have persons knowledgeable in photogrammetry and photogrammetric workstations. Depending on the size and needs of your project you may want to consult with Reclamation people and tap into their experience.

Proper planning is essential to the success of any photogrammetric mapping project. One of the first things that needs to be determined are your data requirements, including the accuracy needed. Data requirements include being able to accurately describe or delineate on a map where you want your photogrammetric data collected and when. Higher accuracy or resolution data does cost more than lower accuracy/resolution data.

A typical scope of work (SOW) for photogrammetric data acquisition would include things such as; project area map, scale of aerial photography needed, film type (panchromatic/BW, color, color infrared), timing of aerial photo acquisition, targeted map/data accuracy, ground control and/or airborne GPS control needed (accuracy driven), contact prints-diapositives-enlargements needed, digital orthophotographs needed (w/pixel size stated), elevation data needs (DEM/DTM, mass points/breaklines, spot elevations, contours, cross-sections, hydro-corrected DEM, etc.), planimetric

features to collect (scale driven) such as roads, curbs, hydrology, buildings, infrastructure, vegetation, etc., file formats and sizes, flight line maps (digital & hardcopy), are any hardcopy map plots needed or just the digital data, delivery dates, etc.

A photogrammetric workflow process should include:

1. Define area to be mapped, data and mapping products needed.
2. Prepare a detailed scope of work.
3. Plan aerial photography and control (ground and/or airborne GPS) acquisition.
4. Aerotriangulation
5. Digital elevation (terrain) model (DEM, DTM) data collection.
6. Digital orthophotographs; radiometric correction, editing, mosaic, format, image compression (if needed).
7. Triangular irregular networks (TIN) and contours.
8. Planimetric feature collection.
9. Edit contours and planimetric features.
10. Map graphics and data file tiling (if needed).
11. Data file formatting; image files, AutoCAD files for engineering, ArcInfo for GIS, etc.
12. Map plots on paper or film; edit, legends, size/scale, index map, etc.
13. Production of FGDC compliant metadata.

The primary pieces of information needed for a photogrammetric mapping project are an image source (aerial photographic film or digital imagery), ground control and/or airborne GPS coordinate data, and a camera calibration report. If these pieces have been properly collected for your project area you can then use photogrammetric equipment and techniques to extract and produce various types of data.

Map accuracy standards

The primary accuracy standards in use today are the National Map Accuracy Standard (NMAS) initially developed in 1947 and expanded upon during the last decade by subcommittees of the Federal Geographic Data Committee (FGDC), and the ASPRS Accuracy Standards for Large-Scale Maps (1990) class 1, class 2, and class 3. The ASPRS Class 1 standards are more rigorous (costly) and contain more definitive statistical map testing criteria, lower classifications will be more economical, with decreased accuracy.

NMAS Horizontal accuracy: NMAS states that for maps of publication scales larger than 1:20,000, not more than 10-percent of points tested shall be in error more than 1/30th of an inch, measured on the publication scale; for maps of publication scales of 1:20,000 or smaller, 1/50th of an inch. These limits of accuracy apply only to well-defined points (easily visible or recoverable on the ground). For example; a 1:24,000 scale map should have a horizontal accuracy of 40-feet (1/50th inch), and a 1:12,000 scale map should have a horizontal accuracy of 33.3 feet (1/30th inch).

NMAS vertical accuracy: As applied to contour maps at all publication scales, shall be such that not more than 10-percent of the elevations tested shall be in error more than one-half the contour interval; i.e. a 10-foot contour interval map should be within 5-feet vertically.

Table 1. ASPRS Class 1: Planimetric Feature Accuracy (X or Y coordinate in feet, for well defined points. (From ASPRS and COE)

Map Scale 1"= x feet	Ratio feet/foot	Limiting RMSE in X or Y (feet)
40	1:480	0.4
50	1:600	0.5
100	1:1200	1.0
200	1:2400	2.0
300	1:3600	3.0
400	1:4800	4.0
500	1:6000	5.0
600	1:7200	6.0
800	1:9600	8.0
1000	1:12,000	10.0
1667	1:20,000	16.7

Target contour Interval (feet)	Topographic Feature Points	Spot Elevation Points
1	0.33	0.17
2	0.67	.33
3	1.0	.50
4	1.33	0.67
5	1.67	0.83
10	3.33	1.67

Table 2. ASPRS Class 1: Elevation Accuracy for Well-Defined Points. (From ASPRS and COE). ASPRS Limiting RMSE in feet

Keep in mind that Reclamation IDIQ mapping contractors have been selected in part due to their rigorous quality control (QC) program. The testing of map accuracy can be costly and time consuming, Reclamation, as with most government entities, relies heavily on the contractors QC program and procedures to check for and catch mistakes. A photogrammetric mapping project should not be an adversarial process, if planned, carried out, and checked properly you will end up with a good project. The vast majority of contractors want to produce good and accurate products, and depend on customers to return with new work. If their reputation suffers due to sloppy or careless work their workload usually suffers too.

Final Map Scale	Pixel Size (ground units) in feet
1"= 50 feet (1:600)	0.25
1"= 100 feet (1:1200)	0.50
1"= 200 feet (1:2400)	1.0
1"= 400 feet (1:4800)	2.0

Table 3. Recommended Pixel Size for Selected Orthophotograph Map Scales:

8. Digital Elevation Models

Digital elevation models of various resolutions and qualities are available for free or purchase from the USGS. The oldest series were derived from 1:250,000 scale topographic maps by the Defense Mapping Agency (DMA) decades ago. They are available in 30 arc-second and 3 arc-second resolution, meaning that data points are every 30 or 3 seconds of arc in latitude/longitude coordinates. This set is continued in the global GTOPO30 DEM for the 30 arc-second series. The user should be aware of flaws in these data. The data do not always match the real topography. Sometimes the georegistration of the data is offset. Some elevations seem quantized at elevations like 200 ft, which is the contour interval on many of the maps used in deriving the DEM. A newer series is the 30 meter DEMs derived from 7.5 minute topographic map contours. More recently, DEMs have been developed as byproducts of digital orthophotos.

In 2000 the Space Shuttle used C and X band SAR radar technology to create a DEM of the entire U.S.A. at 1 arc-second resolution. Since 2003, it can be ordered in Arc-GRID format at <http://srtm.usgs.gov/data/obtainingdata.html>. The Shuttle Radar Topography Mission (SRTM) is a joint project between the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA). For the rest of the world the project produced digital topographic data for 80% of the Earth's land

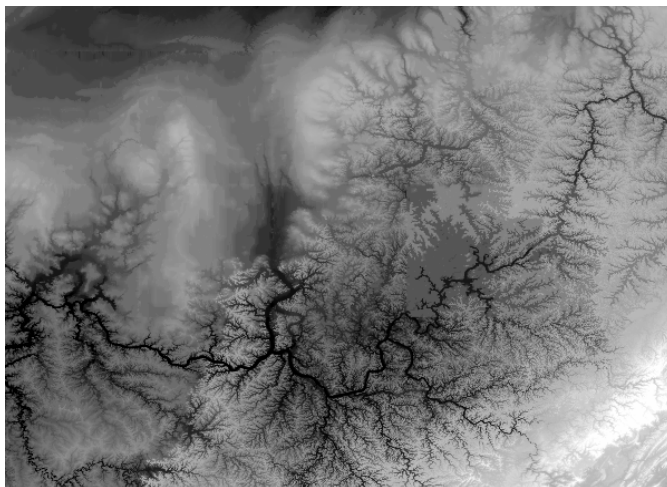


Fig. 139. The DMA DEM for the Ohio region showing flaws.

surface (all land areas between 60 north and 56 south latitude), with data points located every 3-arc second (approximately 90 meters) on a latitude/longitude grid. The absolute vertical accuracy of the elevation data is 16 meters (at 90% confidence). Perhaps a more convenient source in GeoTIFF format is from the University of Maryland site, <http://glcfapp.umi.acs.umd.edu:8080/esdi/index.jsp>, which also has free Landsat and some ASTER data.

To illustrate some of the problems in the older data set, a subset of the 30 arc-second data in the Ohio River valley, N 37° to 41° 20', W 80° to 85° is displayed in Fig. 139. Dark tones are lowlands and bright tones are highlands in this normalized contrast rendition. The Ohio River extends from the upper right to the center left. Across this scene the amount of detail varies significantly. The southern portions have much fine detail. The northwest is greatly smoothed, mostly by the continental Ice Age glaciers. To the right of the center there is a 1-degree square within which are large flat areas, looking very artificial.

For the northwest portion of that DEM data set the software was used to create a solar shading, as if the sun were in the northeast (45° azimuth) at 50° above the horizon (an impossible location). The shaded diagram in Fig. 140, with normalized contrast, is

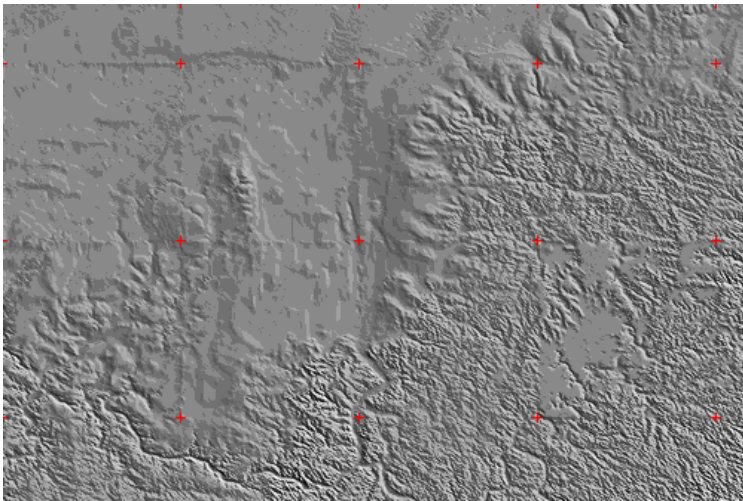


Fig. 140. A shaded relief of the Ohio DEM.

annotated with red marks at the 1° latitude/longitude positions. Notice that there are some edges visible between the 1° squares, indicating a mismatch of elevations. The flat, plateau-like data area is in the lower right portion of this view. Such flaws create severe problems for spatial analysts.

For comparison, the second shaded view in Fig. 141 uses data from the Shuttle mission, subsampled to the same resolution. The flaws are missing and the detail is better. The smooth areas in the northwest now clearly show a set of terminal moraines from the Ice Age glaciers.

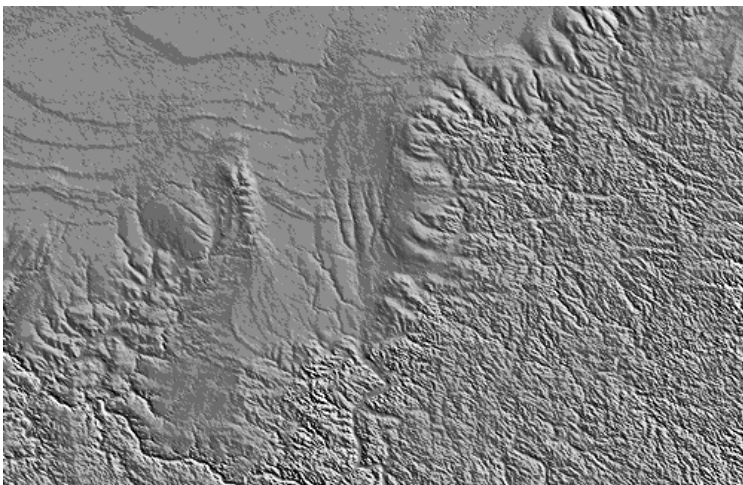


Fig. 141. A shaded relief of the Ohio DEM using Shuttle radar data.

When a solar shading image is created, the software must also derive slope and aspect images. Areas in the slope diagram in Fig. 142 with a value of zero are colored red. This highlights the DEM problem areas. Apart from such flaws, slope images are

best shown with logarithmic contrast. Steep slopes will be bright. The general texture of slope images is one of a pile of spaghetti. Some lines, as in the upper left, seem artificial where there is a jump in the elevation because of analytical resolution in creating the DEM.

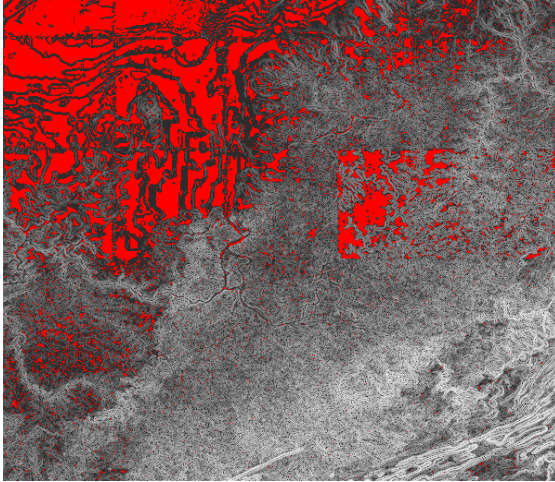


Fig. 142. Slope version of DEM, white are steep slopes

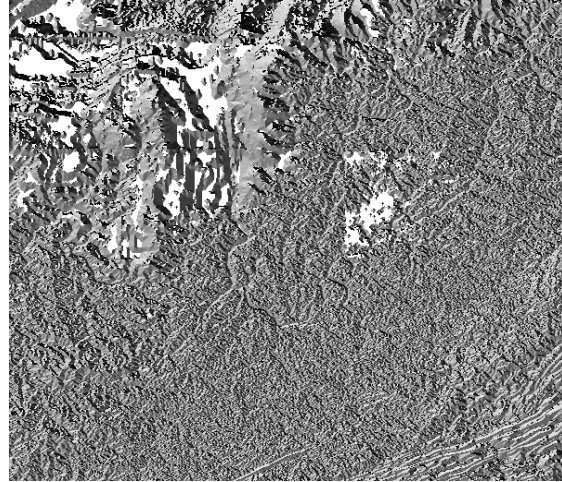


Fig. 143. Aspect version of the DEM.

Aspect images have a different visual texture, that of a metallic surface, shown in Fig. 143. Values of 0 and 240 represent a slope to the north. 60 is eastern, 120 is southern, and 180 is western. Intermediate aspects are proportionally distributed. The white areas in this image are where no aspect could be determined because of zero slope over distances greater than the size of the window within which the aspect is calculated.

Viewshed

DEM data can be used for calculating viewsheds from a particular location. A DEM data set from the southeastern U.S.A. (without serious flaws) has been selected for illustration. (N 32° 40' to 37°, W 80° to 85°). In this solar-shaded view of Fig. 144 the southern

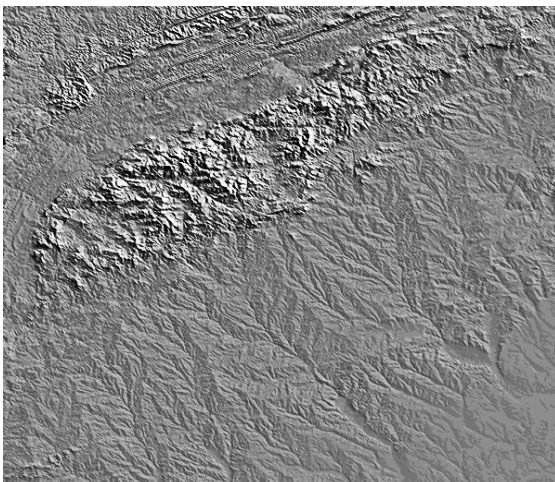


Fig. 144. Shaded relief in southern Appalachians and Piedmont.

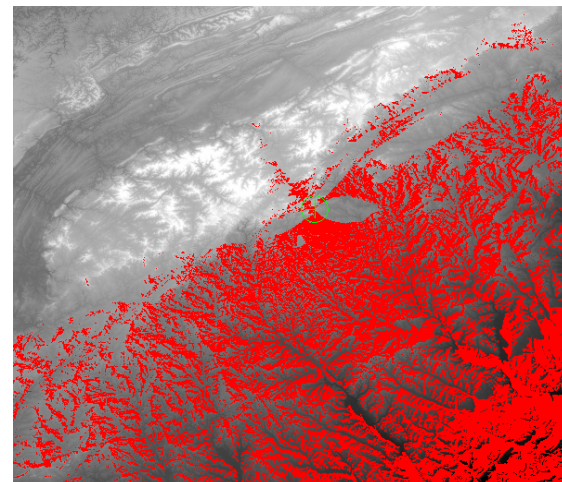


Fig. 145. Viewshed (red) from a mountain peak, sees the Piedmont but not into the mountains.

Appalachian Mountains are prominent, as well as the Piedmont. A particular high point was selected on the southeast side of the range. The viewshed program was instructed to show the terrain as viewed from 3 meters above the peak. The flat-earth solution was computed rather than one simulating earth curvature. The viewpoint is at the green crosshair and circle. In Fig. 145 the terrain in view is colored red on the DEM. The view of the lowlands is excellent, being affected only by local topography. The view does not penetrate into the mountains to any significant extent.

The viewshed program is also useful for crudely predicting FM radio propagation, where a signal might reach the ground. In practice, the computation really needs to use an Earth radius of 4/3 the actual Earth radius to simulate the refraction of radio waves in the atmosphere. It is only appropriate for FM transmissions, which are generally line-of-sight, not for AM or short-wave radio which interact with the ionosphere.

Watershed

The same Piedmont DEM was used in the watershed routine, originally written about 1990 at the USGS EROS Data Center, Sioux Falls, SD, and later adapted to numerous

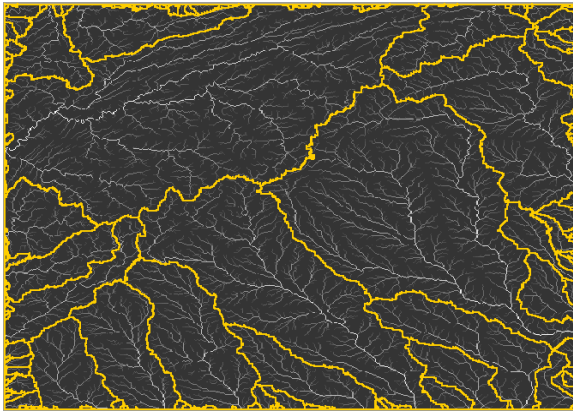


Fig. 146. Water flow accumulation result from a watershed program, with basin boundaries.

software packages. The routine fills in any closed depressions in the DEM, then computes aspects for flow directions. For each pixel it determines the number of pixels upslope, thereby computing an accumulation image. Natural watershed boundaries and flow channels are determined. The routine allows the analyst to nominate one or more “pour points” for the determination of the upstream watershed from that location.

This illustration in Fig. 146 is of the flow accumulations (logarithmic contrast) as white lines on a black background, with

gold lines being the default watershed boundaries determined from which large channels intersect the edge of the view. Many other products could also be displayed.

Vegetation Gradients

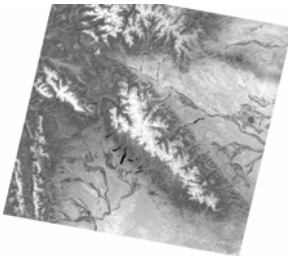


Fig. 147. Landsat view of Wind River Range, Wyoming.

DEMs can also be used as a component in 2-D histograms. A nearly entire Landsat TM scene (red band 3) of the Wind River Range in Wyoming was selected. The elevations of the same area, from the Shuttle SRTM data, were rescaled to an 8-bit range by subtracting an offset and dividing by 12. The scene in Fig. 147 shows bright lowlands with dark irrigated fields. The

highlands are snow covered in this early July scene. In between the slopes are covered with dark conifer trees.

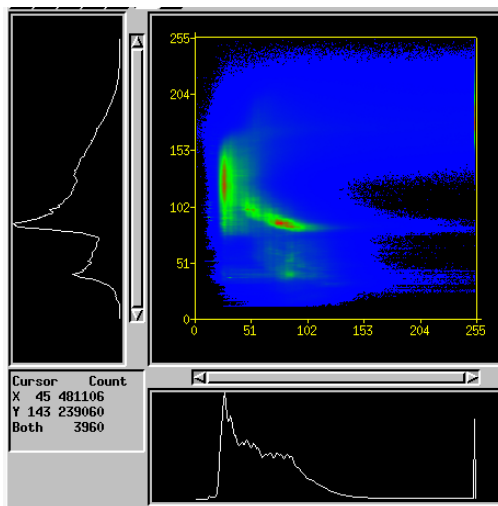


Fig. 148. A 2-D histogram of scene brightness (X-axis) and elevation (Y-axis).

A 2-D histogram of the scene was calculated for Fig. 148. The bottom graph shows the distribution of digital numbers for the red raster, with dark to the left and bright to the right. The left graph shows the distributions of rescaled elevations. The lowest elevations are from the upper right corner, the lower peak from the eastern lowlands, and the main peak is from the southern lowlands. In the colored portion the central green patch with red core represents the southern lowlands, the lower small green dot the eastern lowlands, and the left vertical green patch with red core the conifer covered mountain areas. The snow patches are at the upper right edge, showing saturated brightness. Elevation control of band 3 brightness is strong in this scene.

9. Geographic Information Systems

A Geographic Information System (GIS) is a computer program that organizes data according to their geographic relationships. Originally the term tended to be restricted to a particular software brand and to its descriptions of the boundaries of regions with common properties (fields, roads, rivers, land cover types, etc.). The latest software versions have greatly expanded their capabilities, making the GIS term cover many more techniques.

Rasters

A GIS will usually contain an image processing system that manipulates rasters (2-dimensional imagery). Such imagery can be used as background upon which GIS analyses are overlaid. Rasters are often the source upon which vector (points, lines, areas) interpretations are generated through the process of digitization or direct raster-to-vector conversion.

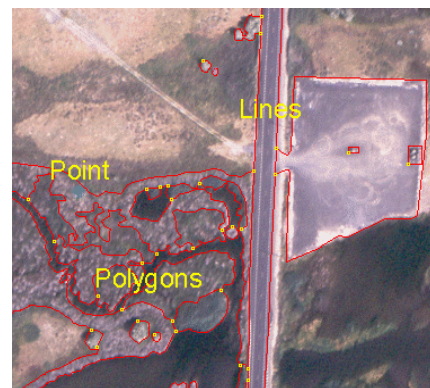


Fig. 149. A view of Winchester Wasteway, illustrating sketched vector features.

Vectors

A vector object is a collection of points, line segments, polygons, and nodes and annotation, illustrated in Fig. 149. Line segments (red) connect points, though some points (cyan) can be left as isolated points to identify locations of particular objects. A set of line segments that encloses an area is called a polygon, which is normally very irregular in shape. Line segments intersect (T, X, or other shape intersection) at a node (yellow). Line segments can end at a dangling node (green). Polygons can be islands within other polygons. Annotation, or Labels, help interpretation. These vector objects can be assigned any desired color and drawing style. Polygons can be filled with solid colors or patterns and be shown with or without border lines.

Vectors can be generated directly from paper (or other physical medium) maps and imagery by the process of digitization. The paper is fastened to a digitizing tablet. The coordinates (x,y pairs) are read electronically as a cross-hair device is moved over the features of interest. The same can be accomplished on a computer screen by “heads-up” digitizing. The map or imagery is scanned and displayed on the computer screen as a raster; the cursor is moved over the features of interest to get the coordinate pairs. Software techniques exist to convert lines in raster imagery into vector lines, as shown later for contour following.

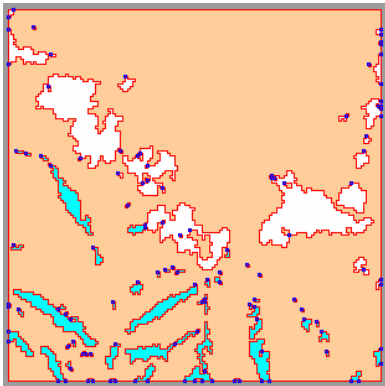


Fig. 150. Vector generated from automated classification.

Similarly, boundaries of solid colors in a raster (created by a classification process) can be converted to polygons. In Fig. 150 a raster was created from Landsat data by a partition process. The white areas are clouds and the cyan are snow on the ground (tan). Nodes are dark. The vector polygons were generated at the pixel edges, as shown by the square-stepped borders. The polygons were automatically assigned a numerical classification code identical to the code represented by the colors.

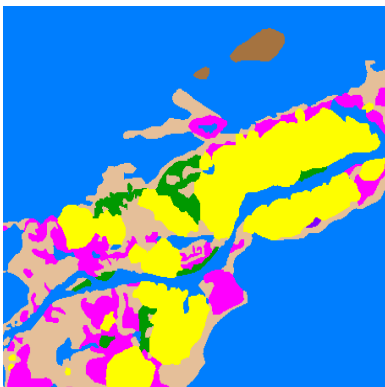


Fig. 151. Vector polygon classification of plant types.

Lines can be used to represent roads, railroads, trails, streams, political boundaries, field boundaries, etc. Polygons can be labeled according to the contents of their interiors. Such can be soil types, land cover, water rights, and many other categories. The Fig. 151 example is a plant classification created by visually examining a scene in stereo aerial imagery, hand-drawing boundaries on a basemap image and assigning the classifications to the resulting polygons. Each plant class is assigned its own color code. Here blue is unclassified land and water, yellow is the reed Phragmites, green is cattails and bulrushes, magenta is flowering purple loosestrife, brown is unhealthy purple loosestrife, and tan is dead purple loosestrife.

loosestrife, all along the Winchester Wasteway in Washington.

Polygons from different data layers (like elevation zones, soil types, land cover, population density, endangered species locations) can be overlapped to show relationships between the different data layers, possibly generating additional categories for classification. Buffer zones at fixed distances from other objects (points, lines) can be created by the software.

Vector sets generally take less storage space than rasters and are faster to analyze. However, they cannot contain the fine image detail of rasters. They are best for generalizing properties under consideration. Vector objects can have data base and text objects assigned to them, whereby the data associated with some vector object can be viewed at will.

The process of generating vector data, either by hand entries (digitizing) or by conversion from raster data, will usually generate errors. Hand vibrations and pixel edges cause wavy line segments which may need smoothing. Line intersections may have overshoots to be removed, or the lines may not connect at all, requiring “snapping” to form a connection at a “node”. A merger of vector data from two sources may have lines that should be the same. However, irregularities in the line data during a merger process cause an artificial creation of tiny polygons along what should be a single line. Such artifacts need to be removed. Vector cleanup is mandatory before analysis can properly begin. For illustration, some vector data were automatically generated from a contour map.

In Fig. 152 the numbers generated junk lines that need to be removed. These are examples of dangling lines. They can be marked for deletion (shown in red) or possibly removed by specifying a short length threshold. Other lines that are not contours also need to be removed. In Fig. 153 there is a small triangular polygon that should not be there. Such artifacts could be removed. In Fig. 154 the errors were generated by contours that were close together. Fig. 155 shows some additional lines (green) were edited manually, while the red lines were marked for deletion. The excess nodes (blue) were then removed.



Fig. 152. Dangling line.

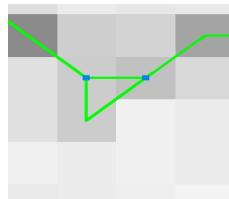


Fig. 153. Bubble artifact.

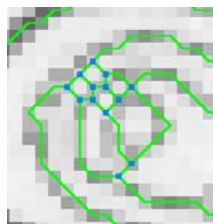


Fig. 154. Multiple bubbles.

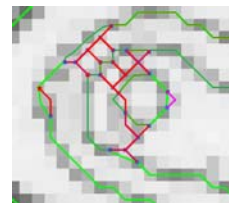
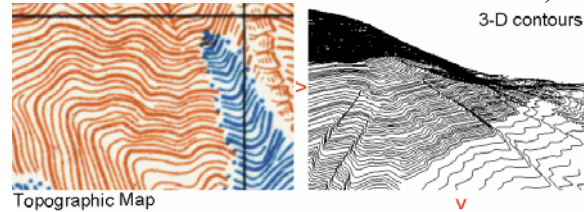


Fig. 155. Hand Scketching

Databases can be attached to vector elements. By touching an element with the cursor the data base information for that element is brought into view. Sometimes values in the database can be used to affect the size of vector symbols.

Though vector sets are normally 2-dimensional, 3-dimensional vectors can be created by assigning elevations to all components. A 3-D representation of a topographic map has the contours with assigned elevations (no contours can cross if their elevations differ) and possibly some individual points (bench markers). Such 3-D contours can be used to generate a surface raster which is a digital elevation model (DEM). The three major steps are shown in Fig. 156



CAD

Vector sets without precise topological rules can be expressed as CAD (computer aided design) objects. Otherwise they are similar.

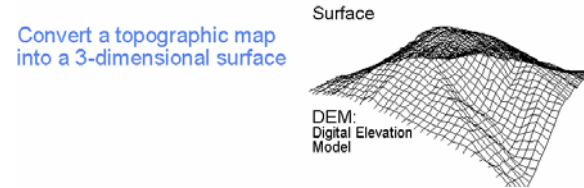


Fig. 156. Steps in making a DEM from a topographic map.

TIN

A triangular irregular network (TIN) is a series of triangles, the nodes of which express some data quantity, such as elevation of a surface. Within each triangle the data are assumed to vary linearly with direction. Where changes are more rapid and non-linear, the triangles are smaller and closely packed. In regions that are generally flat or with a constant magnitude and direction of slope, the triangles are large and sparse. A TIN representation of a variable surface usually takes less data storage space than a DEM and provides computational advantages when generating 3-dimensional perspective surfaces.

Data Bases

Data Bases (DB) allow an organization of data of various types. Software can form an attachment of DB elements to vector objects so that properties associated with the vector objects can be read or interrogated. Sometimes the data base values can be used to control the plotted appearance of the vector objects, such as symbol size or orientation. Queries can be made to quantify and map particular DB values. Data Bases, such as Dbase, Oracle, and Informix, could be easily linked to a GIS. This creates more value for storing, archiving, and analyzing data sets.

Conversions

Rasters can be converted to vectors and CAD. Vectors and CAD can be converted to rasters. DEMs and TINs expressing elevation can be converted to the other type.

Changes

There are many applications in which documentation of changes is of greatest value. This can be a time series of remote sensing and/or GIS data layers. It can be a comparison of conditions before and after some significant event. Remote sensing

products from satellites showed themselves particularly valuable in documenting the extents of damage following the Asian tsunami of late December 2004 and of Hurricane Katrina in southern U.S.A in late August 2005. A small segment of damage in Biloxi, Mississippi, is shown in Fig. 157. The upper half shows a “before” view from the IKONOS satellite operated by SpaceImaging. The lower half is the same view after passage of the hurricane when cloud-free skies allowed viewing from the satellite. At the right side, notice the destruction of the road causeways. At the left side, notice the movements of the casinos to onshore positions. Trees and houses were destroyed in most locations and their debris piled and scattered. Large buildings, with stronger construction standards, remained intact. In other cities all buildings and vegetation within several city blocks of the shoreline were scoured totally, leaving only remnants of the foundations. The same change detection techniques are applicable to other, lesser disasters.

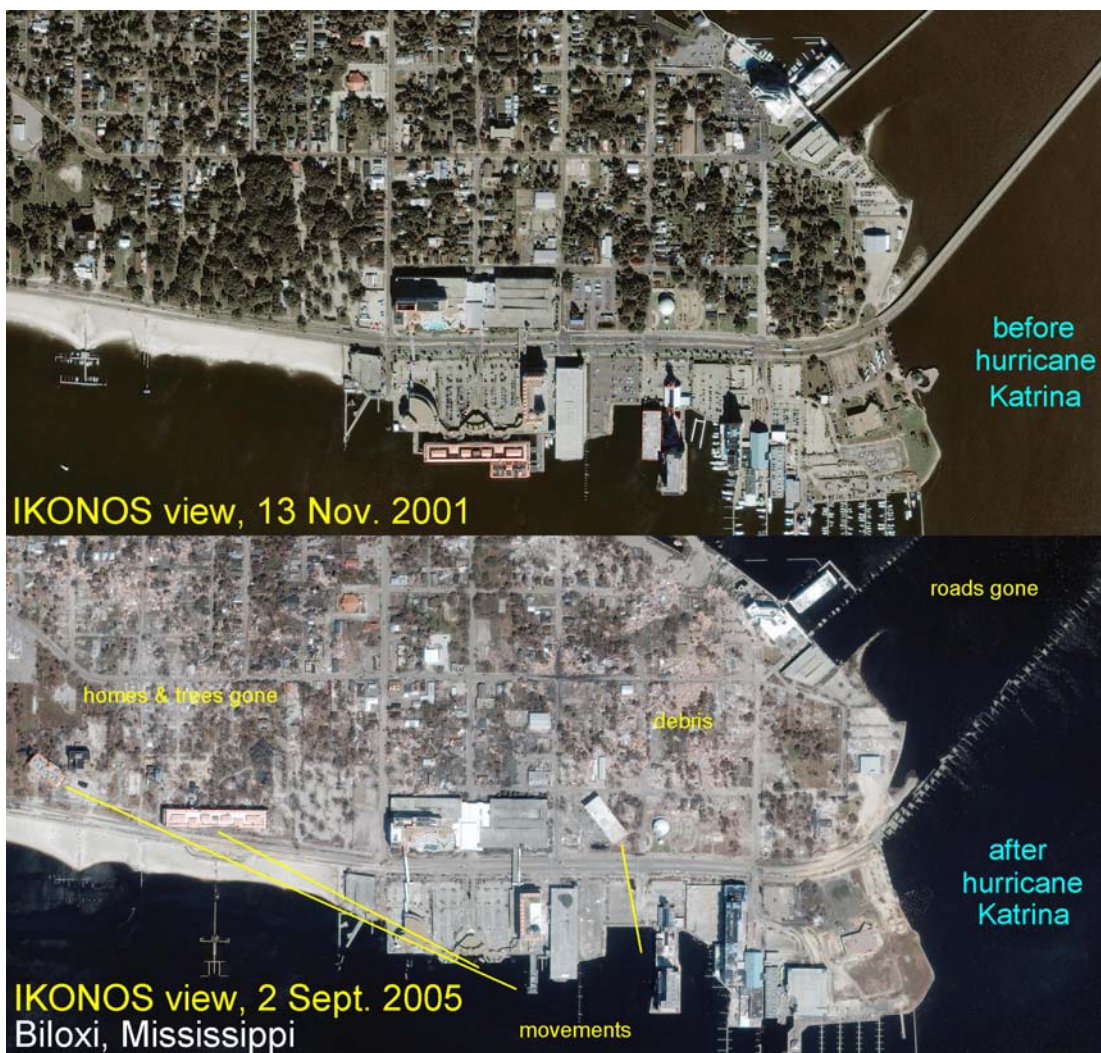


Fig. 157. Before and after IKONOS views of hurricane Katrina damage at Biloxi, Mississippi.

10. Applications

Remote sensing data analyses can be valuable in themselves or as components for a geographic information system. Data in use by GIS software can be used to model relationships between variables and create new variables. The model might show the relationship of backwater areas for various river flow intensities. It might show the progress of a flood along a river corridor. It might show the discharge of a watershed in response to radar-detected precipitation within the watershed. A model might predict locations and extents of habitats required by an endangered species. A list of applications could be lengthy, as shown by Part II of projects already completed.

GIS analyses involve many more topics that are beyond the scope of this report. Here are some of them: Geographic analysis: a. Queries; b. Cartographic analysis; c. Buffering; d. Map algebra; e. Spatial analysis; f. 3-D analysis; g. Modeling techniques; h. Network analysis; i. Charts and reports. Geostatistics and Spatial Analysis: a. Software packages strengths and weaknesses; b. Sampling techniques; c. Descriptive statistics; d. Hypothesis testing - parametric and nonparametric tests; e. Analysis of variance: one way, two way, n-way; f. Bi-variate and multi-variate correlation and regression; g. Principal components analysis; h. Factor analysis; i. Cluster analysis; j. Discriminant analysis; k. Surface modeling techniques: kriging, inverse distance, triangular irregular networks, trend surface analysis; l. Network analytics. Accuracy Assessment: thematic, positional. Metadata: formal descriptions of data. Project Planning: a. Collaboration; b. Scoping; c. Interim and final reports; d. System deployment.

Contact the Remote Sensing and Geographic Information Group (D-8260; phone (303) 445-2267) to see if there are technologies available and appropriate for projects of special interest to your own group.

II. Overview of Usage Within the Bureau of Reclamation

The Remote Sensing and Geographic Information Group (D-8260) of the Bureau of Reclamation has several decades (since 1975) of experience in both research and applications. An appropriate technology is selected for each project to accomplish particular goals within the restraints of available time and budgets. We have encouraged the use of RS and GIS within the regional offices, so that local analysts can address local topics.

There are numerous commercial software products available. The Denver Office uses ESRI (ArcGIS, ArcView, etc.), ERDAS (Imagine), MicroImages (TNTmips), and Research Systems (ENVI) software to accomplish the project and research work. Each system has its own characteristics and specialties, but most capabilities overlap. Our workers tend to specialize in one particular brand of software. Data from each software

can usually be imported and exported in formats of the other brands, enabling the outputs to be in whatever format a client desires.

Supporting tools in our analyses include digitizing tablets, stereoscopes, light tables, printers, flat-bed scanners, and video capture equipment. Computer terminals are networked, allowing easy transfers between computers and servers. Internet access allows rapid download of data available from public sources.

Reclamation Project Examples

The following listing is for projects conducted by the team at the Denver Office since 1975. Regional offices have conducted studies of similar nature. These are listed to give inspiration about the range of possible projects and appropriate technologies. (Many of these could be classified into finer groups and lumped, naming the geographic regions in which a technique was applied.)

CIR photography for vegetative analysis along Rio Grande.

- Aerial imagery analysis for vegetative associations of Spring Canyon and Rifle Range Pumped Storage Survey sites, Lower Colorado region.
- Mapping of vegetative associations at Whipple Wash Pumped Storage site, Lower Colorado.
- Aerial photographic study of Ochoco Dam and Reservoir area, Oregon.
- Land cover analysis for the Republican/Solomon Rivers Water Management Study, Kansas/Nebraska.
- Photointerpretation for wildlife mitigation, New Rockford Canal right of way, Garrison Diversion Unit, Dakotas.
- Aerial photo studies of Clark Canyon Dam and Reservoir area, Montana; Hagmmaier Pond Dam South, Calif.; Tufa Stone Dam, Arizona.
- Land cover analysis and inventory of Tularosa Basin, NM.
- Mapping of Garrison area (Sand Lake, Dakota Lake, Hyatt Slough, Arrowhead Lake), National Wildlife Refuge Monitoring Program.
- Evaluation of riparian vegetation trends in the Grand Canyon using multitemporal remote sensing techniques.
- Post construction analysis at Calamus Dam, North Loup, Upper Missouri Basin.
- Determining impacted wildlife resources in the Grand Valley, CO, by remote sensing.
- Land cover mapping and analysis for Lower Gunnison Basin Unit, North Fork area, CO.
- Aerial photographic documentation of perennial vegetation changes near Granite Reef and Salt Gila Aqueducts, AZ.
- Vegetation identification and mapping for Gila River Indian Reservation, AZ.
- Photo interpretation along Snake River, Minidoka Project, Jackson Lake Dam.
- Vegetation mapping for All American Canal, Calif.

- Use of RS and GIS for estimation of irrigation water use in the Upper Gunnison River Basin of Colorado.
- Use of satellite RS and GIS for estimation of irrigated land acreage in the Newlands Project Area, NV.
- Baker Valley Irrigation District GIS data base and mapping.
- Use of aerial photography for vegetation monitoring along Heyden-Rhodes Aqueduct.
- Use of oblique slides with PC image processing system for Big Horn Sheep habitat analysis, Waterton Canyon, CO.
- Land use and land cover mapping at American Falls Reservoir, PN region.
- Evaluation of wetland changes on Klamath Lake with multitemporal remote sensing.
- Black Sands Area study for land cover trend analysis.
- Pecos River habitat quantification using aerial photography and videography.
- Wetland and riparian mapping along La Plata River, CO.
- Blunt Reservoir, Pierre Canal wetland and wildlife habitat mapping.
- Rio Grande land use inventory.
- Vegetative assemblage mapping of the Nueces River Delta, Texas.
- Using aerial photography (1:5000 scale, natural color positive transparencies in stereo), hyperspectral scanner, and IKONOS satellite imagery to map invasive noxious weed infestations (purple loosestrife, leafy spurge) and biocontrol effectiveness at the Winchester Wasteway, Washington and in the areas near Denver. The latter includes the Spring Creek and Buffalo Creek fire swath areas infested with leafy spurge, for the Forest Service.
- Inventory of wetlands and riparian communities for Animas/Laplata, CO.
- Mapping of riparian vegetation of the Lower Colorado River from Davis Dam to the international border, CA/AZ.
- Seedskadee NWR vegetation inventory.
- USGS - NPS vegetation mapping - Jewel Cave National Monument, SD.
- USGS - NPS vegetation mapping - Devils Tower National Monument, SD.
- USGS - NPS vegetation mapping - Mount Rushmore National Memorial, SD.
- USGS - NPS vegetation mapping - Wind Cave National Park, SD.
- USGS - NPS vegetation mapping - Badlands National Park, SD.
- USGS - NPS vegetation mapping - Theodore Roosevelt National Park, ND.
- Banks Lake and Conconully land use land covering maps.
- USFS Nebraska National Forest, Buffalo Gap National Grassland prairie dog colony mapping.
- Wetlands inventory and drained wetlands water storage capacity estimation for the St. Joe - Calio Coulee subbasin of the Greater Devils Lake Basin, ND.
- Cheyenne Bottoms Wildlife Management area, KS.
- Potholes Reservoir vegetated exposed bed.
- Vegetation mapping using vertical aerial videography along the San Luis Valley Project - Conveyance Channel Closed Basin Division - CO.
- Central Platte River land cover land use mapping, Nebraska.
- Ridgway State Park, CO, vegetation survey and mapping.

- Trinidad State Park, CO, vegetation survey and mapping.
- Rifle Falls and Rifle Gap State Parks vegetation survey and mapping.
- Yampa River Legacy State Park - Elkhead Reservoir vegetation mapping.
- Jemex Mountain, NM - habitat mapping project.
- Sunset Crater Volcano National Monument, AZ, vegetation mapping project.
- Lacreek National Wildlife Refuge, SD, vegetation mapping project.
- Ouray National Wildlife Refuge, UT, vegetation mapping project.
- Jasper Fire area vegetation mapping.
- Mapping of Route 285 for Colorado Dept. of Transportation.
- Knife River Indian Villages National Historic Site vegetation mapping project.
- Fort Union Trading Post National Historic Site vegetation mapping project.
- Zion National Park vegetation mapping.

Agricultural studies

- RS study of land use and irrigated crops in the Lower Sevier River Basin, Delta, Utah.
- Basin-wide remote sensing of irrigated lands in the Bear River Basin of Wyoming.
- Inventory of irrigated lands and reservoir surface areas in the Upper Green River Basin, Wyoming.
- Detailed sprinkler and land classification analysis, Lincoln Valley, Upper Missouri.
- Using Landsat TM imagery for cultivated lands identifications, James River/Oaks, ND.
- Land use, habitat mapping in Imperial Irrigation District, Calif.
- Using Landsat, SPOT and Indian IRS satellite data to map irrigated lands in Upper and Lower Colorado River basins.
- Mapping irrigated lands in the Yakima River Basin, WA, using digital satellite data.
- Mapping irrigated lands in the Clark Fork / Flathead River Basin of western Montana using digital satellite data.

Land Suitability studies

- Vegetation, salt, and soil inventory for McElmo Creek Salinity Control Unit, Upper Colorado.

Geologic mappings

- Lineament analysis at Brantley Dam, NM, using 1:24,000 scale imagery
- Using Landsat imagery of the Strawberry Reservoir area, Utah, for seismic hazard evaluation.
- Using Landsat imagery for lineament analysis of Stillwater Tunnel area, Utah.
- Photogeologic studies of landslide deposits at Lake Sherburne Dam, Montana; of Lake Darling Dam and Reservoir, North Dakota; of Ganado Dam area, Arizona; of Assayi Dam area, New Mexico; of Glendo Dam and Reservoir area, Wyoming; of El Vado Dam and Reservoir area, New Mexico.

- Using Landsat imagery for lineament analysis of Shell Creek Drainage, Wyoming.
- Demonstrated a technique for combining watershed analysis (using DEMs) with a map of Grand Canyon geologic formations, to be used by USGS to evaluate potential for each side canyon to produce debris flows.

Water studies (see also thermal and hyperspectral)

- A study of seepage along the Dry Gulch Canal, Uinta Basin Project.
- Using Landsat imagery to measure the area of Eagle Lakes, Columbia Basin.
- River bank recession analysis, Oroville-Tonasket Pumping Plant, Okanogan River, Pacific northwest region.
- An inventory of playa lakes, Llano Estacado.
- Water quality mapping of Flaming Gorge Reservoir, Wyoming.
- Multispectral Landsat imagery of chlorophyll-a in Flaming Gorge Reservoir, Wyoming.
- Water quality imagery of Bear Lake, Idaho/Utah.
- Using Landsat multi-date imagery of October, 1983, flood extents near Phoenix, AZ.
- Using airborne scanner imagery of Blue Mesa Reservoir, CO, for water quality patterns.
- Using Landsat data to quantify turbidity and chlorophyll content and measure surface temperature patterns in Lakes Havasu, Mead, Powell, Klamath; Flaming Gorge Reservoir.
- Remote sensing study for East Highline Canal seepage, Imperial Irrigation District, Calif.
- Using MAMS 12-channel scanner data for surface water quality patterns on Lake Pleasant, Arizona.
- Using remote sensing (aerial photography, videography) and GIS for backwater studies, sediment transport, channel characteristics along Green River, Utah, below Flaming Gorge Dam.
- Backwater habitat mapping for Colorado River in Grand Canyon.
- Use of SPOT satellite data for mapping chlorophyll on Lahontan Reservoir.
- Aerial photography documentation of changes and vegetation along Coachella Canal, Calif.
- Fontenelle Dam tailwater mapping.
- Remote sensing of San Juan River for habitat mapping for endangered fish.
- Routine monitoring of Green, Colorado, San Juan Rivers by aerial videography.
- Erosion mapping of Audubon Lake Island.
- Water quality studies on Hanks Marsh, Klamath Falls, OR.
- Using aerial video from helicopter flying about 100 ft above canal of Central Arizona Project to quantify and locate patches of aquatic weeds that hinder water transport, for measuring the effectiveness of biocontrol of weeds by grass carp.
- Using aerial video to map rapids and riffles along Yakima River.
- Limnological applications of multispectral remote sensing.
- High/Low flow studies of wetted area and river channels in the Rio Grande River.

- Using aerial photography (1:12,000) to map all man-made structures (dams, canals, channels, pumps, diversions, fish screens) related to water usage in the John Day River Basin, Oregon.
- Utility of GIS for the National Irrigation Water Quality Program in the Grand Valley.
- Green River waterline mapping at 10,900 cfs using airborne videography.

Dam Safety studies

- Clark Canyon Dam, MT, dam failure inundation study.
- Use of geospatial technology to automate dam breach inundation mapping and emergency management within Reclamation.
- Green River flooded bottomlands mapping for two flows.

Thermal studies

- Studies of geothermal sites at Susanville, Holtville.
- Thermal IR imagery at Meeker Dome for salinity control.
- Thermal IR imagery downstream of Theodore Roosevelt Dam.
- From pre-sunrise aircraft flight over the Platte River, Nebraska, to count the number of Sandhill Cranes on each island and sandbar before they moved into the fields to feed..
- Thermal IR imagery of Fontenelle Dam, Wyoming.
- Thermal IR imagery of the New Waddell Dam site, Arizona.
- Using FLIR system (thermal scanner and visible video) from helicopter below the canyon rims in the eastern Grand Canyon and the canyon of the Little Colorado River, to measure the temperatures of the rivers and backwaters and to identify warm springs, to locate favored habitats for endangered fish.
- Using a Daedalus scanner in the Grand Canyon and Little Colorado River to measure river and backwater temperatures.
- Using a Daedalus scanner along the lower Yakima River, Washington, to measure water temperatures in the Columbia and Yakima Rivers, backwaters, isolated ponds, and canals, especially comparing the temperatures of water entering the rivers with the river temperatures there.
- Using Landsat band 6 to measure surface temperature patterns in Lakes Mead, Powell, Klamath.

Hyperspectral studies

- Using ASDI Field Spectrometer to measure fine details of spectra of various rocks, minerals, soils, plants, flowers, Autumn colored leaves, sky, clouds, snow, and man-made substances, with a stress on invasive noxious weeds at various seasonal stages. The more than 4600 measurements are available on a CD or a web site for use by others as reference spectra.
- Using the Probe-1 (128 channels) scanner at the Winchester Wasteway, central Washington, to view a habitat of mixed sand dunes, wetlands and irrigated fields, examining in particular the effects of biocontrol beetles on purple loosestrife infestations, plus distributions of Phragmites (cane), bulrush, and cattails.

- Using the AVIRIS (224 channels) scanner for water quality studies at Klamath Lake, Oregon.

Social, Economical, and Demographic studies

- Numerous population at risk and economic impact studies for modeled dam breach flood zones for many of Reclamation's high and significant hazard dams.

EIS studies

- Garrison Diversion: Photointerpretation for Wildlife Mitigation on New Rockford Canal. 1982
- Remote Sensing for Sandhill Crane Roosting Habitat on the Platte River 1983
- Glen Canyon Environmental Studies, for the Biological Assessment : Evaluation of Riparian Trends in Grand Canyon 1986
- Biological Assessment for the operation of Flaming Gorge Dam, Mapping backwaters in the Green River 1987
- 1988- Platte River Studies mapping Channel Changes
- Environmental Assessment for Coachella Canals Wetland Mapping study 1989
- Refuge Monitoring for environmental Assessment on the James River in North and South Dakota 1990
- Sediment Transport for channel mapping below flaming Gorge in support of the Biological Assessment 1992
- Animas / LaPlata wetland inventory for the EIS 1995

Infrastructure studies

- Closed Basin Infrastructure Mapping.

Environmental Justice studies

- Keechelus Reservoir

Archaeological studies

- A review of available technologies appropriate to archaeological surveys.

Weather remote sensing

- Satellite estimates of incident solar radiation in the western states.
- Using AVHRR imagery from polar orbiting satellites to exclude clouds and measure snow-covered area on the ground, for operational use by the National Weather Service.
- Using NEXRAD radar data to estimate the accumulation of snow in terms of water equivalent and depth, for operational use by the National Weather Service as well as by Reclamation. The results are continuously available on the Internet for numerous areas, such as northern plains, Pacific northwest, lower Colorado River.

Specific-regional GIS and models

- Development of a GIS for Garrison Diversion Unit, Dakotas.
- Creation of a GIS with numerous data layers for monitoring the status and changes within the Grand Canyon.
- The Middle Rio Grande GIS Data Base.
- US Forest Service R2RIS GIS Data Base.
- Development of GIS Data Base for American Falls Reservoir management.
- GIS data bases for Potholes and Scooteney Reservoirs.
- Browns Park NWR GIS data base, vegetation inventory.
- Cheyenne Bottoms Wildlife area GIS, KS.
- Comparing 1990 and 2000 census data for Reclamation dam failure population at risk analysis.
- Walker and Truckee River Basin Lahonton cutthroat trout recovery plan GIS.

Foreign studies

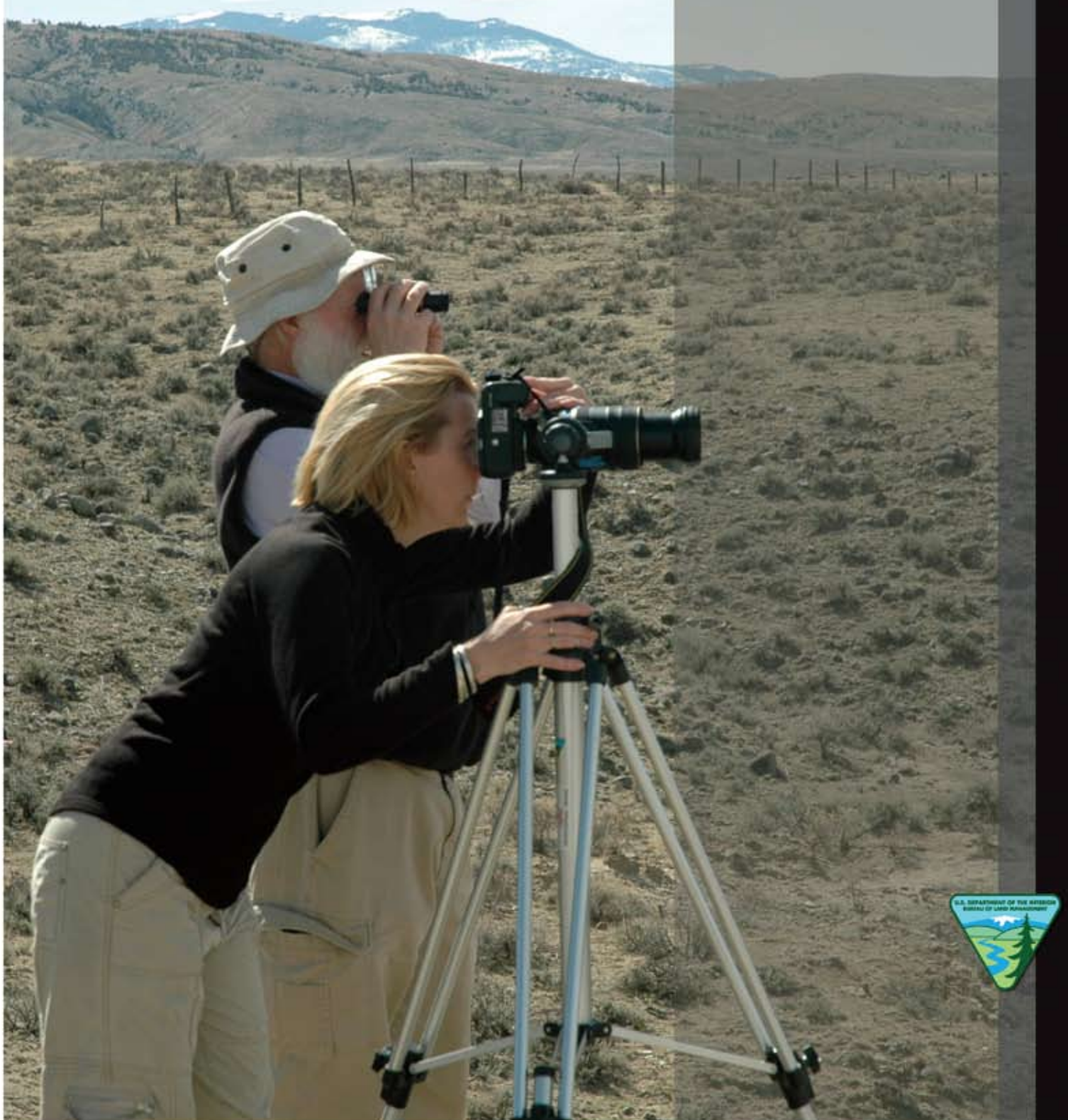
- Remote sensing of cropping patterns along the Lower Nile River System.
- Satellite observations of snow covered area in the High Atlas Mountains of Morocco.
- guidance for projects in Brazil and Spain.

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Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation

Technical Note 428

BLM



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BLM/OC/ST-08/001+9162

The background image is a wide-angle shot of a desert canyon. In the foreground, a man and a woman are using photogrammetry equipment. The man is looking through binoculars, and the woman is operating a camera on a tripod. The canyon walls are made of reddish-brown rock, and a river flows in the distance. The sky is blue with some clouds.

**Aerial and Close-Range
Photogrammetric Technology:
Providing Resource Documentation,
Interpretation, and Preservation**

Technical Note 428

BLM

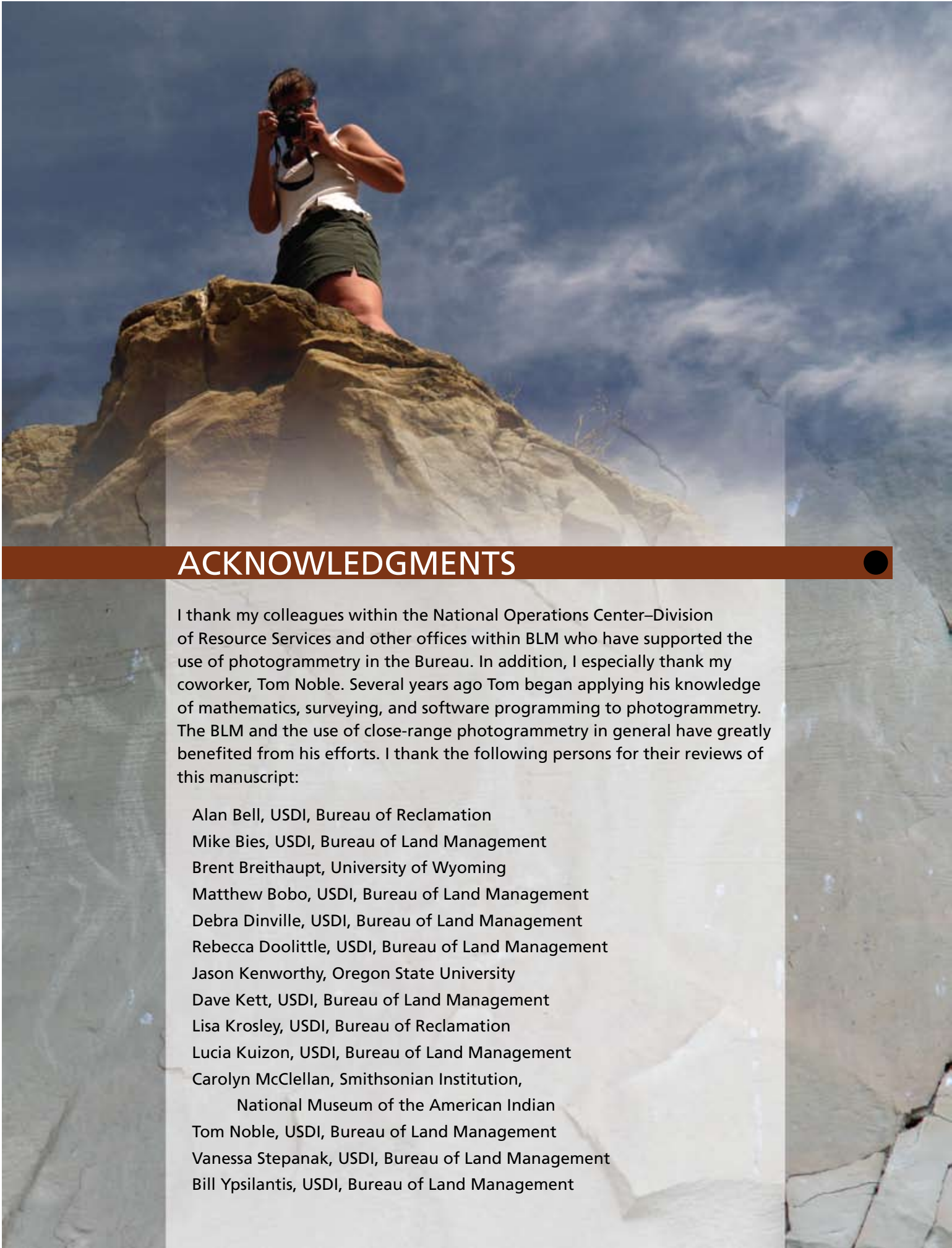
**Aerial and Close-Range Photogrammetric Technology: Providing
Resource Documentation, Interpretation, and Preservation**

By Neffra A. Matthews

Bureau of Land Management
National Operations Center
Denver, Colorado 80225

Technical Note 428

September 2008

A photograph of a person standing on the peak of a large, light-colored rock formation. The person is wearing a white tank top and dark shorts, and is holding a camera up to their eye, taking a picture. The background is a bright blue sky with scattered white clouds. The rock formation has a rough, textured surface with some shadows.

ACKNOWLEDGMENTS

I thank my colleagues within the National Operations Center–Division of Resource Services and other offices within BLM who have supported the use of photogrammetry in the Bureau. In addition, I especially thank my coworker, Tom Noble. Several years ago Tom began applying his knowledge of mathematics, surveying, and software programming to photogrammetry. The BLM and the use of close-range photogrammetry in general have greatly benefited from his efforts. I thank the following persons for their reviews of this manuscript:

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Oblique low-level aerial view of Highway 89, Kanab Creek, north of Kanab, Utah.

ABSTRACT

Photogrammetry is the art and science of obtaining precise mathematical measurements and three-dimensional (3D) data from two or more photographs. The Bureau of Land Management has benefited from its in-house photogrammetric capabilities, support, and expertise for more than 20 years. This support includes creating unique and value-added digital datasets and serving as subject matter experts and contracting officer's representatives to obtain aerial photography and other types of 3D data. Traditionally, most people think of photogrammetry in the context of aerial photography. Photogrammetric techniques can be applied to virtually any source of imagery, whether it comes from 35-mm digital cameras or an earth-orbiting satellite. As long as the images are captured with stereoscopic overlap, one can derive accurate 3D data at a very wide range of scales.

The rapid evolution of digital cameras and increasing capabilities of computers and analytical software has dramatically expanded the variety of situations to which photogrammetry may be applied, while simultaneously decreasing the costs of acquisition, processing, and analysis. A variety of resource specialists (such as hydrologists, soil scientists, archaeologists, paleontologists, biologists, range conservationists, and engineers) can greatly benefit from 3D products derived from modern photogrammetric techniques. This is especially true in the field of ground-based or close-range photogrammetry. This document provides a general overview of photogrammetry, with separate sections focusing on traditional aerial photogrammetry and close-range photogrammetry. The appendices contain technical information on the equipment and suggested methods for capturing stereoscopic imagery. Their purpose is to assist field resource specialists in the successful completion of the imagery collection portion of a basic, close-range photogrammetry project.

INTRODUCTION

The United States Department of the Interior, Bureau of Land Management (BLM) is charged with managing almost 104 million ha (256 million acres) of surface land. This vast landscape includes some of the most ecologically and culturally diverse, scientifically important lands in Federal ownership. Documenting and evaluating the present condition—and in some instances, past condition—of its land is a critical part of the Bureau's mission. Not only do these condition data provide information on the health of the land and serve as a basis for future decision making, but they also provide a tool for determining the effectiveness of

present management practices. To most efficiently support the BLM's management effort, documentation methods that are quantifiable and repeatable are needed.

A tool for capturing present condition is photography. While visually enlightening, a single photograph is in many ways anecdotal and can be biased by the perceptions of the photographer (Mudge et al. 2006). However, photographs can be taken in such a way as to provide detailed and measurable three-dimensional (3D) data, thus providing a more robust dataset from which an analyst can derive quantifiable

information. The science and technology of this process is called photogrammetry (Appendix A). The basic requirement for photogrammetry is an overlapping pair of photographs taken to mimic the perspective centers of human stereoscopic vision. Photography, at virtually any scale (from a pair of images taken from an earth-orbiting satellite to extremely close-up images of a delicate biological soil crust), can be processed by using photogrammetric techniques. The resulting datasets integrate both corrected imagery and 3D surface data that can be viewed, manipulated, and measured by using GIS and other similar software.

Since the 1930s, most of the topographic and thematic maps produced in the United States have been made according to aerial photography and photogrammetric methods. Aerial photography, digital imagery, ground control survey data, and photogrammetry are the basic components for many of the maps and geographic information systems (GIS) data used by the BLM. For more than 20 years, the BLM has maintained some in-house photogrammetric capability with specialized expertise and equipment. This capability assists the Bureau in meeting its unique data needs (e.g., riparian boundary litigation) and by providing large-scale mapping products not available from other government agencies.

Within the last decade, advances in digital imagery and photogrammetric software, combined with lower equipment costs (Matthews et al. 2004), have enabled the use of photogrammetric methods over a wider range of applications, while at the same time reducing equipment costs and decreasing computing times, making the entire process more cost-effective. These advances have revolutionized close-range photogrammetry by removing many of the rigors of traditional aerial photogrammetry, thus moving stereoscopic image collection from the hands of the photogrammetric expert to those of field personnel.

A significant advantage of close-range photogrammetry is that images for a small project can be acquired with minimal field equipment and a small amount of training. Once taken, these images can be processed to a detailed, 3D grid of thousands of precise data points or archived and processed when needed to provide quantifiable measurements of condition. This can support long-term comparisons and provide a visual and metric dataset that cannot be achieved through any other method. Because accurate measurements can be made from the dataset, the resulting determinations are more defensible than simple anecdotal evidence (e.g., a single photo). In addition, these datasets can be more persuasive to both the internal and external audience, thus supporting better-informed conclusions.

In the past year, the 3D measuring and modeling software used to process close-range photographs has increased in its capability and ease of use and decreased in cost. Both traditional aerial and close-range photogrammetric processing are presently limited to BLM staff at the BLM National Operations Center (NOC) and the Alaska State Office. However, software and hardware innovations will continue to increase the accessibility of both stereoscopic processing and viewing, making photogrammetry more accessible within the BLM and providing a cost-effective, responsive, and quantifiable documentation and monitoring technique.

This report is intended to provide resource specialists with an overview of photogrammetry—both traditional aerial and close-range—and to provide examples of projects to which these technologies have been applied. In addition, the appendices contain the requirements of stereoscopic image capture, describe proper camera settings, and outline the basic procedure for field capture of images for a small, close-range project.

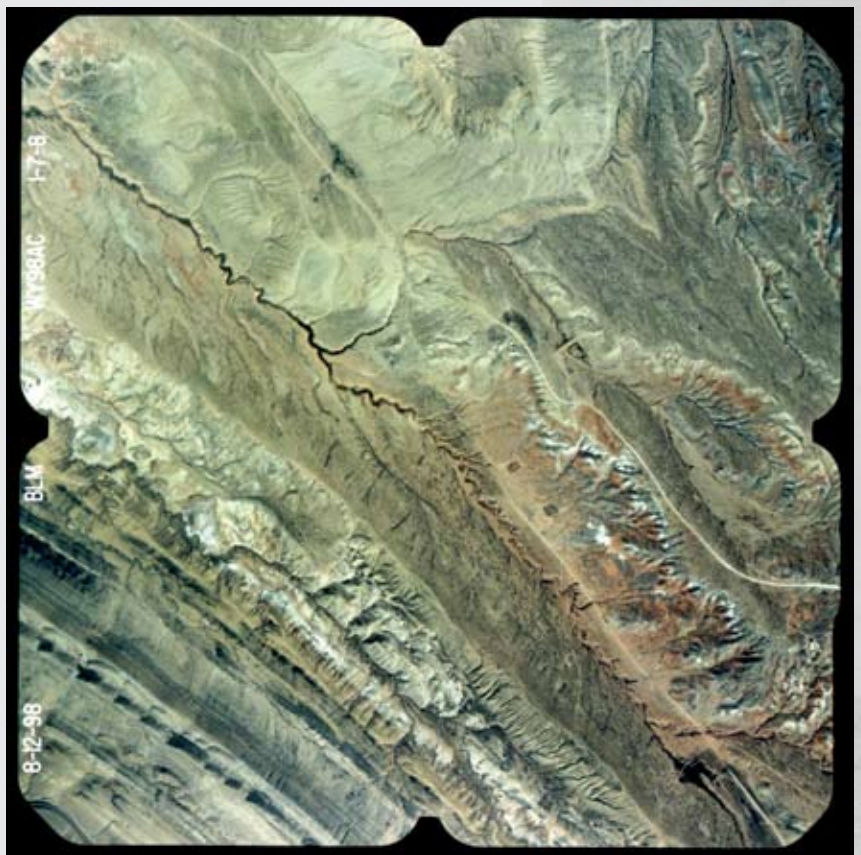
WHAT IS PHOTOGRAMMETRY?

Photogrammetry is the science behind the creation of almost every topographic map made since the 1930s. The human ability to perceive depth is the basis for the science (and technology) of photogrammetry. This ability to see in three dimensions is due to the offset in perspective centers between the left and the right eyes. Photographs taken to mimic this perspective shift are referred to as stereoscopic or stereo (meaning two). A stereo pair (or series) of images is taken from consecutive positions and overlap each other by at least 60%. Through the use of photogrammetry, highly detailed three-dimensional data can be derived from the two-dimensional photographs of a stereo pair.

The formal definition of photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena. In many instances, the use of photogrammetry can be more efficient, less labor-intensive, and more cost-effective than other types of field 3D data collection, resulting in products that have a level of detail, accuracy, range, and price that is difficult to match with other technologies (Birch 2006). As described previously, the main component necessary for a photogrammetric project is a series of overlapping stereoscopic images. The stereo images may be captured by a large variety of cameras at almost any height or platform (from tripod to earth-orbiting satellite).

Photogrammetry is informally divided into two basic categories according to the height of the platform—traditional (or aerial) and nontraditional (or close-range). Advances in commercially available and cost-effective photogrammetric software, high-resolution digital cameras, high-performance laptop computers, and unmanned aerial systems (UAS) have caused those categories to overlap in recent years. This document refers to the traditional process of acquiring and using large-format (e.g., 9 x 9 inch; Figure 1), vertical (film or digital) aerial images as aerial photogrammetry. Close range is used to refer to photographs with an object-to-camera distance of less than 300 m.

Figure 1. Example of a large-format (9 x 9-inch) vertical, natural-color, aerial photograph taken at a scale of 1:12,000. The area covered by the image is in north-central Wyoming. The Red Gulch Dinosaur Tracksite lies near the center of the image.





Onboard a Department of the Interior helicopter at Kanab, Utah, Airport preparing to conduct low-level aerial photography of Moccasin Mountain Tracksite.

● AERIAL PHOTOGRAMMETRY

Aerial photogrammetry utilizes large-format imagery and ground coordinate information to effectively recreate the geometry of a portion of the earth in a virtual environment. In this virtual environment, reliable horizontal and vertical measurements can be made and recorded (or compiled) directly into a geospatial data file. Accurate measurements can be recorded from aerial photographic images, by using traditional methods, only when the following conditions are met: a) stereoscopic image pairs (two or more overlapping photographs) cover the object to be analyzed; b) accurate x , y , and z coordinates are known for at least three defined object points in the overlapping photographs; and c) a calibrated mapping or metric camera is used to take the photographs.

The compilation of planimetric features (such as roads and streams) and topographic information (such as digital terrain models [DTM] and topographic contours) from the photographic sources is accomplished through the use of digital stereoscopic instruments. Digital, or softcopy, photogrammetric workstations require specialized software and hardware for viewing a pair of stereo images. In this virtual environment, an experienced operator can link the images with the ground control to collect precise horizontal and vertical coordinates for a point, line, polygon, or surface. The photogrammetric workstation recreates the geometry of the field subject through a series of mathematical operations (Figure 2). These procedures require a high level of expertise and repetition to maintain the operator's skill. The softcopy instrument has analytical capabilities to a submillimeter level. Thus, high-accuracy ground control coordinate positions are needed to fully exploit the analytical capabilities of these instruments (Matthews et al. 2006).



Figure 2. Digital, or softcopy, photogrammetric workstations support stereoscopic viewing and measuring in a 3D environment, where an overlapping pair of images is viewed with special polarized glasses.

Aerial Photogrammetry Workflow

Most large-format aerial photography is acquired through commercial contractors and is available in hard copy (film) or digital formats. With the exception of the BLM Alaska State Office, the Bureau does not have the capability to acquire large-format aerial imagery without the assistance of a commercial contractor. In most instances, it is best to work through photogrammetric specialists, such as the staff of the Division of Resource Services (DRS) at the NOC to ensure that the technical and user requirements are met. It is important to begin planning for the acquisition of imagery early in the project. Many elements need to be considered to ensure that project requirements are met (e.g., size of the area, terrain, vegetation cover, sun angle, type of sensor, and product accuracy).

Generally, aerial acquisition is designed and planned according to the specifications needed to generate a particular product

with a specific scale and accuracy. The desired resolution dictates the height at which the contractor must fly to acquire the imagery. The following equation states the relation between scale and flying height of the aircraft (Hussain and Bethel 2004).

$$\text{scale} = \frac{\text{focal length}}{\text{flying height above terrain}}$$

For example; when film-based aerial photography is flown at a height of 305 m (1,000 feet) above mean terrain with a 153-mm (6-inch) focal length lens, the resulting photography has a scale of 1:2,000. With the resolving power of modern natural color film, the smallest object that can be detected is 5 cm. The distance of the sensor from the subject in commercial aerial photography is restricted by the altitude at which the plane can operate safely. In addition, the Federal Aviation Administration (FAA) imposes a minimum altitude limit of 1,000 feet above populated areas.

Many land management agencies, including the BLM, maintain collections of historical aerial photography of the lands they manage. The National Agriculture Imagery Program (NAIP) is managed by the U.S. Department of Agriculture Farm Services Agency (FSA) and acquires imagery of agricultural lands in the United States. Other governmental agencies work with the FSA to produce statewide coverage of natural-color, 1-, 2-, and 10-m resolution imagery that has been corrected for terrain and image distortions and is geospatially correct (orthorectified) on a cyclical basis. Information on these archives is available through individual agency websites. The BLM's aerial photography archive is maintained at the NOC.

Traditional, large-format (9-inch × 9-inch) aerial photography is film-based and is available in black and white, natural color, or color infrared formats depending on

the project requirements. Each aerial camera has its own camera calibration report. This is a report generated with the results of a series of tests developed to reveal the geometric characteristics of the camera and lens. The photogrammetrist uses this information in subsequent calculations to remove distortions, which helps to ensure a high-quality product. However, the imaging and mapping industry has started to migrate to a fully digital process in recent years. Often, traditional film is not used, as the imagery is captured in a digital format.

Presently, several sensor systems are able to capture aerial images digitally. The frame digital sensor is similar to a film camera in that it captures single frames. A push broom sensor (an array of several thousand charge coupled device [CCD] sensors) continuously collects data and then divides the data into frames. Digital images can also be captured in panchromatic, multispectral, and infrared modes simultaneously. This is advantageous because the images may be captured concurrently and do not require additional flights. Digital sensors also offer capabilities that allow the photogrammetrist to enhance portions of the image through image processing techniques to compensate for adverse conditions such as shadows or high-contrast areas. This allows data collection in areas that might be obscured on film.

Project Implementation

Many elements need to be considered to ensure that proper project design is met. These elements include the size of the area, scale of the photography, terrain (mountains or rolling hills), vegetation cover (desert or forest), accessibility (rivers, cliffs, or ownership restrictions), sun angle (latitude, longitude, or time of year), and type of sensor. Perhaps the most important

consideration is determining the level of accuracy necessary for the final product. Accuracy, photographic scale, and project size are directly related. Typically, the higher the level of accuracy required, the larger the scale of photography necessary, which in turn affects the magnitude and complexity of the job.

Photo Layout and Flight Line Index Map

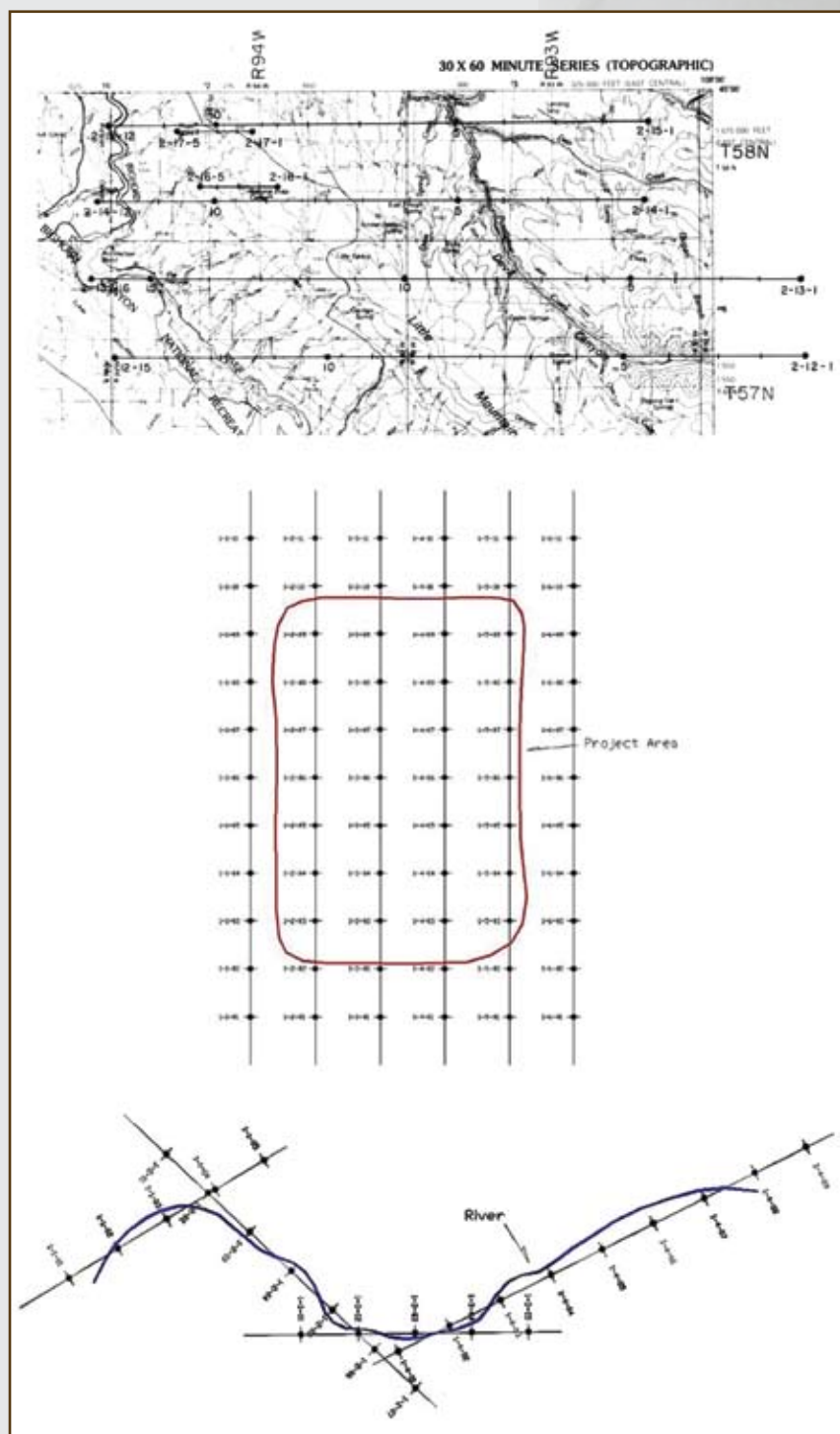
One of the most important goals of project design is to ensure that there will be complete stereoscopic coverage of the area of interest, at the proper scale. Photo layout is a depiction of the extent of each photo in relation to the desired area of coverage. The graphic representation of the photo layout is often referred to as a flight line index map. Depending on the final photo scale, the flight line index map for traditional aerial photography flights are designed on 1:100,000- or 1:24,000-scale topographic or digital orthophoto maps (Figure 3). When designing the flight line, care must be taken to ensure that there is complete overlap between photographs. If more than one line of photographs is needed, there must be adequate side lap between the photos.

Survey Control

Another vitally important part of this process is the ground control survey. The survey is the link between the ground and the aerial photography. Surveys give the geospatial products their identity with regard to projection, coordinates, and final accuracy. A high level of accuracy (geodetic quality) is of the utmost importance when gathering the survey (horizontal and vertical) data. Locations for ground survey control points are indicated in the flight line map. Correct spacing and location of ground control survey points determine the area that can be mapped. Before the aerial photography acquisition, ground control panels or

targets must be placed on the ground as indicated by the flight line index map (Figure 4). A center point for each panel will be indicated by a monument (often with a survey nail or rebar driven into the ground). To make this point meaningful on the final aerial photographs, large "legs" of white material will be nailed down in a cross centered on the nail or

Figure 3. Examples of flight line maps and photo layouts.



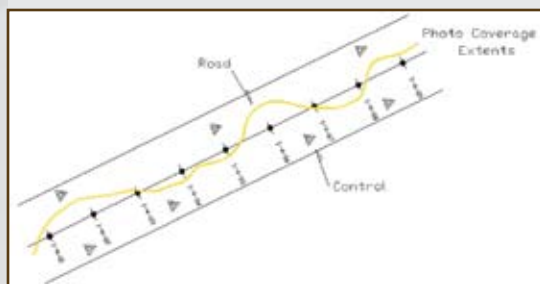


Figure 4. Example of a simple, flight line layout indicating ideal locations for survey control points.

rebar. Ideally, high accuracy horizontal and vertical coordinates for each paneled point will be surveyed before the aerial photography acquisition.

Image Acquisition

After the project requirements have been developed and the flight line and control layouts have been designed, a specification package goes out to bid. At this time standard contracting procedures and schedules come into play. After the contract is awarded, coordination must take place between the contractor, NOC DRS staff, and the field office to ensure the ground control targets are in place before imagery is acquired. After the imagery is acquired, a review copy is provided to the Contracting Officer's Technical Representative for inspection. Once it has been determined that the aerial photography meets the contract specifications, the imagery is accepted. The aerial film and paper prints (if requested) or digital files are then provided to the NOC for processing and inclusion in the BLM's aerial photography collection.

Interpreting the Imagery

The process of extracting data from the aerial imagery begins with combining the digital imagery with the ground control coordinate data. These imagery files can be supplied directly from a digital sensor or by scanning aerial film. Film scanning is performed with an extremely accurate

(micrometer accuracy level) scanner. The result is a digital representation of the film. The photogrammetric workstation re-creates the geometry of the field subject through a series of mathematical calculations. Aerotriangulation is a mathematical process (least squares bundle adjustment) by which the survey data are used to tie the photos together and adjusted coordinate values are distributed throughout the entire project. The oriented image files are displayed on a computer monitor in a way that enables the operator, equipped with a pair of specially designed glasses, to view the digital image files in a 3D environment. In this virtual environment the photogrammetrist can record (or compile) the horizontal and vertical data necessary for producing a reliable map directly into a geospatial data file.

Photogrammetrically Derived Products

A large variety of 3D digital data in support of land use planning and decision making can be developed from both aerial and close-range photography. The photogrammetric process enables the interpretation of imagery and the collection of data necessary to produce reliable maps that support land managers' decisions and are defensible in court. These data customarily take the form of topography (terrain or land surface) or planimetric (such as streams, transportation routes, vegetation boundaries, and cultural) information.

Digital Terrain Model

A digital terrain model (DTM) provides a digital representation of the terrain surface. A DTM can be produced in a manual or automated mode. Manual mode is a process in which a specialist, using a photogrammetric workstation, observes each point in accordance with a specified spacing and records its location, both horizontally and

vertically. Automated digital terrain extraction is commonly referred to as autocorrelation or digital image matching. It is a process in which sophisticated software matches pixels (picture elements) with unique spectral and geospatial values in one digital image to similarly valued pixels in the adjacent image of the stereo pair. The addition of more information, such as breaklines (polylines in which each vertex has its own x, y, z, location) may be required to aid the software in determining pixel matches in difficult-to-interpret areas. Topographic contour lines can be generated by using DTM, breakline, and planimetric data.

Digital Orthophoto

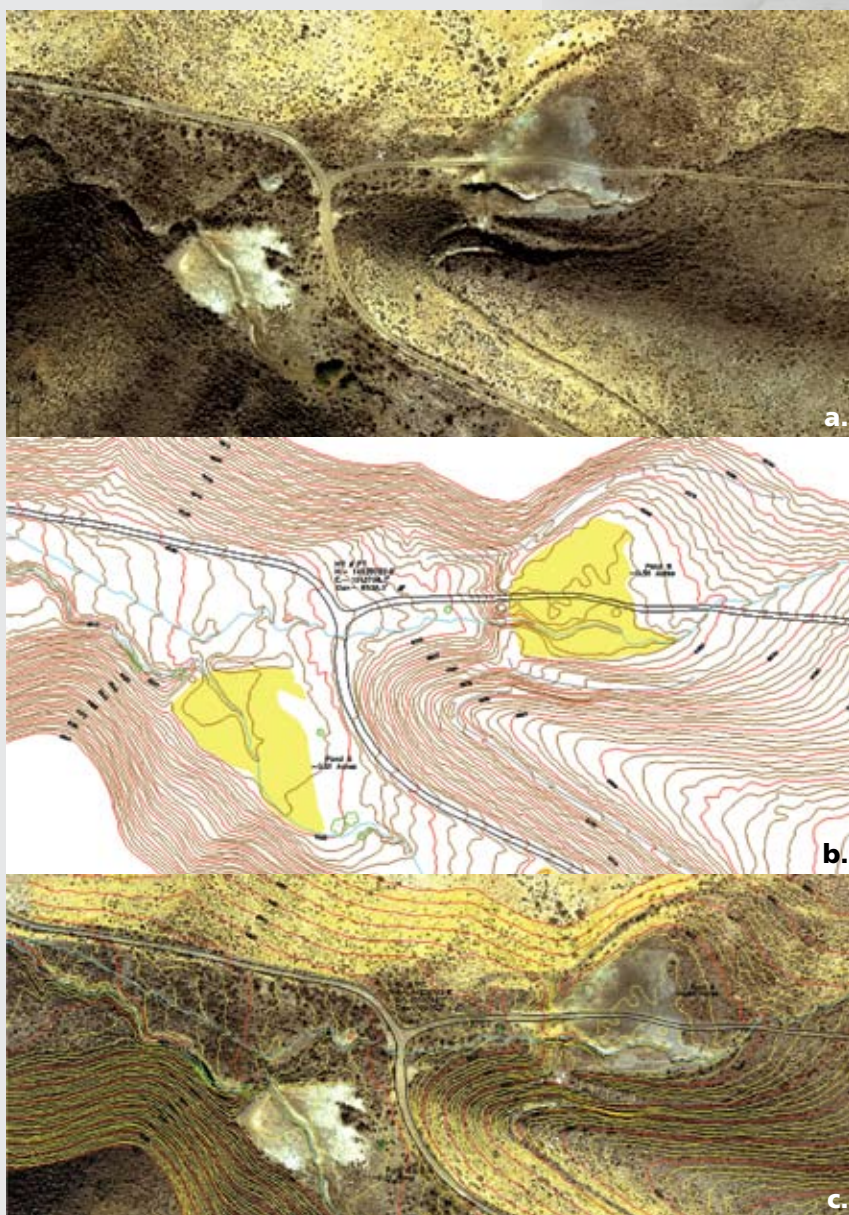
A digital orthophoto is a photograph that has been corrected to eliminate distortions and differences in scale (Figure 5a.). The effects of camera tilt and relief displacement (features at higher elevations are displaced away from the center of the photo) are the main causes of these distortions. To eliminate these, the ground geometry is re-created as it would appear from directly above each point in the photo. This is accomplished by applying a process called differential rectification to each pixel in the image. The resulting corrected image can be used as a map.

The orthophoto can be printed as a stand-alone product or displayed as a backdrop with other spatial information. Perspective views can be produced by draping the orthophoto image over the terrain surface. This process allows one to make a “virtual” visit to the area. The parameters of this virtual surface can be further manipulated to enhance, exaggerate, or isolate a certain feature or part of the image. Topographic contours and planimetric data can be draped onto the orthophoto in three-dimensional space. This virtual visit can be extremely useful for land use planning decisions and communicating with the public.

Vector Map

Vector data customarily take the form of topography (terrain or land surface) or planimetric (streams, transportation routes, vegetation, and cultural) information. Planimetric features are compiled in a manual mode, in which the photogrammetric operator digitizes (in real-world coordinates) points, lines, or polygons representing features of interest (Figure 5b and 5c). The resulting data files can be imported directly into ArcMap for GIS use or into AutoCAD for engineering design.

Figure 5. a. Digital orthophoto map. b. Vector map depicting roads and topography. c. A combination of the vector map overlain on the digital orthophoto map. These digital products were created photogrammetrically at the BLM National Operations Center (Denver, Colorado) in support of remediation at the Rip Van Winkle Mine site in Elko County, Nevada.





Imagery captured from a variety of perspectives such as this image of a mesa west of Kanab, Utah, can be acquired from aerial platforms.

CLOSE-RANGE PHOTOGRAMMETRY

The same basic principles of traditional aerial photogrammetry can be applied to stereoscopic pictures taken from lower altitudes or from the ground. Terrestrial, ground-based, and close-range are all descriptive terms that refer to photos taken with an object-to-camera distance of less than 300 m (1,000 feet). This distance equates to the minimum safe flying height above populated areas, as required by the FAA. Since the same basic principles apply to photographs taken from a camera mounted on a tripod (terrestrial) or suspended from a light sport aircraft (low-level aerial), both types of nontraditional photogrammetry are referred to in this report as close-range photogrammetry (CRP).

A variety of cameras and platforms may be used to obtain the photographic images to be used in CRP processing, including cameras housed in unoccupied airborne vehicles, suspended below helium-filled blimps, and mounted on tripods (Figure 6; Breithaupt et al. 2004). Through the use of these nontraditional methods, a resolution or ground sample distance of 0.25 mm and

a spatial accuracy equivalent to 0.025 mm can be achieved. Theoretically, there is no limit to the resolution that can be achieved from CRP images (Matthews et al. 2006).

The BLM's national center in Denver has used close-range photogrammetric techniques to document resources since the late 1980s. At that time, although producing high-quality results, the close-range photogrammetric process could be tedious and time-consuming mainly because of the need to apply traditional techniques, workflow, and equipment to close-range image capture and processing. However, recent advances in commercially available and cost-effective three-dimensional measuring and modeling (3DMM) software, high-resolution digital cameras, and high-performance laptop computers have revolutionized the CRP process. With these advances, the photogrammetric process can be moved from the laboratory environment into the field, and taken strictly from the hands of the photogrammetry expert and moved to the hands of the resource specialist.

Figure 6. A variety of cameras and platforms may be used to obtain the photographic images used in close-range photogrammetric processing, including cameras housed in unoccupied airborne vehicles, suspended below helium-filled blimps, and mounted on tripods. All images were taken at the BLM's Red Gulch Dinosaur Tracksite in Wyoming.





Close-Range Photogrammetry Workflow

As with traditional photogrammetry, the first step in the close-range project workflow is establishing project requirements. These requirements include the area to be covered, type of ground cover, access to areas surrounding the subject, weather, accuracy of the final product, format of the final product, public visitation at the site, and others. However, with the relatively recent availability of reasonably priced, high-quality digital cameras and 3DMM software, many of the traditional requirements in the photogrammetric process can be accomplished in nontraditional ways, providing a high level of flexibility.

An example of the increased flexibility can be seen in image acquisition. In most situations, a person who is experienced with CRP (such as the staff at the NOC), using a high-resolution commercial digital single-lens reflex (SLR) camera, can successfully capture ground-based photographs for a variety of projects. Most persons, following a few simple rules and taking good-quality photographs, can capture the images necessary for completing a successful CRP project. See Appendix C for more details on taking proper photographs and camera requirements and settings.

Project Design

Once project requirements have been determined, the process of project planning can begin. Accuracy, photographic scale, and project size are directly related. Typically, the higher the level of accuracy required, the larger the scale of photography necessary, which in turn increases the magnitude of the job. CRP projects can be placed into one of two categories. These categories are small (simple) and large (complex).

Small projects are those for which the area of interest is equivalent to about 5 m² or smaller. This type of project may also be referred to as extreme close range, as a high precision of data points is expected. Although proper planning strengthens any project, the small terrestrial project may afford greater flexibility in the planning process. Project design and image acquisition for projects of this scope may be successfully carried out by the resource specialists in the field. By following a set of standard operating procedures (Appendix C), successful completion of the capture of imagery for an extreme close-range project may be accomplished.

Large projects are those for which the area of interest is greater than 5 m² or where complexities of terrain or access add to the level of expertise needed for planning and execution of the project. Projects that fall into this category may require a preliminary site visit or the inspection of overview photographs taken of the area. A preliminary reconnaissance of the area will determine if close-range photogrammetry is the best method for data capture, and if so, estimate resources necessary to accomplish the project. Also at this time, the data requirements and expectations of the end user can be discussed. Projects of this scope are best accomplished by those who have experience with close-range image capture and processing.

Sometimes the needed vantage points to capture imagery may not be present, necessitating alternatives to ground-based capture. In these situations, a large ladder, aerial blimp, UAS, or other type of elevated platform may be needed. For these reasons, it is advantageous to contact the photogrammetric specialist for consultation early in project development to help with such items as budget, scheduling, site visit input, and others.

Photo Layout

Close-range photogrammetric projects have more latitude in their design and execution than do traditional aerial projects because the 3DMM software is more capable of handling photographs taken at oblique angles to the subject and in connecting lines of stereophotos that have less consistent overlap than conventional aerial photogrammetry software. Nonetheless, knowing the lay of the land in advance can be critical to project success. This type of evaluation can be gained either through an onsite visit (which is preferable for complex projects) or from inspection of existing imagery. This imagery may take the form of snapshots of the area taken from the ground or existing, small-scale aerial imagery. It is a good investment in time and resources to investigate the existence of digital orthoimagery, which may be available over the Internet, or historical, large-format aerial photography available from agency collections. Site reconnaissance not only aids in identifying strategies for capturing complete stereoscopic coverage of the subject, but can also be used to identify obstacles to imagery acquisition. These obstacles most often take the form of vegetation, which can obscure points of view and terrain issues. Terrain obstacles can range from a lack of an elevated perspective to perilous drop-offs adjacent to the subject of interest.

While the formal flight line index map described previously in the aerial photogrammetry section may be bypassed for simple close-range projects, preplanning can certainly maximize field time, as it would calculate the object-to-camera distances, proper base-to-height ratio, and size and number of reference targets. However, flight line planning is advised for complex projects, especially those using photographs taken from a light sport aircraft or UAS. In these instances, a formal

flight line index map may be required to convey expectations to the pilot.

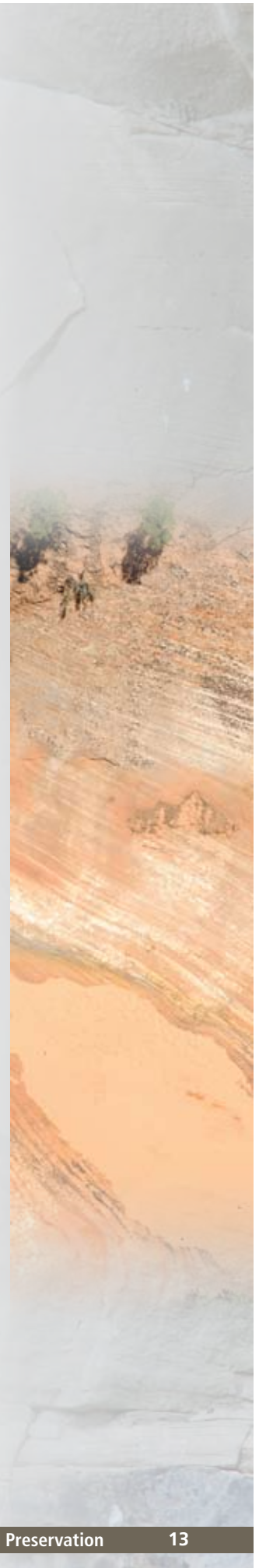
Survey Control

“Surveyed” ground control is not needed for a CRP. During the 3DMM processing, the camera lens system is calibrated. This technique elevates the camera from simply a device for capturing images to a virtual surveying and data collection instrument. By placing an object of known length in the overlap area of stereo models, a very accurate coordinate system can be created. However, GPS survey does give the products an identity as far as projection, coordinates, and final accuracy are concerned and can be easily integrated into a CRP project.

Image Acquisition

The increased flexibility provided by CRP is most completely realized in the image acquisition. Because many of the rigors imposed by traditional photogrammetric processing are removed from CRP, almost any person who can take good quality photographs can take the photos necessary for 3D data processing (see Appendix A). This can be most successfully realized when field personnel have undergone training or thoroughly read this technical note and have completed their own small project. For a large CRP project, a person who is experienced with CRP, such as the staff at the NOC, can successfully capture ground-based photographs for a variety of projects.

When the needed vantage points to capture stereoscopic imagery cannot be attained from a ground-based setup, it will be necessary to investigate more “airborne” options. This may include simply using a ladder or elevated platform to obtain the needed perspective. However, when the area to be documented is large and there is no opportunity for oblique image collection, it may be necessary to employ the use of some type of low-level



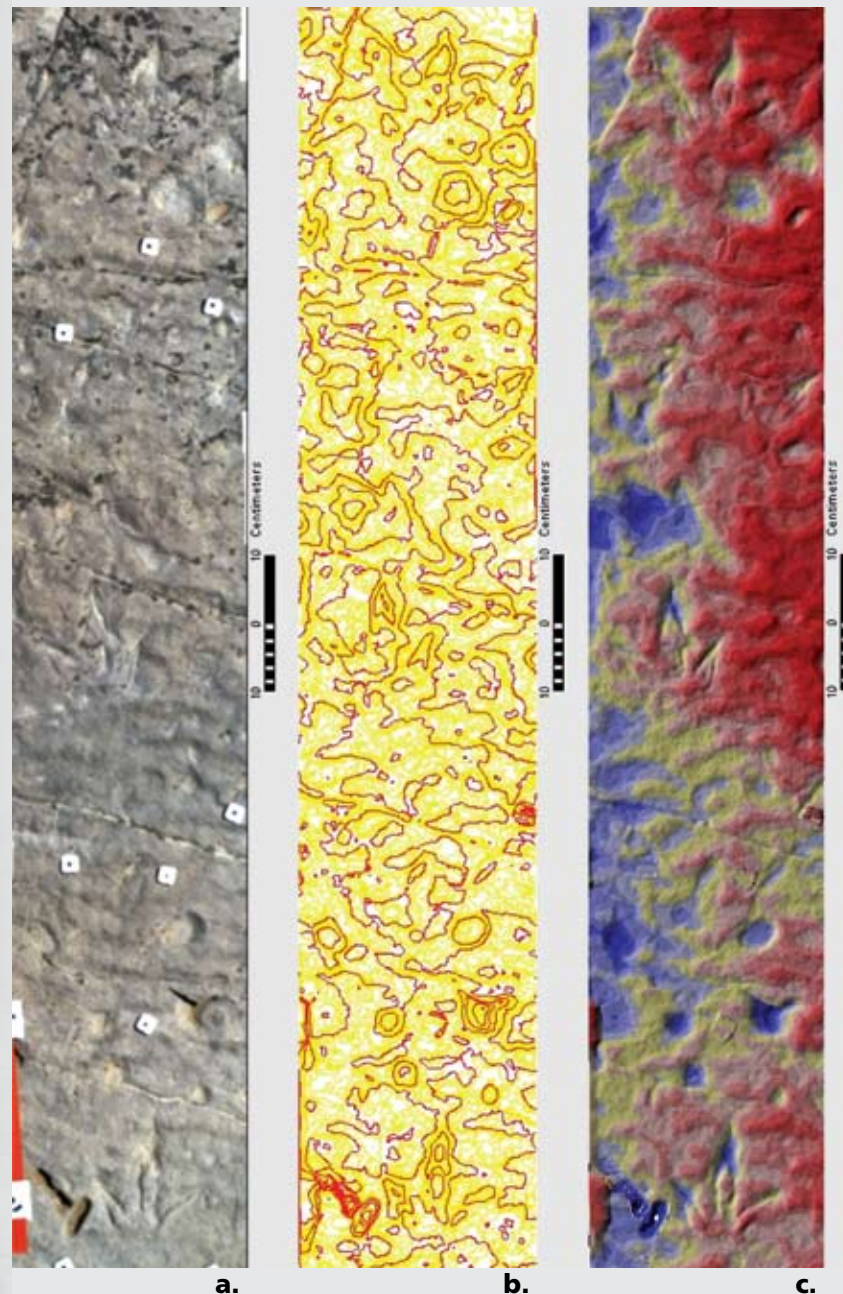
aerial system. In such instances, it will probably be necessary to go through a commercial provider as is done with traditional aerial imagery acquisition.

Interpreting the Imagery

The process of extracting data from the CRP imagery is another area where increased flexibility is realized compared to traditional aerial photogrammetry. The 3DMM software can run very efficiently on most laptop computers. Thus, processing

of digital images may begin in the field as soon as the imagery is acquired and downloaded. This can provide a real time look at the success of the photography coverage and provide for near real time measuring and recording of features. In addition, the photographs may be taken by trained field personnel and archived for later processing in a workstation environment. The resulting 3D image files can be, in turn, sent back out to field personnel for viewing in free viewer software. If more in-depth analysis is required, ArcGIS Stereo Analyst and LIECA Photogrammetric Suite (LPS) (both available within the Bureau) can be used for data compilation.

Figure 7. a. Digital orthophoto map. b. Vector map depicting topography. c. Digital terrain surface colorized by elevation. These maps were produced by photogrammetry at the BLM National Operations Center (Denver, Colorado) with a tripod-based camera and close-range photogrammetric techniques; they depict a dinosaur trackway from the BLM's Red Gulch Dinosaur Tracksite in Wyoming.



Close-Range Photogrammetry Products

The same cadre of products (digital terrain model, digital orthoimagery, vector maps, and others) that can be created from traditional aerial photogrammetry can also be generated from CRP (Figure 7). In addition, new and unique visuals can be easily produced from within the 3DMM software (Figure 8). Therefore, it is much

more efficient to produce animations and digital-rotatable 3D objects that can be integrated into 3D raster streaming Web technology. A 3D Adobe Portable Document Format (PDF) file can be produced and embedded in PowerPoint presentations and documents. In addition, the dense and accurate 3D surface files can be used to produce solid model printouts using a variety of techniques at very large scales, even 1:1.



Figure 8. Three-dimensional surface and image datasets can be packaged as industry standard files that can be viewed and rotated in 3D by a number of software programs. Shown is a right angle cliff face from the Bighorn Basin, Wyoming.



Getting a better vantage point to photograph a test plot in the Falcon Road Open OHV area within the Gunnison Gorge National Conservation Area near Montrose, Colorado.

EXAMPLES

Cyclic Documentation for Change Detection

The ability to detect small changes in soil movement can provide valuable insight for assessing the effects of surface disturbing activities across the landscape (Matthews et al. 2007). Close-range photogrammetry is an excellent method for capturing detailed information about changes, such as erosion, on scales ranging from 1 square meter plots up to an entire hillslope. CRP is especially effective for monitoring erosion on areas that are devoid of vegetation, such as roads, OHV trails, and construction sites (Ypsilantis, personal communication).

Close-range photogrammetry was used to create 3D surface information to help quantify effects from rapidly increasing off-highway vehicle (OHV) use in the BLM's Uncompahgre Field Office. In August 2005, five permanent, variable-sized plots were established north of Montrose, Colorado. Two sites are located in dry wash channels, which cut through sandstone, shale, and coal, in the Dry Creek Extreme OHV Area. An additional three sites were located in the Falcon Road open OHV area within the Gunnison Gorge National Conservation Area (Figure 9) on adobe badlands composed of Mancos shale (Ypsilantis et al. 2007).

Natural features, such as bedrock (when present outside the traveled area) or rebar plot control stakes, served as *x*, *y*, *z* coordinate reference points. The rebar plot stakes were buried beneath the soil surface to ensure that the permanent reference points were not disturbed and to eliminate safety hazards for recreational users. A series of stereoscopic photographs were taken of the plots, concurrently with the camera calibration photographs, to facilitate stereoscopic viewing and analysis of the subject area. Establishing plots, site



Figure 9. Five permanent study plots were established in 2005 in the vicinity of Montrose, Colorado: A. Scratch and Dent; B. Calamity; C. Falcon; D. Falcon II; and E. Beyond Falcon (Ypsilantis et al. 2007).

preparation, and photographing for all five plots were accomplished in 2 days.

In September 2006, the five plots were reestablished and site preparation, GPS coordinate collection, and photography were conducted in 1 day. Real-time kinematics (RTK) GPS positions (accurate to <1 cm) were taken for the control monuments and selected points within each plot locality. The resulting coordinate data were used to tie the digital terrain models to a real-world coordinate system (NAD83 Colorado Central State Plane Zone). In addition, this control was used to process both the 2005 and 2006 photography to aid in ensuring positional integrity between the 2 years (Ypsilantis et al. 2007).

Ten unique, highly detailed 3D surface datasets were produced photogrammetrically. The estimated vertical accuracy

of these data is between 0.1 and 1.0 cm. The ten (2 years for each of five plots) 3D digital terrain datasets were analyzed in ArcGIS by using ArcMap and ArcScene. This process included creating a tin surface from the 3D datasets, converting the tin to a grid, and generating a hillshade from the grid (Figure 10). The grids were created with a resolution of 3 cm. Cut-and-fill and surface subtractions were made using the surface grids (Figures 10 and 11). According to the results of the analysis of the surfaces, all five sample plots exhibit loss and gain (or movement) of soil.

The soil gains and losses on the Mancos Shale hillslopes in the Gunnison Gorge NCA are high, with average soil loss rate of 163, 219, and 121 tons/acre calculated for the three sites. Figure 11b illustrates an area of high impact at the top of the slope at one site and an area of minimum impact at a similar slope position. The soil loss for the area of high impact was 585 tons/acre and 367 tons/acre for the area of minimum impact. This indicates that soil loss is greater in the dirt bike trail entrenched into the hillslope than in the area that showed little visual evidence of recent OHV use (Ypsilantis et al. 2007).

Figure 10. Falcon II plot. a. Photograph taken in August 2005. b. 3D surface model generated from the 2005 photography rendered as a hillshade. c. Photograph taken in September 2006. d. 3D surface model generated from the 2006 photography rendered as a hillshade (Ypsilantis et al. 2007).

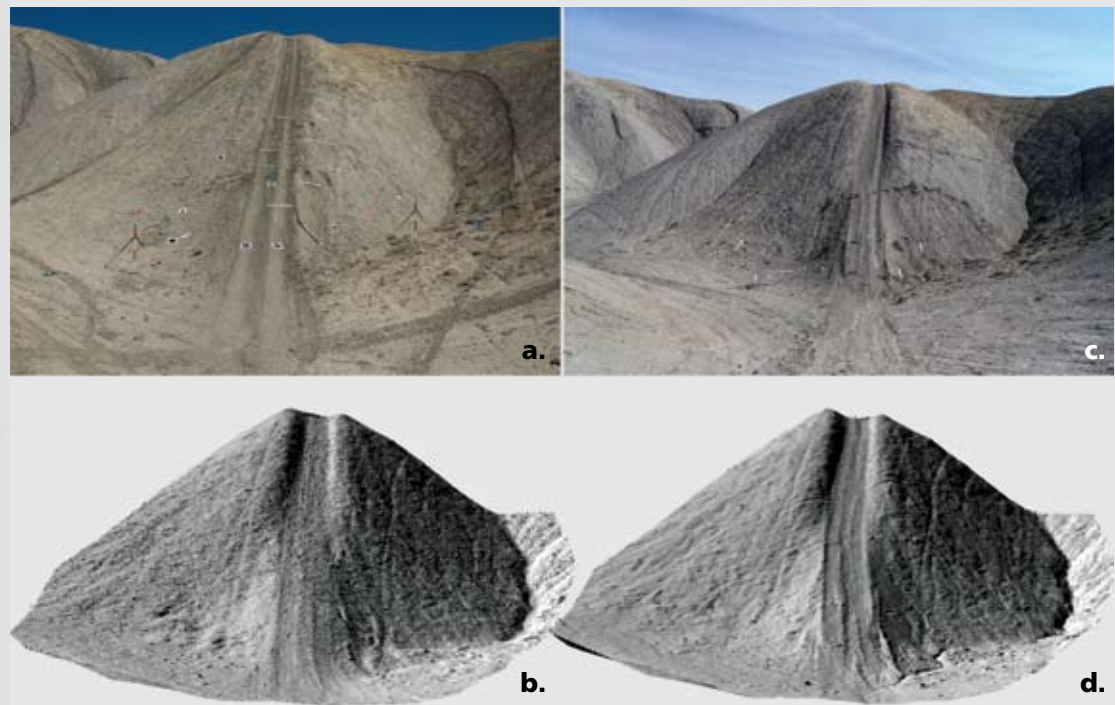
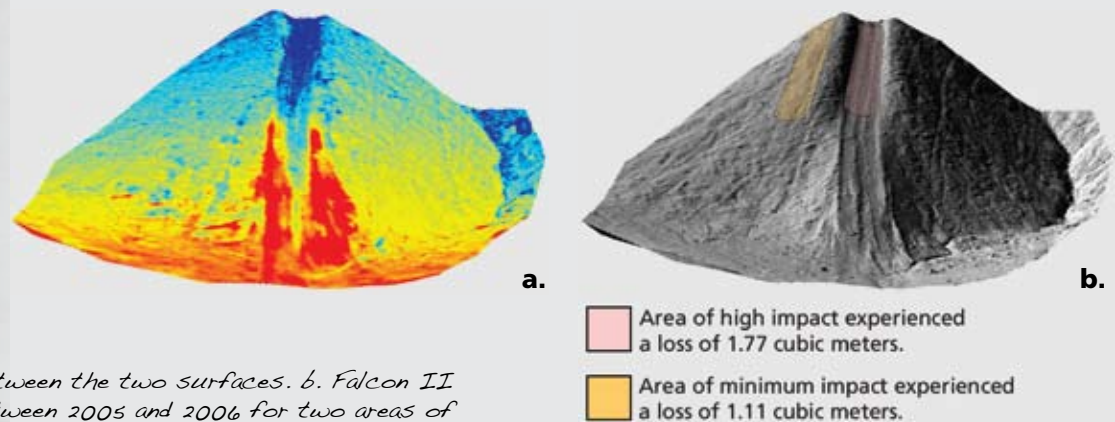


Figure 11. Falcon II plot. The 3D surfaces generated from the 2005 and 2006 photography were compared in ArcGIS. a. Graphic generated by using surface subtraction of the 2005 surface from the 2006 surface. The dark blue and dark red colors represent areas of greatest separation between the two surfaces. b. Falcon II plot. Volumetric loss between 2005 and 2006 for two areas of 17.77 m³ (Ypsilantis et al. 2007).



The Dry Creek Basin sites were along a trail in an ephemeral drainage area. The modified OHVs on the trail can climb boulders and dig the sides of their tires into the hillslopes (Figure 12). This results in deposition of soil material below that hillslope, which is available for transport by the stream during high precipitation. One interesting anomaly shown in Figure 13 is the two large boulders that have been moved approximately 2 m downslope, apparently by OHV activity. The amount and direction of movement could be reliably determined through the use of stereoscopic images taken during the study.

The results of the study were compiled into a report (Ypsilantis et al. 2007) and provided to the Uncompahgre Field Office for use in the travel management plan. In addition, graphics generated from the report are being used in public presentations in support of management decisions.



Figure 12. Scratch and Dent plot. a. Photograph taken in August 2005. b. 3D surface model generated from the 2005 photography rendered as a hillshade.



c. Photograph taken in September 2006. d. 3D surface model generated from the 2006 photography rendered as a hillshade (Ypsilantis et al. 2007).

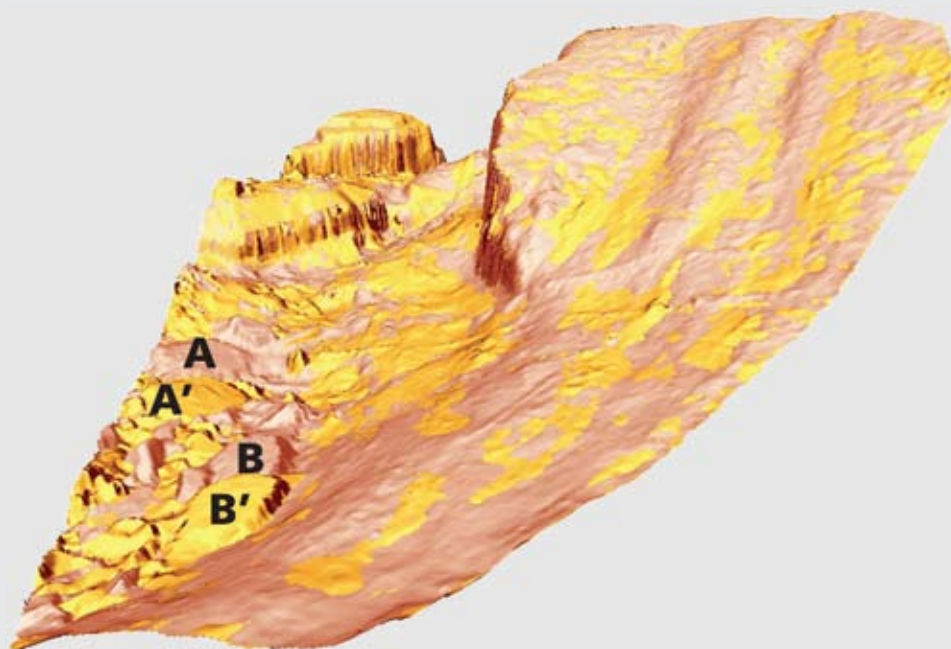


Figure 13. Scratch and Dent plot. Two boulders (A and B), each approx $1 \times 0.6 \times 0.5$ m, moved about 2 m down the channel (A' and B') between August 2005 and September 2006 (Ypsilantis et al. 2007).

Integrating Multiscale Imagery for Riparian Habitat

Coalbed methane discharge water has the potential to influence aquatic and riparian habitats in and along the Powder River of northeastern Wyoming (Figure 14). The Powder River Aquatic Task Group is investigating the use of remote sensing data and techniques to develop economical and effective means of monitoring change in affected aquatic and riparian habitat (Figure 15). This study is evaluating the utility of very large scale aerial (VLSA) imagery for classifying riparian and aquatic habitat types, as well as testing close-range photogrammetric, stereo-based image modeling techniques for change detection, documentation of vegetation composition and structure, and quantifying bank erosion and stability (Bobo et al., 2008).

A transect-based aerial-sampling protocol was proposed for the first phase of this project to facilitate the capture of ground control to support the CRP work. In related work, the integration of GPS/IMU systems with CRP techniques to accurately and rapidly geocorrect VLSA photography is being explored. The georeferenced VLSA imagery can in turn be used as training data for wider area mapping by using



Figure 14. Location map for the Powder River, Wyoming, coalbed methane aquatic monitoring study (Bobo et al. 2008).

satellite platforms such as Quickbird. Georeferencing of the VLSA imagery is presently conducted with both 0.60-m resolution Quickbird imagery and 0.25-m resolution AeroCam imagery (Noble et al. 2008; Figure 16). Once the spatial links between the three sets of imagery were set, the VLSA was used as a classification tool for the more coarse resolution imagery.



Figure 15. 3D image model developed from close-range photogrammetry along the Powder River, Wyoming. Images from two different times of year are merged to highlight the change in vegetation. With the 3D information available from multi-temporal 3D dataset, changes in vegetation heights, bank erosion, slope, water depth, vegetative cover, and bare ground can be measured (Noble et al. 2008).

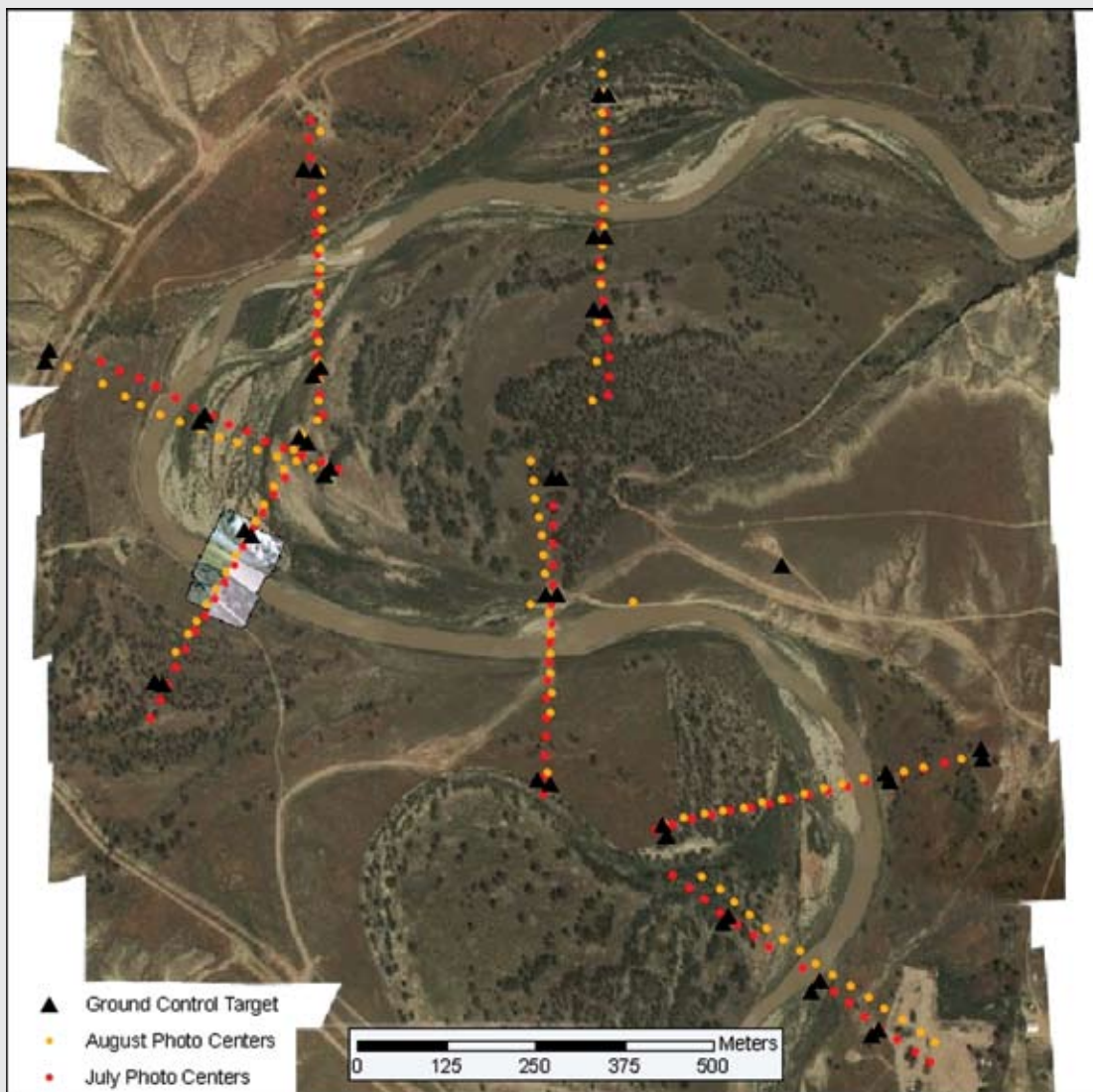


Figure 16. Photo targets were placed along selected transects across the Powder River, Wyoming, to assist with geocorrection of large-scale aerial imagery (Noble et al. 2008).

The integration of GPS/IMU systems, VLSA imagery, and CRP techniques hold the potential to greatly expand field sampling intensities, thus enabling more representative coverage of the environmental gradients in the landscape. This will lead to better monitoring information and increased classification accuracies of coarse-scale remote sensing data. Additionally, the integration of these technologies would facilitate the development of proactive monitoring protocols for invasive species.

At all three study sites for which VLSA imagery was obtained, tamarisk (*Tamarix spp.*)—a salt-accumulating, desiccation-tolerant invasive alien species—was shown to have cover values comparable to the

native cottonwood (*Populus fremontii*). Given the high percentage of emergent features of the Powder River channel and the documented tamarisk succession scenarios of other western streams, tamarisk poses an immediate threat to the aquatic habitat and native riparian vegetation. By automatically geocorrecting VLSA imagery using the integration of GPS/IMU systems, great potential for cost-effective monitoring exists. This will allow for the development of protocols for riparian corridors that would enable invasive species to be identified before becoming so infested in an area that management actions become too expensive to implement (Bobo et al. 2008).

Documenting Cultural Resources

The Legend Rock State Archaeological Site enables visitors to view more than 300 petroglyphs spanning a period of thousands of years and representing multiple cultures. Legend Rock, located 28 miles from the town of Thermopolis in north-central Wyoming (Figure 17), was listed on the National Register of Historic Places in 1973 and is world-renowned. A series of sandstone cliffs contain the petroglyphs. Ownership of the cliffs is split among a private land owner, Wyoming State Parks, and the BLM. In 2006, the Legend Rock Interagency Steering Committee was formed. This Committee includes land management agencies, as well as State and local preservation groups and museums. The mission of the Committee is to provide guidance and recommendations to the Wyoming Division of State Parks and Historic Sites on the restoration, maintenance, management, interpretation, promotion, and public accommodation at the Legend Rock State Archaeological Site (Loendorf et al. 2008).

Figure 17. The Legend Rock State Archaeological Site is 28 miles from Thermopolis in north-central Wyoming.



Photogrammetry staff from the NOC was included in the committee from its inception. In fall 2006, NOC staff, accompanied by imaging specialists for Cultural Heritage Imaging, a nonprofit organization that is developing an imaging technique (Mudge et al. 2006) complementary to CRP, joined archaeologists for a visit to the site. This reconnaissance visit provided an opportunity to see and access the site and to determine the approach and resources needed to fully photograph the rock art panels. As a result of the scoping trip, several proof-of-concept 3D image datasets were produced. These virtual 3D models and the CRP techniques were presented at committee meetings, professional archaeological meetings, and for the 2007 Wyoming Joint Senate House Subcommittee on Recreation, Travel, Wildlife, and Cultural Resources. The 3D models provided stunning visualizations of the intricacies and uniqueness of the rock art, offering an early success and a catalyst to energize the committee (Figure 18).

A multiphased approach for documenting the site was developed. During the first phase, a spatially accurate photographic mosaic base map of the sandstone cliff was created. The corrected mosaic, tied to a digital real-world system with RTK GPS, served as base maps for field location,



Figure 18. The close-range photogrammetric digital 3D image models can be created and viewed on a laptop computer in the field, providing an on-site demonstration.

inventory, and documentation of rock art panels. The cliff face was photographed from a distance of about 200 m with a 150-mm lens (Figure 19). A resulting resolution and positional accuracy of about 1 cm was achieved (Figure 20). In addition, the digital photo mosaic can be used to provide visual context to more detailed, three-dimensional digital models of individual panels.

The second phase provides detailed three-dimensional modeling and imaging of individual petroglyph panels. The virtual models can be used to record the petroglyphs and to detect even minute changes to the rock art that may occur over time. These highly detailed digital re-creations of the individual panels provide a resolution and accuracy in the tenths of millimeters and provide a baseline for monitoring the site for natural degradation and vandalism. Because of the enormity of the workload for DRS staff, the NOC photogrammetrists provided training in stereoscopic image capture to a State of Wyoming archaeologist involved in the project (Figure 21). In summer 2007, all the

panels on the State-managed land were successfully photographed. In summer 2008, the remaining rock art panels were photographed during a Passport in Time (PIT) project. The PIT program, originated by the Forest Service, allows qualified volunteers to assist in the restoration, recording, and preservation of cultural resource sites. During the 2-week program, photogrammetrists from the NOC provided training in stereoscopic image collection and software processing to the PIT volunteers (Loendorf et al. 2008).

Since the formation of the Legend Rock Interagency Steering Committee, funding for the site has increased, resulting in improvements to infrastructure. An archaeological survey was conducted (Walker et al. 2007) before improvements were made to roads, trails, and parking. The construction of a visitor's center and accommodations for a site host are under way. The photogrammetric documentation will be used as a baseline for inspection and monitoring and for interpretive materials, to include a guide book for the site and interactive digital displays that



Figure 19. The cliff face at Legend Rock State Archaeological Site, Wyoming, was photographed from about 200 m with a 150-mm lens. Inset shows camera orientation and setup.



Figure 20. a. A corrected mosaic of the cliff face at Legend Rock State Archaeological Site, Wyoming, was created by using close-range photogrammetric techniques. b. Close-up view of the mosaic indicated by the black rectangle in a. The pixel resolution of the mosaic is about 1 cm.

incorporate the virtual 3D image models. In addition, the Wyoming Joint Senate House Subcommittee on Recreation, Travel, Wildlife, and Cultural Resources

made the preservation and interpretation of Wyoming's cultural resources its first priority for interim study in 2008.

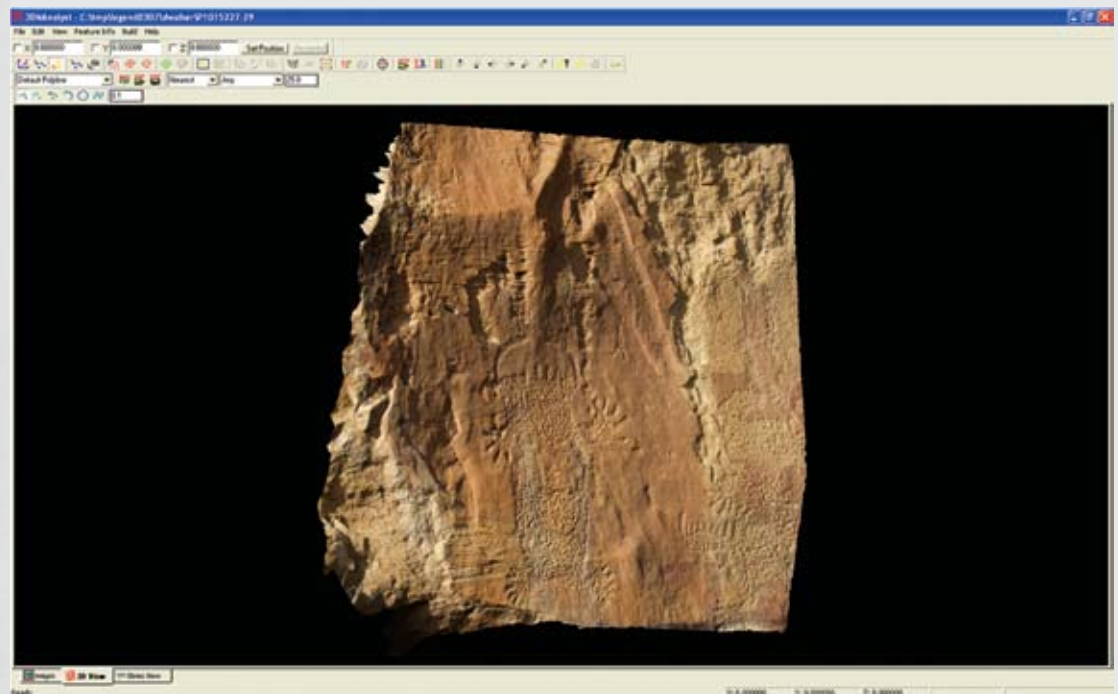


Figure 21. 3D image model of a rock art panel from Legend Rock State Archaeological Site, Wyoming. The stereoscopic images were taken by a State of Wyoming archaeologist during on-site training conducted by photogrammetric staff from the BLM National Operations Center.

CONCLUSION

Documenting and evaluating the condition of its land is a critical part of the Bureau's mission. Condition data obtained by applying photogrammetric techniques provide information on the health of the land and serve as a basis for future decision making; they also provide a tool for determining the effectiveness of present management practices. The availability of digital cameras and the increasing capabilities of computers and analytical software have dramatically expanded the variety of resource applications to which photogrammetry may be applied, while simultaneously decreasing the costs of acquisition, processing, and analysis. The software used to process stereoscopic images to the viewing stage (corrected imagery and 3D surface data) and for use in GIS is presently available within only a few BLM offices. However, the capability to take the needed photographs for close-range photogrammetric projects is not. Field personnel with a vision toward the future will see the value in capturing stereoscopic photographs now. As the types, capability, efficiencies, and availability of 3DMM software increase, these photographs can be used in the future to document changes in condition critical to the Bureau's mission.

The fundamentals of perceiving depth, stereoscopic viewing, and photogrammetry have remained constant through changing technologies. Various 3DMM softwares available on the market today may suggest additional photographs

to increase efficiencies. However, the basic geometry will remain the same and allow for measurements to be made from stereoscopic photographs taken 100 years ago, yesterday, or 100 years in the future. Because of this, the concepts of capturing the data and not processing via specific software have been stressed in this document.

The following appendices contain technical information to assist field resource specialists in the successful completion of the imagery collection portion of a basic close-range photogrammetry project. Appendix A outlines the basics of stereoscopic photography. Appendix B discusses the features that should be considered when choosing a camera for CRP documentation. Appendix C discusses factors that can affect picture quality and offers suggestions on taking photographs that will provide successful results. Finally, Appendix D outlines the general steps for conducting the field collection of the photographs for a small CPR project. Also included in Appendix D is an equipment list. When reviewing this list, note that the majority of items (with, perhaps, a few exceptions) are the standard equipment most often taken to the field. That is the benefit of CRP: for the initial field trial of this technology, there is no substantial investment in equipment, only of time—time to read and be familiar with the contents of this document and time to practice taking the needed photographs in the field.



A fixed grid of varying height was used as an early method of providing x,y, and z control at the Red Gulch Dinosaur Tracksite in Wyoming.

REFERENCES

- Birch, J. S. 2006. Using 3DM Analyst Mine Mapping Suite for rock face characterisation. *In* F. Tonon and J. Kottenstette, editors. *Laser and Photogrammetric Methods for Rock Face Characterization*.
- Bobo, M., T. Booth, S. Cox, N. Matthews, R. McDougal, G. Meyer, and T. Noble. 2008. Application of high resolution remote sensing for monitoring aquatic and riparian habitats within the Powder River Basin in Wyoming. *In* 12th Biennial USDA Forest Service Remote Sensing Applications Conference RS-2008. [abstracts and program]
- Breithaupt, B. H., and N. A. Matthews. 2004. An integrated approach to three-dimensional data collection at dinosaur tracksites in the Rocky Mountain West. *Ichnos* 11(1–2):11.
- Forbes, K., A. Voigt, and N. Bodika. 2002. An inexpensive, automatic, and accurate camera calibration method. *In* Proceedings of the Thirteenth Annual Symposium of the Pattern Recognition Association of South Africa.
- Hussain, M., and J. Bethel. 2004. Project and mission planning. *In* J. C. McGlone, editor, *Manual of Photogrammetry*, 5th edition. American Society for Photogrammetry and Remote Sensing. 1151 pp.
- Loendorf, L., and C. McClellan. 2008. Management of Legend Rock Archaeological Site. Paper presented at the Binational Petroglyph Conference, Albuquerque, New Mexico, September 2007.
- Matthews, N. A., T. A. Noble, and B. H. Breithaupt. 2004. Page 348 *in* Dinosaur tracks to dam faces: A new method for collecting three-dimensional data. *Geological Society of America Abstracts* 36(5).
- Matthews, N. A., T. A. Noble, and B. H. Breithaupt. 2006. The application of photogrammetry, remote sensing, and geographic information systems (GIS) to fossil resource management. Pages 119–131 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. *Fossils from Federal Lands*. New Mexico Museum of Natural History and Science Bulletin 34.
- Matthews, N. A., T. A. Noble, M. Bies, L. Loendorf, D. N. Walker, M. Mudge, and C. McClellan. 2007. Photographing the past, protecting the future: Using close-range photogrammetry to capture 3D images of the Legend Rock Petroglyph Site, WY. *In* 34th Annual Meeting of the American Rock Art Research Association, Abstracts and Program. La Pinta 33(4).
- Matthews, N. A., T. A. Noble, W. G. Ypsilantis, and D. Murphy. 2007. Of time and the soil: Detecting microtopographic changes using extreme close-range photogrammetry.
- Mudge, M., T. Malzbender, C. Schroer, and L. Marlin. 2006. New reflection transformation imaging methods for rock art and multiple-viewpoint display. *In* M. Ioannides, D. Arnold, F. Niccolucci, and K. Mania, editors. *Proceedings of the Seventh International Symposium on Virtual Reality, Archaeology, and Cultural Heritage (VAST2007)*. Eurographics Association.

Noble, T. A., and N. A. Matthews. 2007. A new look at capturing detailed 3D images of rock art: Advances in close-range photogrammetry. *In* 34th Annual Meeting of the American Rock Art Research Association. La Pinta 33(4). [abstracts and program]

Noble, T. A., N. A. Matthews, T. Booth, S. Cox, and M. Bobo. 2008. Application of close-range photogrammetric techniques to Very Large Scale Aerial (VLSA) Photography for monitoring aquatic and riparian habitats. *In* 12th Biennial USDA Forest Service Remote Sensing Applications Conference RS-2008. [abstracts and program]

Walker, D. N., M. Bovee, M. Karnopp, and T. Noble. 2007. Archaeological Investigations and Rock Art Recording at Legend Rock State Archaeological Site, Wyoming. *In* 65th Annual Plains Anthropological Conference Abstracts.

Ypsilantis, W. G., T. Noble, and N. Matthews. 2007. OHV Use Monitoring with Extreme Close-Range Photogrammetry. Project report to the BLM Field Office in Montrose, Colorado. Bureau of Land Management, National Science and Technology Center, Denver, Colorado. 6 pp. [unpublished]

● APPENDIX A

CONCEPTS OF STEREOSCOPIC PHOTOGRAPHY

Stereoscopic photographs are taken to mimic the three-dimensional viewing capability resulting from the offset of a person's left and right eyes (Figure A.1). The first consideration when designing the stereophoto layout is the needed precision

(scale) that is required to adequately represent the subject. As in traditional film photogrammetry, the scale has a geometric relationship between the height of the sensor and the focal length of the lens (Hussain and Bethel 2004).

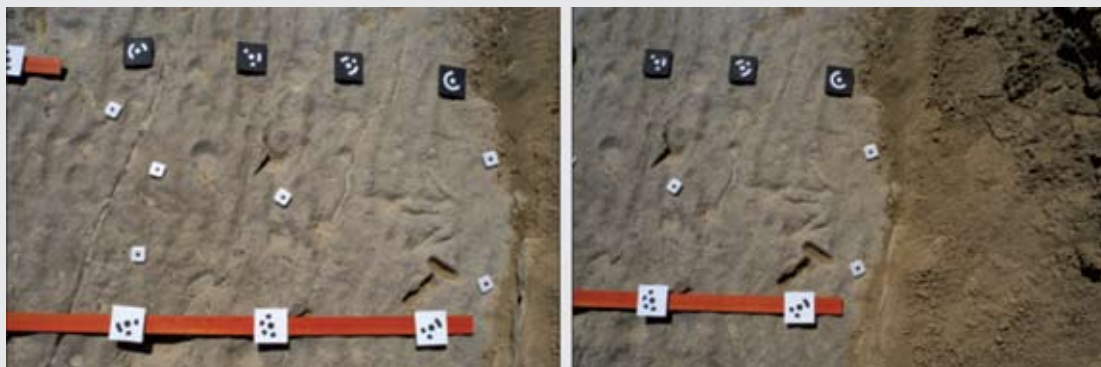


Figure A.1. Stereoscopic photograph pairs of a dinosaur track from the Red Gulch Dinosaur Tracksite, Wyoming.

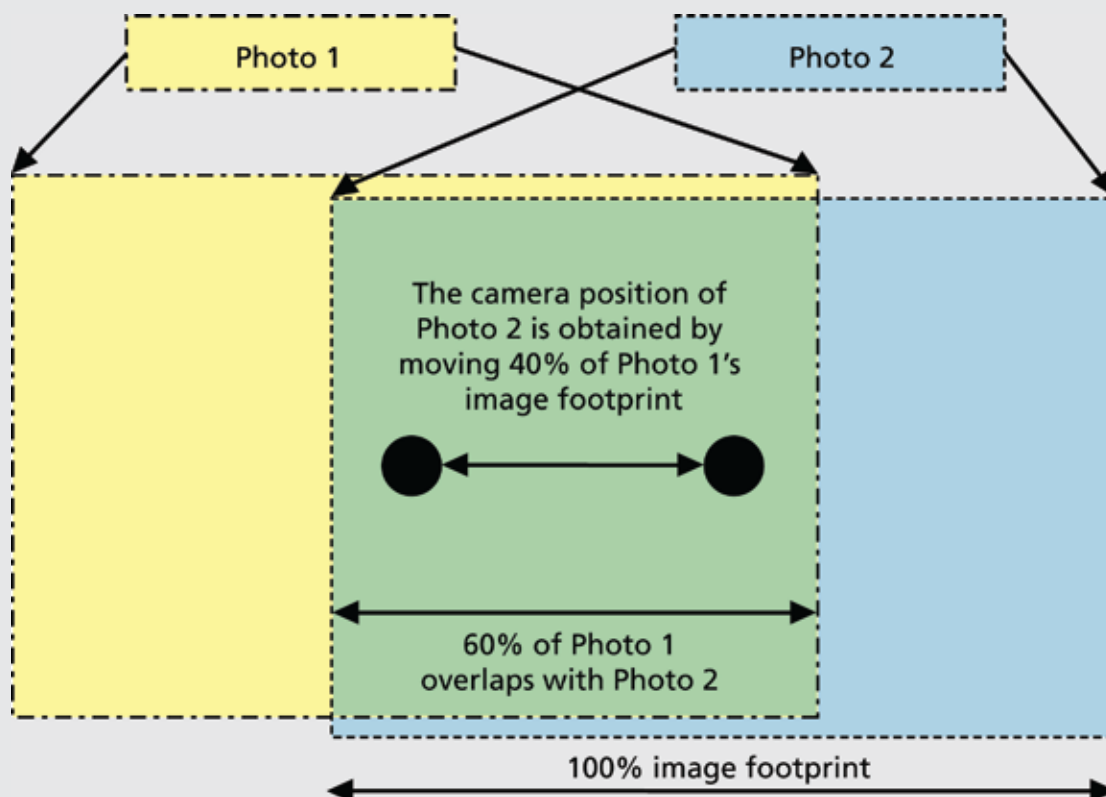


Figure A.2. The large black dots represent photo centers and thus the camera position. A dashed rectangle is associated with each photo center dot and represents the field of view, or footprint, of that image. The best stereophoto pairs overlap each other by 60%. This is achieved by actually moving the camera position of each photo by 40% of the photo's footprint.

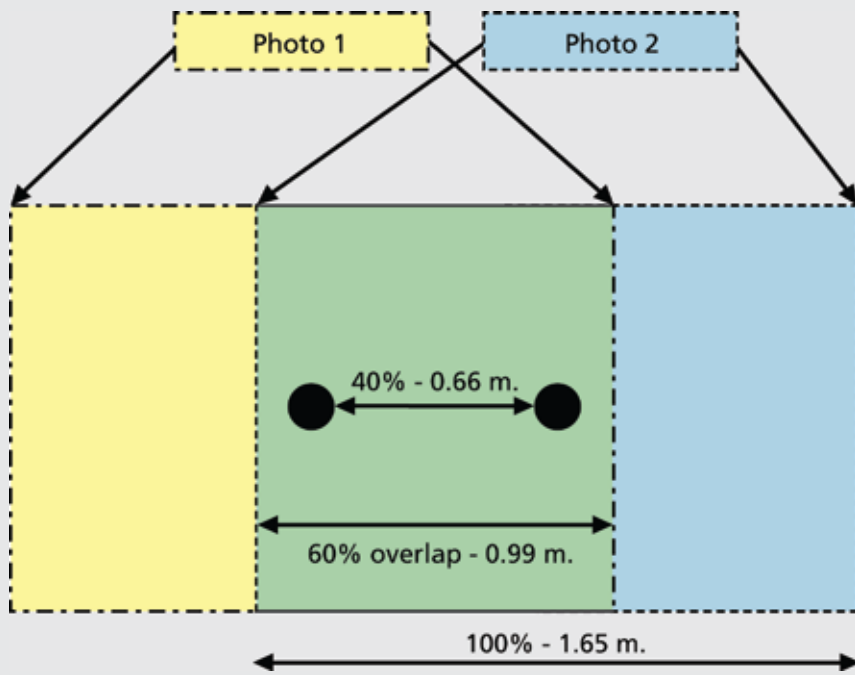


Figure A.3. In this example, each image footprint is 1.65 m, thus the amount of stereoscopic overlap (at 60%) is 0.99 m ($0.60 \times 1.65 = 0.99$). To achieve 60% overlap, the camera must be moved by 40% of the image footprint, which is 0.66 m ($1.65 \times 0.4 = 0.66$).

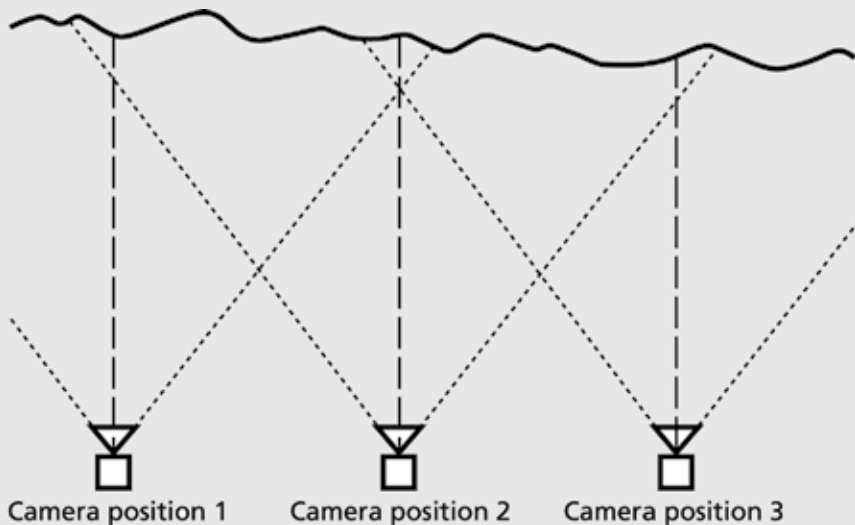


Figure A.4. Graphic of parallel images with typically 60% overlap (Birch 2006). An imaginary ray (dashed line) drawn through the center of the lens should be as perpendicular to the plane of the subject as possible. All images are taken with one camera that is moved in sequence from position one to two, to three, and so forth.

$$\text{scale} = \frac{\text{focal length}}{\text{height above terrain}}$$

For example: $\frac{6 \text{ inches (0.5 feet)}}{2,000 \text{ feet}} = 0.00025$

$$1/0.00025 = 4,000$$

$$\text{Scale} = 1:4,000$$

The pixel resolution, or Sensor Pixel Size (SPS), of a commercial digital camera can be factored into the preceding equation to determine the ground resolution, or ground sample distance (GSD), of the resulting image. The SPS is computed by taking the physical width of the sensor divided by the width of the sensor in pixels.

$$\text{GSD} = \text{SPS} * H / f$$

where SPS is the Sensor Pixel Size (in micrometers),

H is the camera height, or distance from the object (in meters), and f is the focal length of the lens (in millimeters).

GSD will be in meters; multiply by 1,000 for GSD in millimeters

The best stereophoto pairs have an overlap of 60% (Figure A.2). Once the desired GSD is determined, the camera height and distance between camera stations can be calculated.

For example, when using a 10 megapixel SLR with a sensor size of 23.6 × 15.8 mm and pixel dimensions of 3,872 × 2,592, the $\text{SPS} = 23.6 / 3,872 = 0.00610 \text{ mm}$. Therefore, with a 20-mm lens, and shooting at a height of 1.4 m above the subject, the GSD—is 0.43 mm. The area covered (or footprint) of each photo would be 1.65 × 1.11 m. For a 60% overlap, the distance between camera stations is 0.66 m, which is 40% of the image footprint (Figure A.3).

A simple way to determine the image footprint in the field is to mark points on the ground on either side of the frame of the viewfinder when the camera is at the appropriate distance from the subject. Then measure the distance between these points and calculate 40% of that distance.

The orientation of the camera or sensor to the subject is also an important consideration. It is most desirable to have imagery that is taken as close to nadir—that is, with the camera perpendicular to the subject—as possible. A tripod (with an extension arm when shooting down) can greatly aid in positioning the lens directly over the subject (Figure A.4). This also positions the plane of the sensor parallel to the subject and helps to reduce perspective distortions in the image (Figure A.5).

In some instances, nadir photography is not practical because of constraints imposed by the terrain or project size. In such instances, oblique photography must be used.

Photographs deviating significantly from nadir that have a high angle to the object are referred to as high-angle oblique photos (Figure A.6a). When nadir photos are not a practical option, high-angle oblique



Figure A.5. It is important for the camera to maintain a consistent relation to the subject. Keeping a perpendicular angle to the subject is preferable. The dashed line represents the ray described in Appendix Figure A.4. A tripod with an extension arm was used when photographing a dinosaur trackway at the Red Gulch Dinosaur Tracksite, Wyoming.

photos are preferred for several reasons: ability to get closer to the subject while still filling the frame, stronger angles for resolving the 3D coordinate positions, and less distortion of features.

Photographs taken at a low angle to the subject are referred to as low-angle oblique photos (Figure A.6b). Low-angle oblique photos are not desirable, as both the subject and control targets can be highly distorted. However, if an in situ object is being photographed and low-angle oblique photos are the only option, they may be used. With experience and care, low-angle oblique photos may successfully be used for measurement.

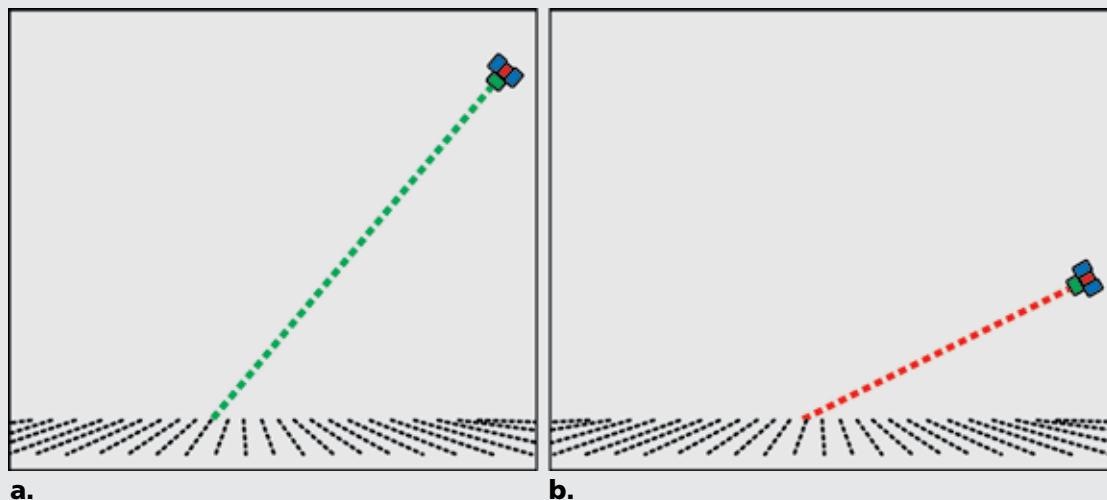


Figure A.6. A line of sight not directly nadir (perpendicular) to the subject is considered oblique. a. Photos taken at a high-angle oblique camera angle can be used when needed and will provide successful results. b. Photos taken when the line of sight to the subject is sharp (a low-angle oblique camera angle), should be avoided unless absolutely necessary to provide stereo overlap.



Extending the reach to photograph a difficult to access rock art panel in the Bighorn Basin of Wyoming.

● APPENDIX B

CHOOSING A CAMERA

Digital cameras and 3DMM software have most certainly revolutionized the CRP process. Previously, an expensive metric or surveying camera was required. These cameras are equipped with required fixed-focus lenses with predetermined focal distances and are manufactured to a high level of precision and stability. However, even with care in manufacturing, lens distortions could not be completely eliminated and a manufacturer's calibration report would accompany each camera. The calibration report includes the size of the frame, location of any fiducials, the focal length, principal point, and distortion coefficients of the camera–lens system. The information from the calibration report is used in setting up the stereo model so that the resulting measurements could be made without the effects of distortion from the camera–lens system.

Now the 3DMM software allows us to exploit the ever-increasing number of digital cameras on the market today. The main reason for this is that the 3DMM provides a camera calibration function. This not only removes the restriction of using an expensive metric camera, but also allows for the ad hoc calibration of most camera–lens systems. This is exciting, as it provides for the capability to increase the ground sample distance (GSD) as cameras come on the market with improved sensors. However, it also makes it difficult to suggest a particular camera, as innovations seem to occur frequently. It is important to note that, whereas a digital SLR camera is suggested, successful projects can be accomplished with a point-and-shoot camera. Thus, the following recommendations

highlight features to consider when choosing a camera for CRP documentation.

Resolution

The final accuracy of your measurements and resulting terrain surface are governed by the resolution, or GSD, of the stereoscopic images of your subject. The GSD is governed by the resolution of the camera sensor (higher is better), the focal length of the lens, and the distance from the subject (closer is better). The resolution of the images is governed by the number of pixels per given area and the size of the sensor. A 6 megapixel resolution generally provides good results for a variety of subjects. However, an 8 to 10 megapixel resolution provides much more flexibility and achieves higher accuracies. The sensor size does have to be considered along with the resolution. The conventional way to categorize digital camera sensor size is similar to the sizing of television screens; that is, dimensions are given across the diagonal. The ratio of the sensor is often compared to the 35-mm film that it has replaced (43.3 mm diagonal). The sensor does have a bearing on image quality, with the 28.4 mm sensor found in most digital SLR cameras having the best quality. The sensors of midrange cameras are often 11.0 mm, whereas those of compact digital cameras are 6.72 mm. These smaller sensors can introduce noise in the image. Thus, a compact digital camera with a 1/2.7-inch sensor, even at 12 megapixels, would produce a less desirable image than one with a 11.0 mm sensor, at 8 megapixels.

Lens Flexibility

The length of the lens directly affects the field of view (the base-to-height ratio, the distance from an object and, finally, the accuracy and number of photos needed to cover a subject). Shorter lenses (18 to 30 mm) provide the widest field of view and are good for capturing a subject from close distances with a minimal number of photographs. Longer lenses (100 to 300 mm) are excellent for capturing a subject from greater distances but provide a narrower field of view. However, it can be expensive to have a variety of fixed-length lenses on hand.

Many digital SLR cameras are sold in a “kit” with a compound zoom lens. A fixed-focus lens will always produce a higher quality image; however, the kit lenses are good in that they provide versatility and can reduce start-up costs. Successful CRP projects can be accomplished with zoom lenses when special care is taken.

Manual Focus

Ensuring that a series of stereophotos are captured at the same focal distance is vital to the successful completion of a project. The capability to “take control” of the focus from the camera is accomplished by the manual focus setting. Most SLR and midrange consumer cameras have this capability. The manual focus setting helps to ensure that each photo in the stereo sequence is taken with the same focal distance (although autofocus can be used as long as a constant distance between the camera and the subject is maintained).

Aperture Priority

The aperture setting not only determines the amount of light that reaches the sensor but also controls the depth of field (the point at which the image begins to blur). Thus, it is necessary to use a camera for which the aperture can take priority over the other settings that affect the lighting, such as shutter speed or ISO (International Organization for Standardization; http://www.dpreview.com/learn/?/Glossary/Digital_Imaging). Although this feature is standard on digital SLR cameras, it may not be available on compact cameras.

Image Format

There are a number of different digital image formats. Each format has advantages and disadvantages based on the use and type of compression. Digital image files that are unprocessed, or RAW, contain the original information from the sensor and capture a greater bit depth than other standard formats. The RAW images must be processed in some type of image manipulation software, which often comes with the camera, or third party software such as Adobe Photoshop. The ability to manipulate the RAW image provides for the opportunity to make some exposure corrections after the photos are taken and may allow for the extraction of detail in areas of deep shadow. Other types of image files, such as .jpg (Joint Photographic Experts Group) and .tif (Tagged Image File Format), are processed within the camera and will not provide the same amount of flexibility in post processing (http://www.dpreview.com/learn/?/Glossary/Digital_Imaging). Cameras that capture images in RAW file format, or a combination of .jpg and RAW, are preferred.

Lens Distortion

All camera lens systems have distortions because of the curvature of the lens and the alignment of the lens with the sensor. To quantify these distortions and effectively remove them, 3DMM software provides camera calibration functions as part of the project workflow (Figure B.1). The additional images needed for the camera calibration can be easily integrated into the stereoscopic workflow and are discussed in Appendix C.

The following cameras have been successfully used within the BLM for CRP projects: Canon Powershot A640; Olympus C8080 and EV500; Nikon D70, D80, D200, and D3; and Canon 5D and 1D.

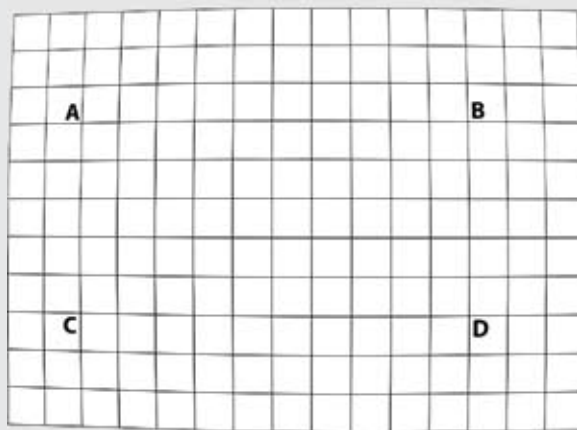
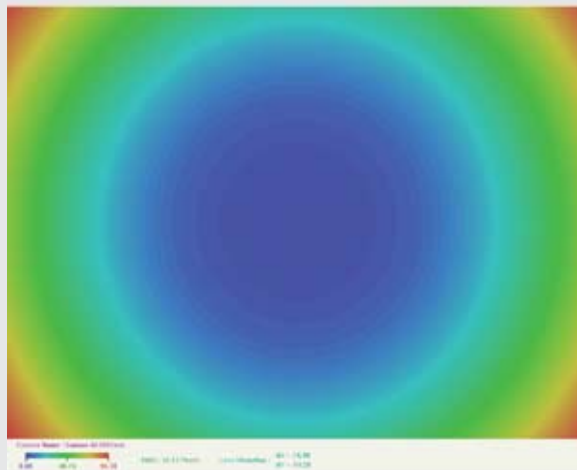


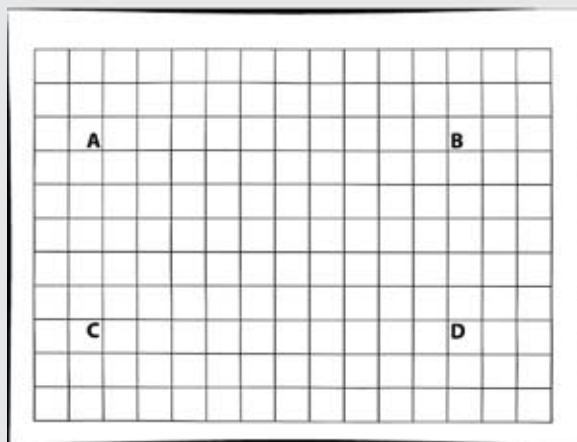
Figure B.1. a. Photograph of a straight-line rectangular grid. The curvature of the lines is due to the most common type of lens distortion, which is barrel distortion.

a.



b. Graphic representation of lens distortion. The least distorted portion of the lens is in the center (depicted in blue). During the camera calibration process, the focal length, format size, principal point, and distortion coefficients (K_1 , K_2 , K_3 , P_1 , and P_2) of the camera-lens system are calculated.

b.



c. The corrected photograph from a. after the lens distortion parameters were applied. The results can be seen in the straightening of the grid lines and a visible change of the image.

c.



Due to the minimal equipment requirements of close-range photogrammetry, subjects in difficult terrain, such as this area north of Albuquerque, New Mexico, can be documented more readily.

● APPENDIX C

TAKING GOOD PICTURES AND SUGGESTED CAMERA SETTINGS

The crucial element to a successful close-range photogrammetric process is attaining “good” photographs. In this instance, the term good refers to a series of pictures that have uniform exposure and are high-contrast, sharp images that fill the frame with the subject. Close-range photographs may never appear on the cover of *National Geographic* magazine or thrill your friends and neighbors, but they must be of sufficient quality that the autocorrelation function of the 3DMM software can function properly.

Environmental factors, the camera used, and the experience of the photographer all contribute to the success of the CRP project. The following section offers recommendations for composing your photos and correctly adjusting the camera settings. It is important to have adequate experience with the camera you are using and be able to adjust it to meet the circumstances. If you can operate your camera and understand the techniques for capturing CRP, you will be able to document, in measurable 3D, almost any subject at almost any time, just with a camera and your brain.

Taking Good Pictures

Several requirements must be met when taking photos suitable for photogrammetry. Every photo needs to be clear, properly exposed, and have adequate overlap with adjacent photos (Appendix A).

Lighting is one of the most critical factors in taking good CRP photographs, and perhaps one of the most difficult to control. The 3DMM autocorrelation process works very well for properly illuminated, high-contrast areas. However, areas of low

contrast and uniform color, areas with high relief displacement, or areas that are obscured (by deep shadows or other features) can lead to mismatching and poor terrain correlation. One of the biggest causes of poor photos is inconsistent light caused by shadows. Shadows can be created by features of the subject that you are documenting or cast by features outside the area of interest (such as your head). When photographing out-of-doors, choose a time of day when shadows are minimal. This may occur when the sun is directly overhead.

The resulting photographs may not emphasize the subject visually; however, properly exposed images taken in full sun have outstanding results during autocorrelation. Use proper camera settings to ensure photographs taken during full sun are not overexposed. Other times of consistent lighting can occur on overcast or cloudy days, or when the subject is in full shadow. In these instances, it may be necessary to slow the shutter speed or use a tripod to ensure that photographs are not underexposed. Keep in mind that lighting and weather conditions can change quickly.

When shooting indoors, make sure the area is as well lighted as possible. Take a few test shots and examine them to make sure that images are not underexposed or blurry. Indoor illumination can be a problem and it may be necessary to slow the shutter speed or use a tripod to ensure that photographs are properly exposed. Using the flash function of the camera is not a good option, as it can cast odd shadows and flares that fall differently through successive stereo pairs, thus affecting autocorrelation. However, stationary light sources such as floodlights, which evenly illuminate the subject, may be necessary in

very low light conditions. When setting up lighting, make sure to provide adequate room around the subject for taking a complete set of stereophotos.

Filling the frame with the subject is also crucial. For small CRP projects, it may be most straightforward to observe the subject through the viewfinder to best determine camera height and overlap. When photographing a larger project or when oblique orientations are necessary, remember to center your subject in the frame. There is often no need to ensure the horizon or other points of reference are in every frame, especially if they detract from the subject that is being documented.

Camera Settings

The 3DMM software used for close-range photogrammetry documentation supports a great variety of cameras. Therefore, it is beyond the scope of this document to list each setting on each camera that could possibly be used for CRP documentation. The following should serve as a general checklist and reminder of settings to check for and should aid in avoiding pitfalls. However, it is important that the operator be familiar with the camera to be used for CRP and with the results that will be produced as settings are manipulated.

Focal Length and Distance

The settings that most dramatically affect success of the CRP project are the focal length (lens or zoom length) and focus distance. A fixed focal length lens makes this process most efficient; however, the zoom capability of multifocal length lenses can be an asset in variable field conditions as the camera lens system may be zoomed or focused to any setting that is appropriate for capturing project detail. However, it is necessary to perform the camera calibration and conduct the project at the same focal length and focus distance. A streamlined

approach for multifocal length lenses is to zoom to either the minimum or maximum extent of the lens and set the focal distance to infinity. Use tape with a minimal amount of residue, such as painters tape, to fix the lens in position.

For cameras that allow the operator to switch freely between autofocus and manual focus, the following produces effective results: Hold the camera at the height or distance at which you will be shooting or mount it on the tripod. Turn the control to autofocus and take a shot. Check that the distance registered on the lens is accurate and check the LCD (Liquid Crystal Display), or download the image to make sure it is in focus. Then switch to manual focus and tape the lens ring to make sure it does not move for the session in which you will be shooting at that constant distance.

Focus Weighting

Many cameras allow you to dictate how the appropriate focus is determined. For example, the camera may take readings from the center of the field of view, average readings from a number of locations, or take continuous readings. It is important to take several test shots and vary the mode of determining the autofocus to ensure that the appropriate focus is achieved for a particular situation.

Aperture

Set the camera on aperture priority. An aperture of f8 (or 35 mm equivalent) is recommended for CRP, as this provides a good depth of field. Proper depth of field ensures that the entire subject is in good focus, which is important for image matching. When shooting at a close distance to the subject, it may be necessary to increase the aperture to f11 or stop down the aperture to get the best depth of field. Refer to your camera manual or digital photography guide for a thorough discussion of aperture and depth of field.

“Film” Speed

The sensitivity of the sensor to light is defined by the International Organization for Standardization (ISO; http://www.dpreview.com/learn/?/Glossary/Digital_Imaging). The ISO setting affects the amount of light that the sensor will absorb during a defined period. The ISO range of a camera is dependent on a number of factors and it is helpful to consult the camera manual when setting the ISO. In general, the brighter the lighting conditions the lower the ISO. When shooting outside on a bright, sunny day, an ISO of 100 (or even lower if supported by the camera) is appropriate. In low-light situations, it may be necessary to increase the ISO to compensate for the aperture setting of f8. It is possible to get graininess or artifacts when the ISO has been pushed too high. Testing for the optimum ISO is important in low-light conditions.

Shutter Speed

While the shutter speed will be determined automatically by the camera once the aperture and ISO have been set, it is a good idea to be aware of the shutter speed. A shutter speed of at least 1/200th of a second is required for handheld photography. For lower shutter speed, adjusting the ISO or mounting the camera on a tripod may be necessary. Should there be camera motion from the wind or an unstable platform (such as a ladder), high shutter speeds (more than 1/1,000th of a second) may be necessary.

File Format

If possible, set to a combination of RAW + FINE. If not, set the file format to RAW if available; otherwise, set to the highest quality .tif or .jpg possible.

Image Rotation

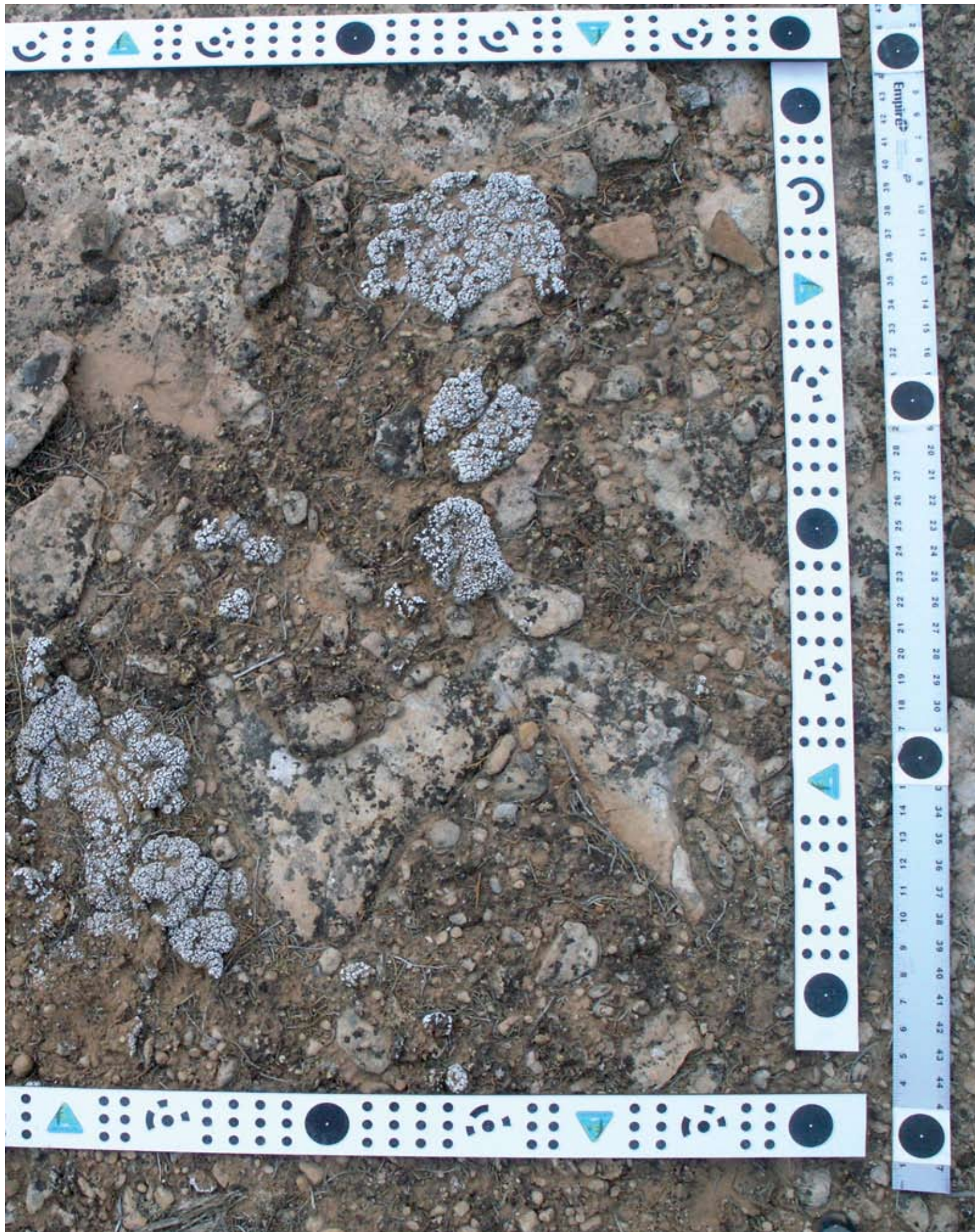
Turn this setting off. The photo orientation must be known with respect to the camera and lens. Automatic image rotation will rotate the image 90° clockwise or counter-clockwise. At first, this may not seem like it would cause a problem, but experience has shown otherwise. When taking nadir photos, it is sometimes impossible to tell which way the camera was rotated when the picture was taken. This can easily happen if photos are taken on opposite sides of a subject with no horizon in the view. The camera calibration cannot be applied correctly if the original orientation is not known.

File Naming

Most digital cameras provide the option to customize the file name or numbering template. Two basic options are the continuous numeric incrementing of file names and restarting the numbering sequence each time the memory card is reinserted. Consecutive numbering is the best option, as it helps to ensure that image files are not overwritten during download. In addition, duplicate file names may be a problem when processing several sequences of images together in the same project.

Custom Settings

As digital cameras advance, so do the options for settings that are tailored to a specific brand of camera. These settings include auto sharpening, white balance, vibrating of the sensor to dislodge dust particles, and others. Once again, it is strongly recommended that time is taken to experiment with how each of these settings, will affect image quality and usability in a CRP project. In most instances (especially image sharpening, stabilization, and sensor vibration for cleaning), it is important to turn off these options.



Objects of known length, with circles at a calibrated distance and circular barcodes, surround a 1-meter-square area of biological soil crust in the Dry Creek Basin near Montrose, Colorado.

Appendix D

Conducting a CRP Project

To take useable stereophotos, some procedures must be followed. By adhering to these procedures, quality photos and efficient processing of those photos is ensured. In general, the steps to be followed are the same regardless of the camera or subject being photographed. However, certain circumstances will require flexibility and ingenuity, which comes with experience.

Close-Range Photogrammetry (CRP) projects can be placed into one of two categories—small (simple) and large (complex). Large projects are those with an area of interest greater than 5 m² or where complexities of terrain or access add to the level of expertise needed for planning and execution of the project. Projects that fall into this category may require a preliminary site visit or the inspection of overview photographs taken of the area. In some instances, the needed vantage points for capturing imagery may not be present, necessitating alternatives to ground-based capture, such as the use of a large ladder, aerial blimp, unmanned aerial system, or other type of elevated platform. Whereas the same basic procedures and equipment apply to both small and large projects, it would be difficult to address all the complexities that could arise with large projects and is beyond the scope of this document.

Small projects have an area of interest equivalent to or smaller than about 5 m². This type of project may also be referred to as extreme close-range as high precision of data points is expected. Design and image acquisition for small projects may be successfully carried out by resource specialists in the field. An overview of the procedures for small or extreme CRP will be provided in this appendix.

Project Planning

The first step in project planning is to establish the need for capturing 3D data of a subject and the detail and accuracy at which the data must be captured. Because of the versatility of the CRP process, the images needed for 3DMM process can be easily captured. This provides great flexibility in the subjects and uses for 3D data. Examples of data capture and use include the establishment of plots for vegetation or erosion monitoring, baseline capture of a feature, taking measurements of a delicate subject that can (or should) not be touched, and dense surface capture for hardcopy reproduction.

Because of the flexibility of the CRP technique, it is possible to obtain high accuracy 3D data from subjects that are at almost any orientation with respect to the camera position. Documentation can be conducted looking straight down at the ground, looking straight ahead at a rock art panel or historical structure, looking at a hillside from an oblique angle, or looking overhead. In all these instances, the same basic principles apply. It is important to get the plane of the sensor and lens parallel to the subject, to maintain a consistent height (or distance) from the subject, to ensure the subject has consistent illumination, and to make sure there is an object of known length in at least three images. To streamline the following discussion, it will be assumed that the camera is facing straight down at the subject. If this is not the situation, camera distance can be interchanged for camera height.

In general, the subject of 3D documentation falls into one of two categories based on the size of the feature to be captured.

Either it is small enough that it may be captured in its entirety (such as a rock art panel) or it is so large that only samples of the area can be economically captured (such as soil erosion monitoring plots). These subjects are referred to as predetermined and sample, respectively. Predetermined subjects are specific features that are to be documented, such as a dinosaur track, historical structure, specific erosional feature, or something specific that must be measured. Sample features refer to situations where there is a defined area to be studied, but the exact site of the CRP project can be selected within that area. An example would be the establishment of a plot for erosion, vegetation, or other types of monitoring. The following section makes recommendations for establishing a sample monitoring plot.

Sample Plot Establishment

For areas as large as 5 m², stereoscopic images with a GSD of 0.5 mm are easily achievable. For most applications, this would provide a suitable level of 3D documentation. It is, therefore, necessary to determine the size of the plot. Depending on the study to be undertaken, the size can vary from 0.5 × 0.5 m² to a rectangular area of 1.0 × 5.0 m. It is recommended that sites be selected with different geomorphic characteristics. Keep in mind that vegetation can have an effect on the density of 3D data collection. This can result from plant movement caused by wind during successive stereophoto acquisition or by simply obscuring the ground. Choosing a site with minimal vegetation would be optimal; however, information may be gained by selecting sites with varying vegetation types, heights, and percentages of ground cover.

Choose a location where the effect on the site can be limited. Try not to step or walk within the sample area, especially if the activity will affect the results of the study. If the CRP is going to be repeated over

successive intervals, it is important to place monuments, such as survey nails or rebar (if appropriate), at the four corners of the site and at least one additional point in the middle of each side, for a total of six monuments. Longer plots should have additional monuments along the sides (one every 1.5 m is suggested). The monuments should be driven flush to the ground to minimize movement. File the top of the rebar to smooth the top surface and the edges. Make sure the top of the rebar is as smooth as possible. Monuments should have a small center point punched into them for exact positioning or marking. It is important that the monument be visible in the stereo sequence. To ensure ease of location it is helpful to place a circular object over the rebar. A compact disk (CD) that has been spray-painted white works very well. It is important to ensure that the rebar used is small enough to fit snugly inside of the hole in the CD. If a number of plots are to be established, it is important to consider both the amount of time required to travel between sites, as well as setup time.

Predetermined Sites

For projects in which the subject is predetermined, the size of the area to photograph will be dictated by the extent of the feature. Deviations from this may occur when the feature is larger than 5 m², and only a portion of it will be documented. In this instance, it is necessary to choose an area that will provide the most representative information for the entire site. Although the long-term goal of the documentation may be monitoring, it is not always permissible to mark many subjects (such as cultural resources) with a monument. In these instances, selecting unique, photoidentifiable natural features as reference points may be necessary, and the use of high-accuracy GPS to relocate established control points over time may be required.

Photo Layout

Once the size and area of interest have been established, the next step is to determine the most effective photo layout. It is important to strike a balance between the level of resolution needed, completely covering the area with overlapping stereophotos, setup time, and processing time. Two approaches can be taken—one minimizes the number of photos needed

and the other sets out to achieve a particular resolution.

Several examples (Figures D.1, D.2, and D.3) illustrate the layouts that can be used for CRP, including single strip and block layouts. When preplanning a photo layout or doing so on an ad hoc basis in the field, it is important to maintain a consistent height and 60% overlap for good stereoscopic photographs (see Appendix A).

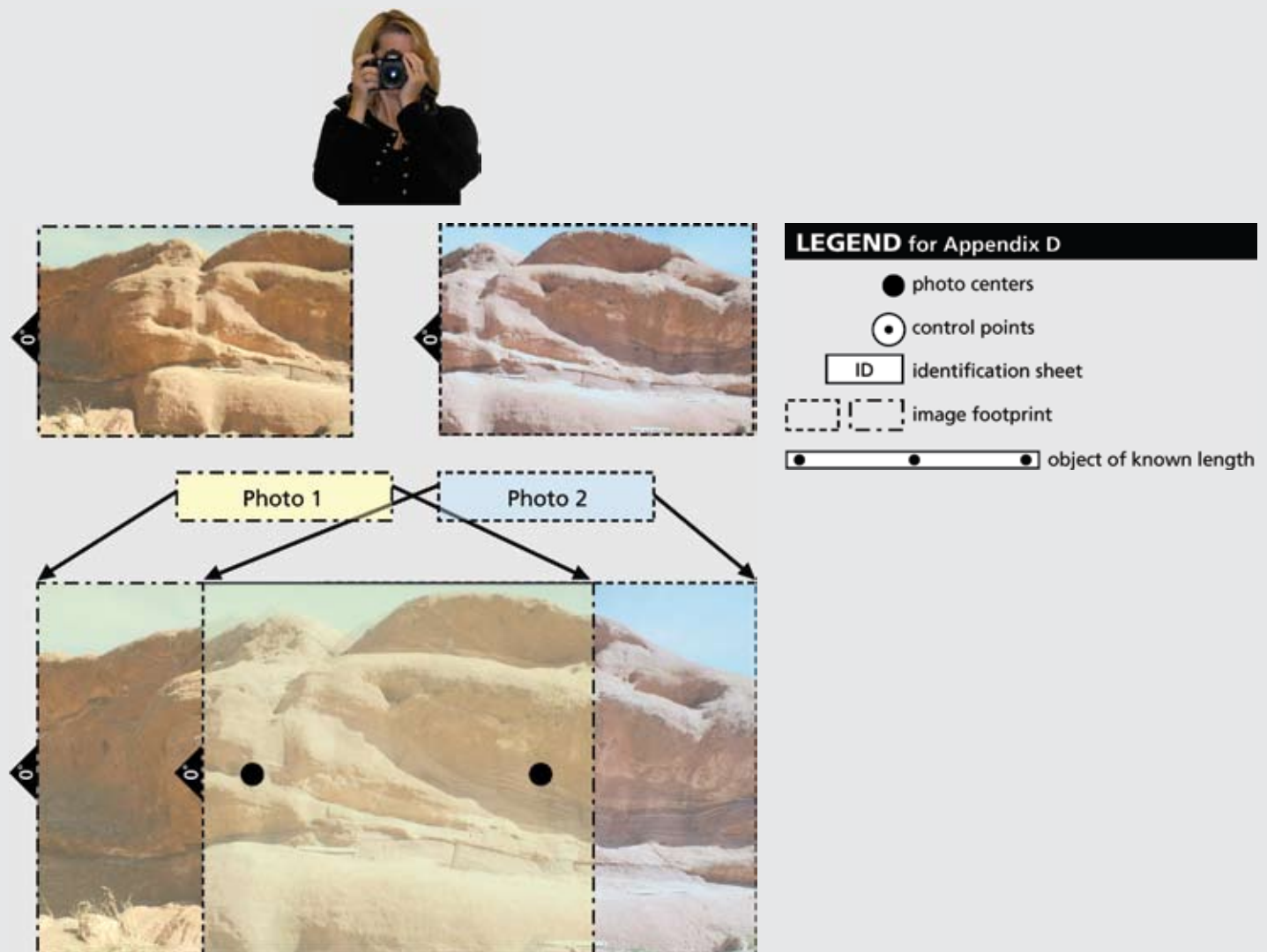


Figure D.1. A small subject requiring a single stereo pair. When needed, an identification (ID) sheet can be placed in the first frame of the stereo sequence, to the left of the area of interest. ID sheets are helpful when photographing a series of subjects that have reference identification codes, such as monitoring plot numbers or museum catalogue codes. The date, weather conditions, photographer, and other types of information can be added to the ID sheet.

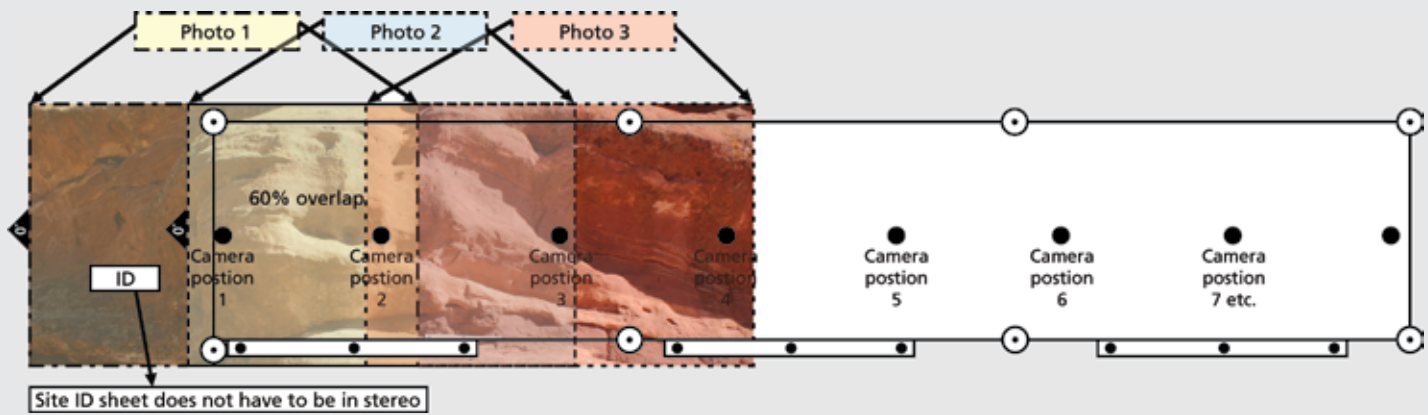


Figure D.2. Photo layout for a single strip of overlapping stereoscopic photography. A single camera is used to photograph each image in succession by moving from one camera position to the next. Note that control points are only necessary when tying photographs to an established reference, such as real-world coordinates or a monitoring datum. An object of known length or calibrated control stick is always necessary.

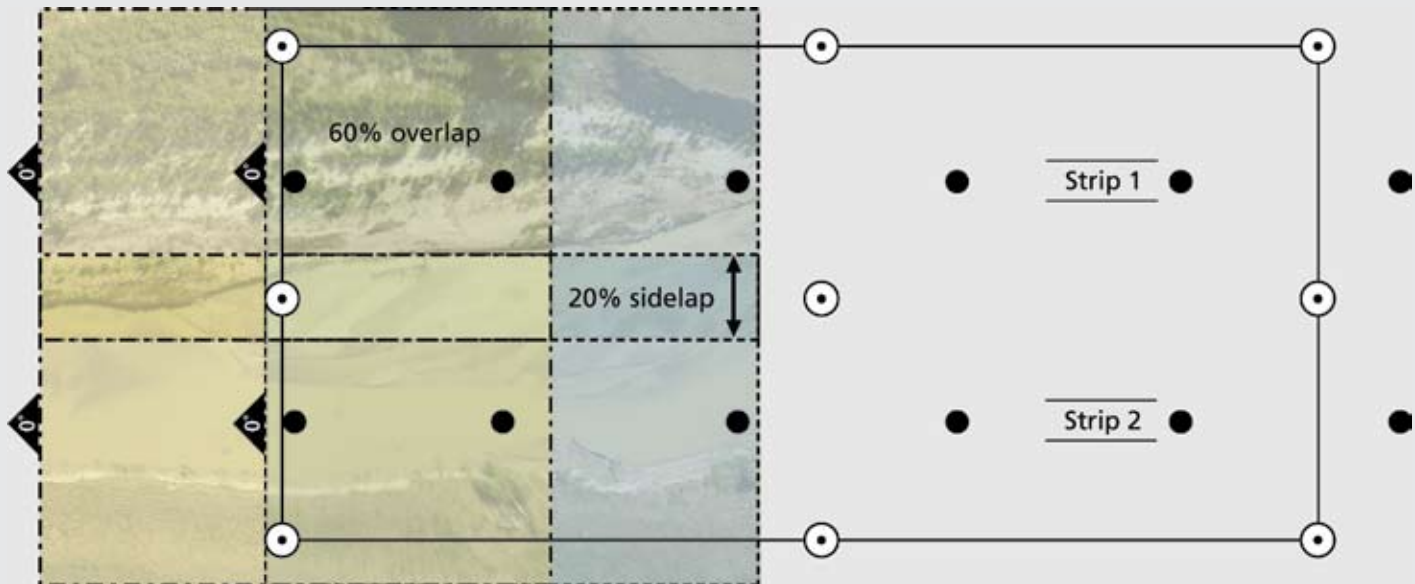


Figure D.3. In some instances, the size of the subject may dictate that two or more lines, or strips, of photography are needed to completely capture the subject in stereo. In these instances, a block approach is taken. For a block it is necessary to maintain about 20% sidelap between strips. Control points in the sidelap area are useful. This figure uses low-level aerial images from the Powder River Monitoring project to illustrate overlap and sidelap for block setup.

Camera Calibration

Camera calibration photographs must be captured at the same settings as the stereophotos. This can be achieved by simply taking at least two additional photos turned 90° to the previous photos and two additional photos turned 270° to the previous photos (Figure D.4). This is easily accomplished by adding two additional photographs at the beginning or end of the stereo shots. The main purpose of the

camera calibration is to determine and map the distortions in the lens with respect to the sensor location. The software accomplishes this most effectively when there are a large number of autocorrelated points in common between the stereoscopic images and the additional 90° and 270° photos (Figures D.5 and D.6). In some instances (such as a strip of only a few models), it may be desirable to recapture the entire strip at 90° and 270°.

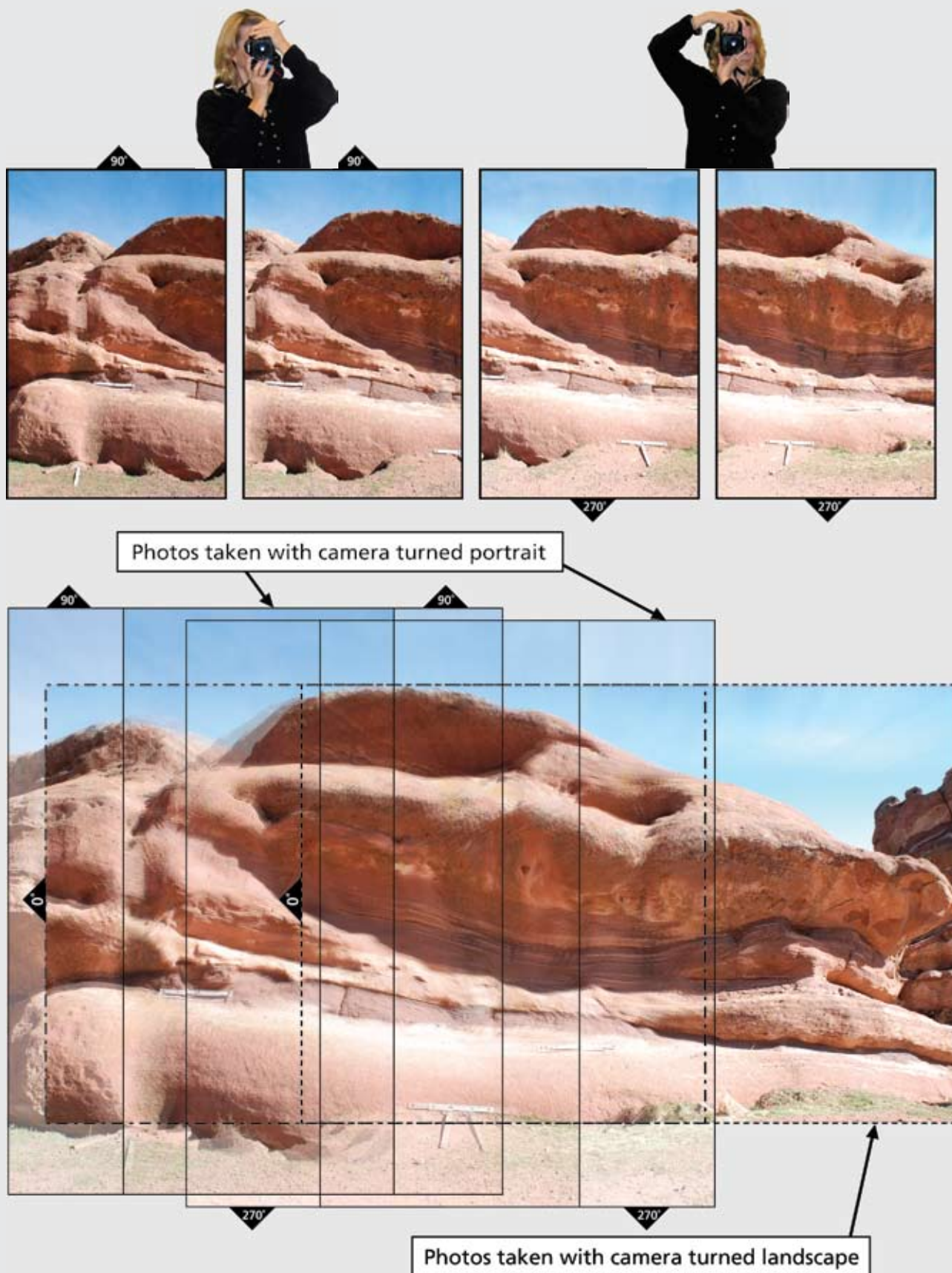


Figure D.4. The camera calibration process requires at least four additional photos. By concentrating the previously taken stereoscopic photos (landscape) and portrait-oriented photos taken at 90° and 270° over the same area, maximum benefit will be achieved in the camera calibration portion of the software.

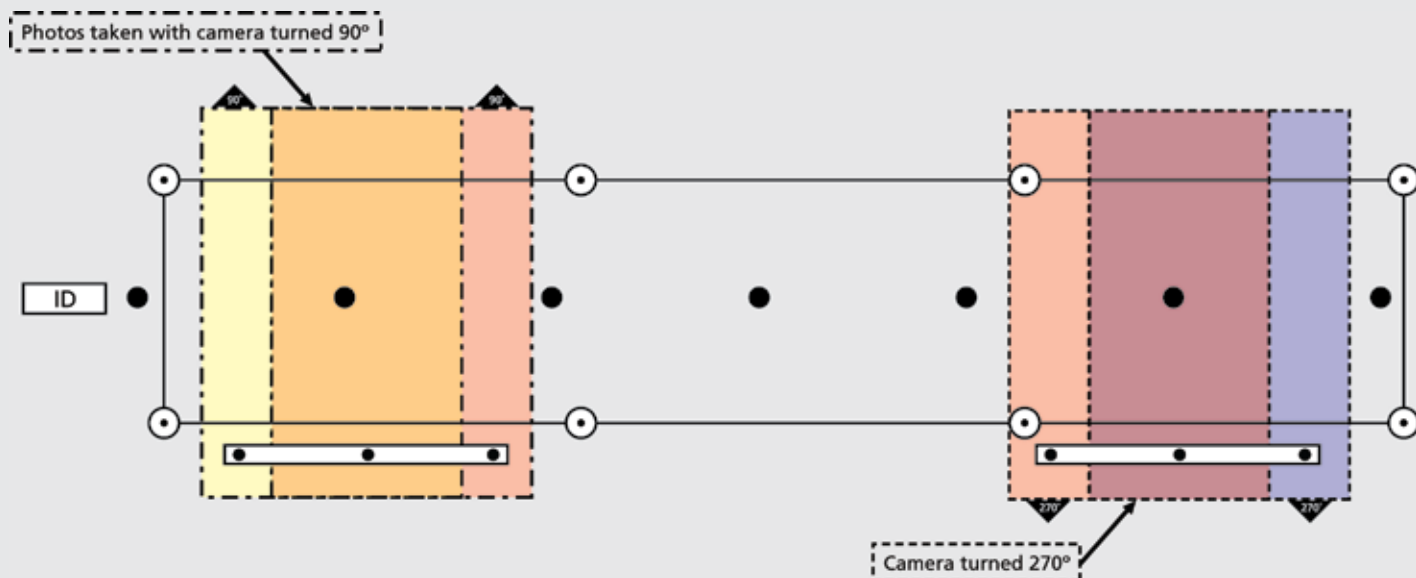


Figure D.5. To ensure project accuracy, it is necessary to take additional photographs to be used in the camera calibration process. These photos are taken at right angles, or 90° and 270° , to the sequence of stereoscopic photos and **MUST** use the same settings (particularly focus and focal distance). At least four photos are needed and should be stereo pairs. They may be taken at any position in the stereoscopic sequence as long as they are in common with it. At least one stereo pair must be taken with the camera turned at 90° , and then the camera should be turned 270° with another pair of photographs taken at a slightly different location.

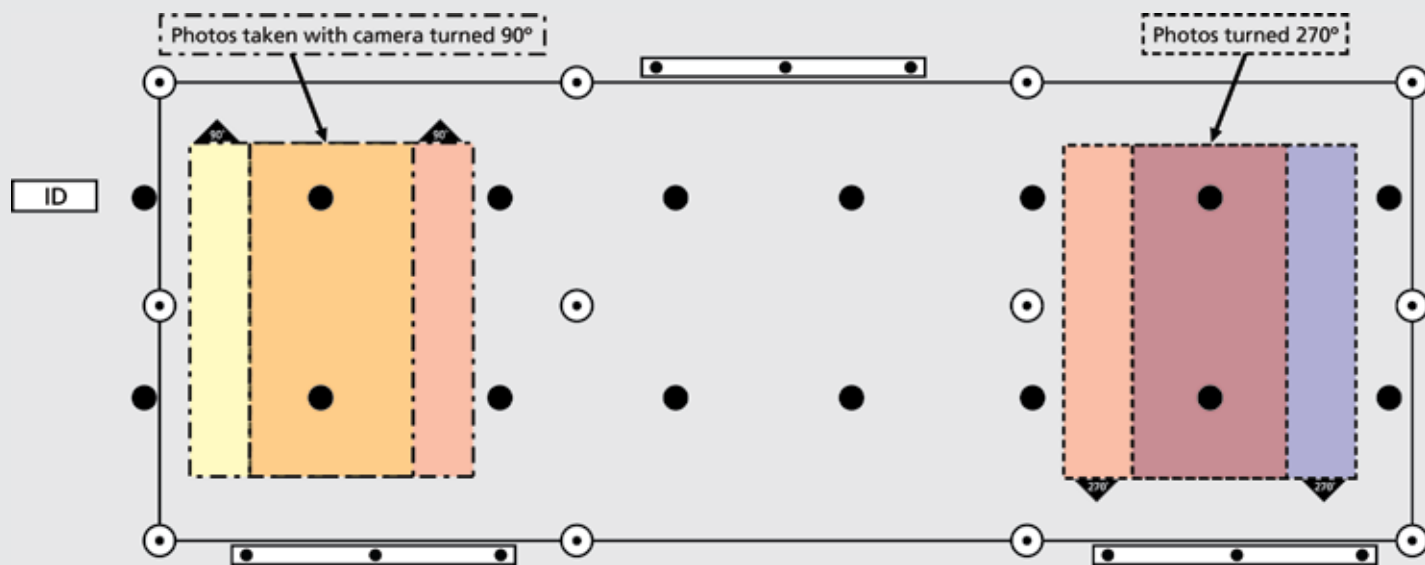


Figure D.6. Camera calibration photos for a block setup. In addition to the camera calibration, images taken in the above configuration can serve to tie the two strips together and improve accuracy (Figure D.3).

LEGEND for Appendix D

- photo centers
- control points
- ID identification sheet
- image footprint
- object of known length

Photo Control

Another level of flexibility provided by CRP over traditional photogrammetry is in the way a subject may be controlled. Control for a user defined coordinate system can be accomplished as simply as adding an object of known dimension (meter stick, 6-inch scale, or other object) that is visible in at least two stereo models. This allows the subject to be scaled to real-world values. It is preferable to have two or more such objects, to ensure that they are visible in at least three photographs and for accuracy assessment. Experience has shown that an object of known dimension is more accurate and reliable than measuring between two points in the field. However, measuring and recording the distance between two or more points is another excellent means for confirming project accuracy.

Calibrated target sticks (CTS) may be used in addition to the object of known dimension (Figure D.7) to provide extra control, and in some instances, can help tie photos together during processing. The CTS depicted in Figure D.7 are equipped with large, black circles that are a calibrated distance apart. In addition to the calibrated circles, a series of circular bar codes (Forbes et al. 2002) can be generated within some

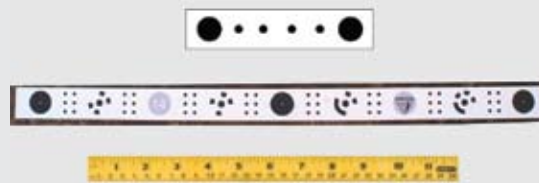


Figure D.7. Examples of calibrated target sticks (CTS) and an object of known length. The center CTS contains circular bar codes, which are used by some three-dimensional measuring and mapping software and assist with the initial image orientation process.

3DMM software. Each unique code can be recognized, correlated to the same code visible on other photographs, and marked with very little user interaction. If coded targets are not available, solid color circles of high contrast to the background (black on white) can be used by subpixel marking methods to define the center of a circle.

To tie the CRP project into a real-world coordinate system, GPS positions for known points within stereo overlap are necessary. For monitoring or other studies that require a time sequence of image capture, it is beneficial to get high-accuracy horizontal and vertical coordinates from an RTK GPS. The GPS coordinates should be taken at the monumented points; additional coordinates can also be captured for other photo recognizable features to strengthen the resolution and for accuracy checking. For projects in which location is not as critical, a resource grade GPS unit may be used and point coordinates taken at the CTS circles.

Other Considerations

Context Photos

While capturing the stereoscopic photos, it is also helpful to take an overall contextual photo (yes, you can include the horizon). It helps to remind you of how things were set up and can be used as an interesting illustration (Figure D.8). Also, make sure to get some photographs of the photogrammetric documentation in progress (Figure D.9). It is preferable to have a secondary camera (this can be a point-and-shoot), which allows photographs to be taken without disrupting the focus or settings of the primary camera.

File Management

File management is extremely important. The digital age has advanced us to where the acquisition of photographs is practically free. With the help of 3DMM softwares, photos can be used to make quantifiable measurements, transforming them from

just pictures to data. Stereophotos may be used for data extraction the day they are taken, or years later. To ensure that these photos are still accessible, it is recommended that a consistent approach to file management be taken.

One strategy is to group files into directory structures that are organized by State or field office, site, date, and then by camera or lens, for example:

UTMoab/date/nik25/photos.tif

This may seem unlikely, but getting more than 10,000 close-range photographs may take a relatively short time. One of the values of the photogrammetric techniques is that photographs taken from the past (or future) can be incorporated into a project so that sites can be compared and monitored for change detection. For some projects photographed over multiple years, those digits can add up quickly.

Figure D8. The results of merging a contextual photo with the camera locations generated in the three-dimensional measuring and mapping software are very good for displaying image relations. (Camera stations are depicted above the surface as blue rectangles and the image prints are depicted as blue and green Xs on the surface.) The image highlights locations of extreme close-range photogrammetric documentation at the Twentymile Wash Dinosaur Tracksite, Utah.

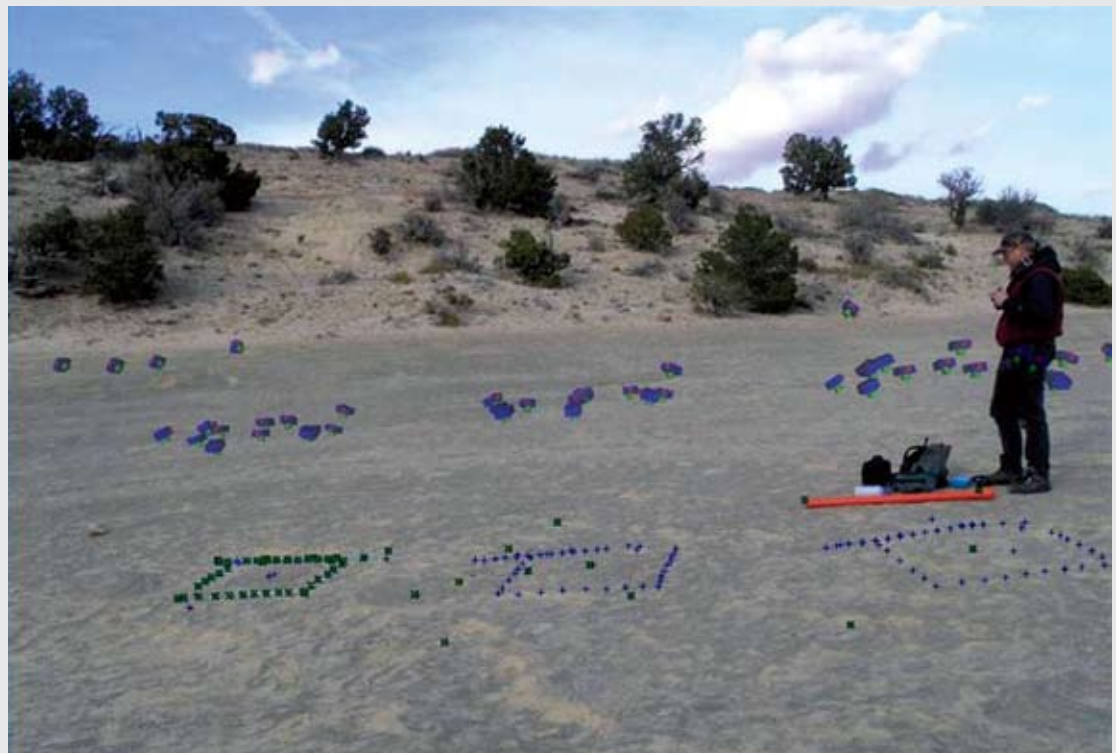
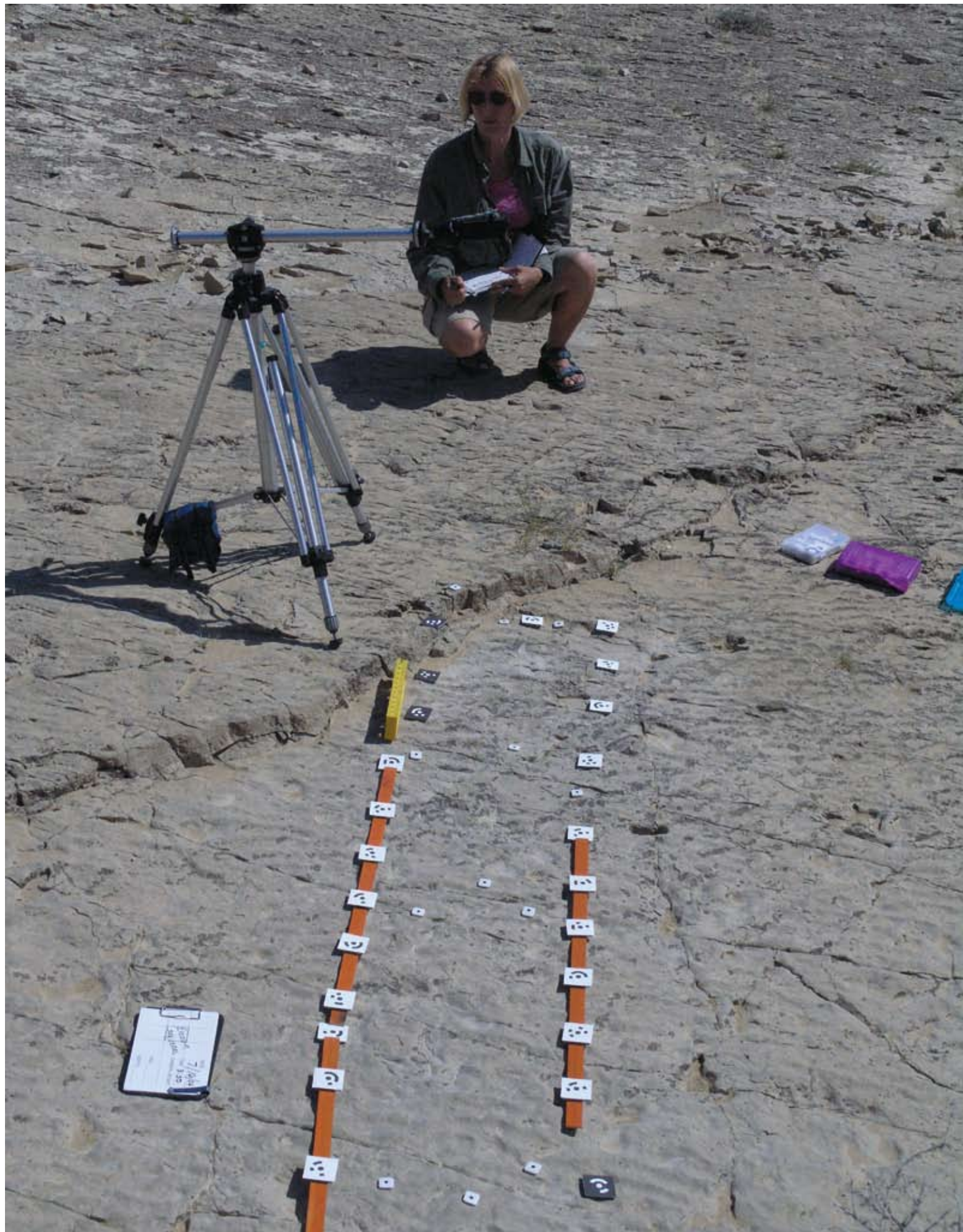




Figure D9. Work in progress at a camel trackway on BLM land near Santa Fe, New Mexico.



Preparing to take a single sequence of overlapping photographs at the Red Gulch Dinosaur Tracksite in Wyoming.

Project Workflow

The following section is a general workflow for a small project. It is presented in outline form to serve as a guide and

checklist. As the photographer becomes more familiar with the process, this list can be tailored to his or her experience and specific project requirements.

General Procedures for a Small, Close-Range Photogrammetric Project

- Evaluate subject and establish extent of the area to be photographed.
 - Assess public interactions. When working at a site visited by the public, it may be necessary to have an additional person to act as docent. This person can serve the dual function of reducing the effects of visitors on the photogrammetric process and explaining the photogrammetric work to the public.
 - Temporarily mark the area to be photographed.
 - If necessary, prepare the site by removing extraneous debris or objects that may be obscuring the terrain to be measured.
 - Sweep or clean, if hard surface. Proceed with care when documenting fragile or protected subjects!
- Determine the sun angle and best location to stand or position the tripod without casting shadows onto the subject.
- Establish final extents of project area.
 - If appropriate, place a monument with survey nails or rebar while disturbing as little of the area as possible.
 - Place CDs over each of the rebar monuments. (CDs should be painted with flat white paint). The CDs will obscure some of the sample area; however, the ground will already have been locally disturbed.
- Lay target sticks parallel to a long side, just outside the sample area.
 - Follow the photo layout (Figures D.1, D.2, D.5, and D.6)
 - Do not obscure features or control.
 - Position the target sticks along the side that the photographs will be taken from.
- Set up the tripod; attach the boom arm and add counterbalance weights to the legs, if necessary, to offset the camera if working on a slope. Set the tripod to proper height.
- Fill out the site recording sheet
 - Date
 - Site ID
 - Record next photo number.
 - Place the recording sheet clipboard on the ground outside, but near, the site.
- Set the camera to the appropriate settings (see Appendix C). Change the ISO, if necessary, for light conditions.
- Mount the camera on the tripod, adjust height, and ensure that the proper overlap is achieved.

- Set the camera to autofocus, take a picture, and inspect it for quality—focus, exposure, and other characteristics. Make adjustments as necessary.
- Once the focus is set, turn the camera to manual focus and tape the focus ring in place.
- Proceed systematically from left to right along the length of the site and take as many photos as necessary to ensure complete stereo coverage.
 - To maintain a proper 60% overlap, the camera must be moved a distance equivalent to 40% of a single photo field of view (Figure A.2).
 - Remember—the entire area must be covered by at least two overlapping photos, this will require positioning the left extant of the project in the first frame of the sequence.
- In order to create a camera calibration, take additional photos turned 90° and 270° to the previous photos:
 - At the end—turn and take a picture of the end of the site. Camera will be turned 90° and 270° to the site.
 - Go back to the start of the site and take a picture. Again, camera will be turned 90° and 270° to the site.
 - Additional 90° and 270° photos can be captured anywhere along the strip.
- When conducting several small projects in sequence, it may not be necessary to change focus or camera settings if the height remains constant. In this situation, it is helpful to have a sight recording sheet in the first image of that sequence.

If possible, download photos and inspect for proper exposure and overlap before removing target sticks or CDs positioned on GPS control.

- Back up images (including RAW files) onto DVD or external hard drive.

Equipment Check List

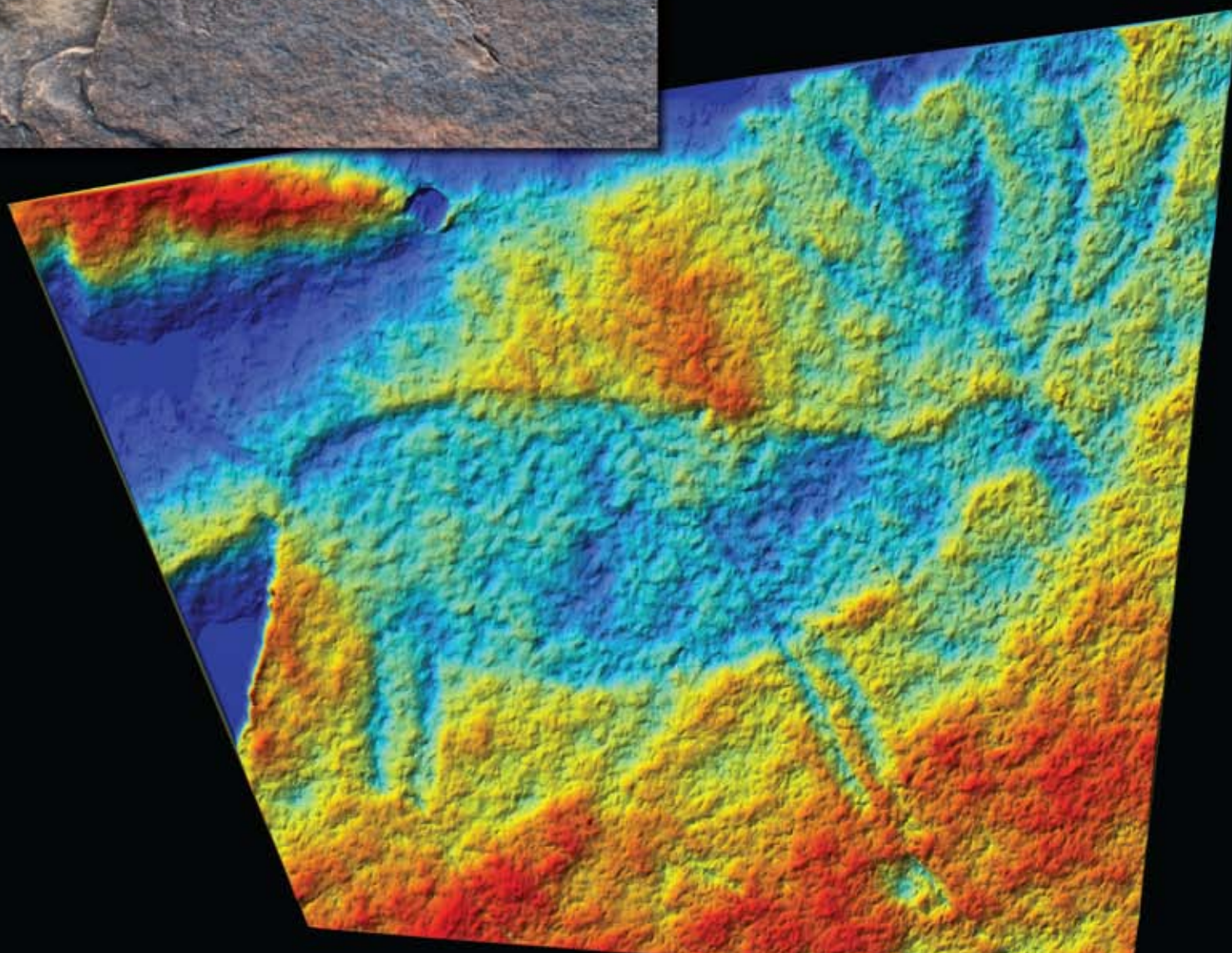
- ___ People
 - ___ Person to take photographs
 - ___ Assistant to prep the site and keep track of work progress
 - ___ Docent to interact with public (may be needed at visited sites) and take photos of documentation process
- ___ Camera and lens for CRP documentation
- ___ Secondary camera for backup and to document CRP process
- ___ Camera Accessories
 - ___ Battery charger or extra batteries
 - ___ Additional lenses equipped with protective bypass filters
 - ___ Painter's tape or other low-adhesive tape
 - ___ Spare memory cards
 - ___ Remote shutter release
 - ___ Lens cleaner or brush
 - ___ Padded camera case
- ___ Laptop Computer
 - ___ Card reader or appropriate cable for downloading images
 - ___ Image backup—either portable hard drive or blank DVDs
 - ___ Image software (preferably the software that came with the camera)
 - ___ Power cord
 - ___ DC adapter (if available)
- ___ Objects of known dimension
 - ___ Commercial meter (or yard) sticks
 - ___ Calibrated target sticks of varying lengths (see Figure D.8)
 - ___ Removable adhesive putty may be used for temporarily securing target sticks, although even this may not be appropriate for some delicate surfaces.
- ___ Sturdy Tripod
 - ___ Boom or extension arm
 - ___ Quick release head
 - ___ Extra release plates
 - ___ Small screwdriver
 - ___ Leg weights for camera counterbalance to keep the tripod from tipping over
- ___ When Establishing Location
 - ___ GPS unit
 - ___ Resource grade or RTK system (depending on desired product accuracy)
 - ___ Survey nails or rebar
 - ___ Sledge hammer, small chisel, and file
 - ___ CDs spray-painted white
- ___ Power Accessories
 - ___ Multiple-receptacle power strip
 - ___ DC power inverter for car use
- ___ Miscellaneous Items
 - ___ Measuring tape
 - ___ Notebook and pencil
 - ___ Pocket calculator
 - ___ Small dry erase board or clipboard with identification sheet and markers
 - ___ Circular disks (such as clay poker chips) to mark features or image extents
 - ___ Step stool or ladder
 - ___ Small tarp for shade or wind protection
 - ___ Rope
 - ___ Duct tape
 - ___ Wisk and push brooms (when appropriate)
 - ___ Tree loppers or pruners (when appropriate)
 - ___ Pin flags or flagging tape
 - ___ General field necessities (water, snacks, sun screen, insect repellent, hat, other items)



Setting up a GPS unit to reestablish positions for change detection at the Falcon Road Open OHV area within the Gunnison Gorge National Conservation Area near Montrose, Colorado.

PhotoModeler is a product of Eos Systems: <http://www.photomodeler.com/>
ImageStation is a product of Intergraph: <http://www.intergraph.com/listationssk/>
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**Three-dimensional surface data with false color based on changes in elevation.
Image of the natural rock art surface near Newcastle, Wyoming, shown in the inset.**



Oblique aerial view, taken with a large format (9 x 9 inch) aerial camera, of Escalante Canyon in the Grand Staircase-Escalante National Monument in Utah.

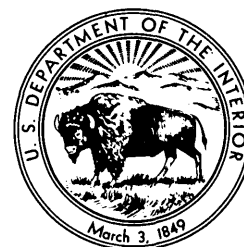
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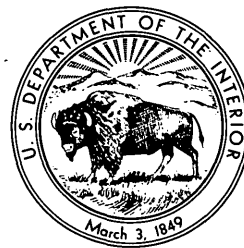
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Aerial Photographs in Geologic Interpretation and Mapping

By RICHARD G. RAY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 373

The use of aerial photographs to obtain qualitative and quantitative geologic information, and instrument procedures employed in compiling geologic data from aerial photographs



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AERIAL PHOTOGRAPHS IN GEOLOGIC INTERPRETATION AND MAPPING

By RICHARD G. RAY

ABSTRACT

Aerial photographs today are widely used to obtain both qualitative and quantitative geologic information; vertical aerial photographs are used almost to the exclusion of other types. Techniques and procedures described herein relate primarily to vertical photography.

Geologic interpretation of aerial photographs is based on the fundamental recognition elements of photographic tone, color, texture, pattern, relation of associated features, shape, and size. The scale of photographs, as well as the vertical exaggeration that is present in most stereoscopic models, also are significant in photointerpretation.

The amount of geologic information that may be obtained from aerial photographs is primarily dependent on the type of terrain (igneous, metamorphic, or sedimentary), climatic environment, and stage of the geomorphic cycle. Because features are more readily recognized where strong differences exist in the erosional resistance of adjacent rocks, sedimentary terrain may be expected to yield the greatest amount of information from aerial photographs. Metamorphic terrain may yield the least information because metamorphic processes tend to destroy differences that may have existed in the unmetamorphosed rocks. Combinations of criteria such as photographic tone, texture, pattern, and vertical exaggeration permit inferences as to rock type and geologic structure, which are important in petroleum exploration, ore-deposits search, and engineering geology.

In petroleum exploration aerial photographs provide a wealth of information primarily with regard to potential structural traps. Folds commonly may be interpreted from a study of strike and dip of bedding and from stream patterns; anomalous stream characteristics, such as stream deflections, may suggest subsurface structures. The variety of photorecognition criteria that suggests faults permits aerial photographs to be of particular use in many ore-deposits studies. Analysis of soil patterns yields information regarding permeability of the surficial materials that are a concern of the engineering geologist.

The instruments used for viewing photographs, measuring geologic features, and compiling geologic maps range from simple stereoscopes and stereometers, or measuring bars, to complex double-projection instruments such as the multiplex or Kelsh plotter. Some instruments require the use of paper prints; others require the use of glass-plate diapositives. Measuring devices primarily provide spot heights or differences in altitudes; these quantitative data may be geologically significant in measurement of stratigraphic thickness and dip of beds and in structure contouring. Accuracy of vertical measurements is related fundamentally to the scale of photography and the instruments used for making measurements. In general, accuracy of measurement is greater

when large-scale photographs are used and when double-projection instruments rather than simple parallax bars are employed.

INTRODUCTION

Use of aerial photographs to obtain geologic information—popularly called photogeology—has contributed to mineral and fuel discoveries, and to engineering geology studies, as well as to the general geologic mapping of many areas; it also has increased the efficiency of many geologic mapping groups by adding speed, economy, and accuracy to areal mapping as well as adding certain geologic information that is impossible, difficult, or economically impractical to obtain by routine field-mapping methods. The past financial success of consultants in geologic interpretation of aerial photographs attests to successful geologic application of photogeologic procedures and techniques, particularly in petroleum geology, and to lesser extent in mining and engineering geology.

Many technical papers on the geologic interpretation of aerial photographs have been published, primarily since the end of World War II; on several occasions symposia on photointerpretation, and specifically photogeology, have been presented. Much of the information currently available has been published as individual articles and they are scattered throughout the literature; comprehensive treatments on the geologic interpretation of aerial photographs are generally unavailable now (1959) (see Eardley, A. J., 1942; Smith, H. T. U., 1943b; and Petrusevich, M. N., 1954). In addition to the published information much unpublished information also has accumulated in recent years. The collection and synthesis of much of this information, together with discussion of photointerpretive and related photogrammetric procedures, are the main objectives of this paper. The paper is particularly intended as a guide to geologic interpretation of aerial photographs as applied as a tool in reconnaissance geologic mapping, and as a reference to published papers representative of the photogeologic literature.

The primary objectives of photogeology are (a) to contribute to geologic mapping, which in turn is basic to mineral and fuel exploration, engineering geology studies, some water-resources investigations, and related studies, and (b) to contribute to geologic knowledge through research. The objectives of photogeology may be economic or academic, and procedures used can be expected to differ widely, ranging, for example, from use solely of simple lens stereoscopes for qualitative interpretation to employment of precision stereoplotters for making geologic measurements. Regardless of procedures used, however, photogeology to date has contributed principally to the broad aspects of geologic study, that is, in mapping distribution of rock types and structures. The interpreter can only infer the composition of rock types from photographs; he cannot identify mineral types or absolute ages of rocks. Thus, maximum use of photogeologic procedures is attained by combining photogeologic studies with various laboratory studies and with field investigations.

The uses of aerial photographs and the various photogeologic procedures are discussed herein under the general headings of interpretation and instrumentation. The part dealing with interpretation is widely illustrated with stereoscopic pairs and triplets, single photographs, and mosaics, together with explanatory notes, to demonstrate the kinds and amounts of geologic information that can be obtained from aerial photographs of differing geologic terrains and to illustrate some uses of photographs in specific studies, such as the search for petroleum. These photographs demonstrate primarily the qualitative uses of the fundamental recognition elements in geologic interpretation; they represent only a sampling of the tremendous number of illustrations available. Because reproduction processes tend to obscure details only subtly expressed on aerial photographs, selection of photographs used in this paper was confined principally to those that illustrate clearly defined recognition elements and geologic features. All aerial photographs (figs. 39-114) are at the end of the paper. Agencies holding the negatives of these photographs are given in a list that follows the photographs.

Methods and significance of determining quantitative geologic information from aerial photographs are described under the heading of instrumentation.

THE AERIAL PHOTOGRAPH

The aerial photograph is an instantaneous record of the ground details as determined chiefly by the focal length of the camera lens, the flying height of the airplane at the time of exposure, and the film and

filters used. It may also be defined as a composite of photographic images, which make up the recognition elements used for interpretation. The aerial photograph is a perspective photograph that is geometrically related to the type of camera in which it is taken; it may be a vertical photograph, taken with the camera axis pointing essentially vertically down, or it may be an oblique photograph, taken with the camera axis purposely tilted from vertical, generally 20° or more. Vertical photographs currently are used almost to the exclusion of oblique photographs for geologic interpretation, and most photogrammetric instruments used in photogeology in the United States are designed to accommodate vertical photographs; hence the following discussion is limited to techniques applicable to the study of vertical photography. Twin low-oblique photographs—those in which the apparent horizon is not shown—generally may be transformed and the resulting paper prints used as vertical photographs; however, low-oblique photographs cannot be used in many stereoplotting instruments unless the instruments are specially designed.

A general knowledge of the geometry and terminology used with vertical aerial photographs is necessary if one is to understand and make maximum use of photographs for interpretation and mapping purposes. The terminology and geometry of the vertical photograph are presented in figure 1.

FACTORS THAT AFFECT THE PHOTOGRAPHIC IMAGE

Factors that affect the photographic image, and hence interpretation, may be divided into two groups: (a) The relatively constant man-controlled factors, such as focal length of lens, flying height, film and filter combinations, and lens angle; and (b) the variable natural factors including color of objects photographed, position of an object with respect to the angle of sun, amount of haze in the atmosphere, and others. The constant factors are discussed briefly below; effects of natural factors on the photographic image are described where appropriate throughout the text.

FOCAL LENGTH AND FLYING HEIGHT

Focal length and flying height may be considered together because of the relation of photograph scale to these two factors. In terms of focal length and flying height, the average scale of a photograph is expressed as

$$S = \frac{f}{H}$$

or

$$\text{Scale} = \frac{\text{focal length (feet)}}{\text{flying height (feet)}}.$$

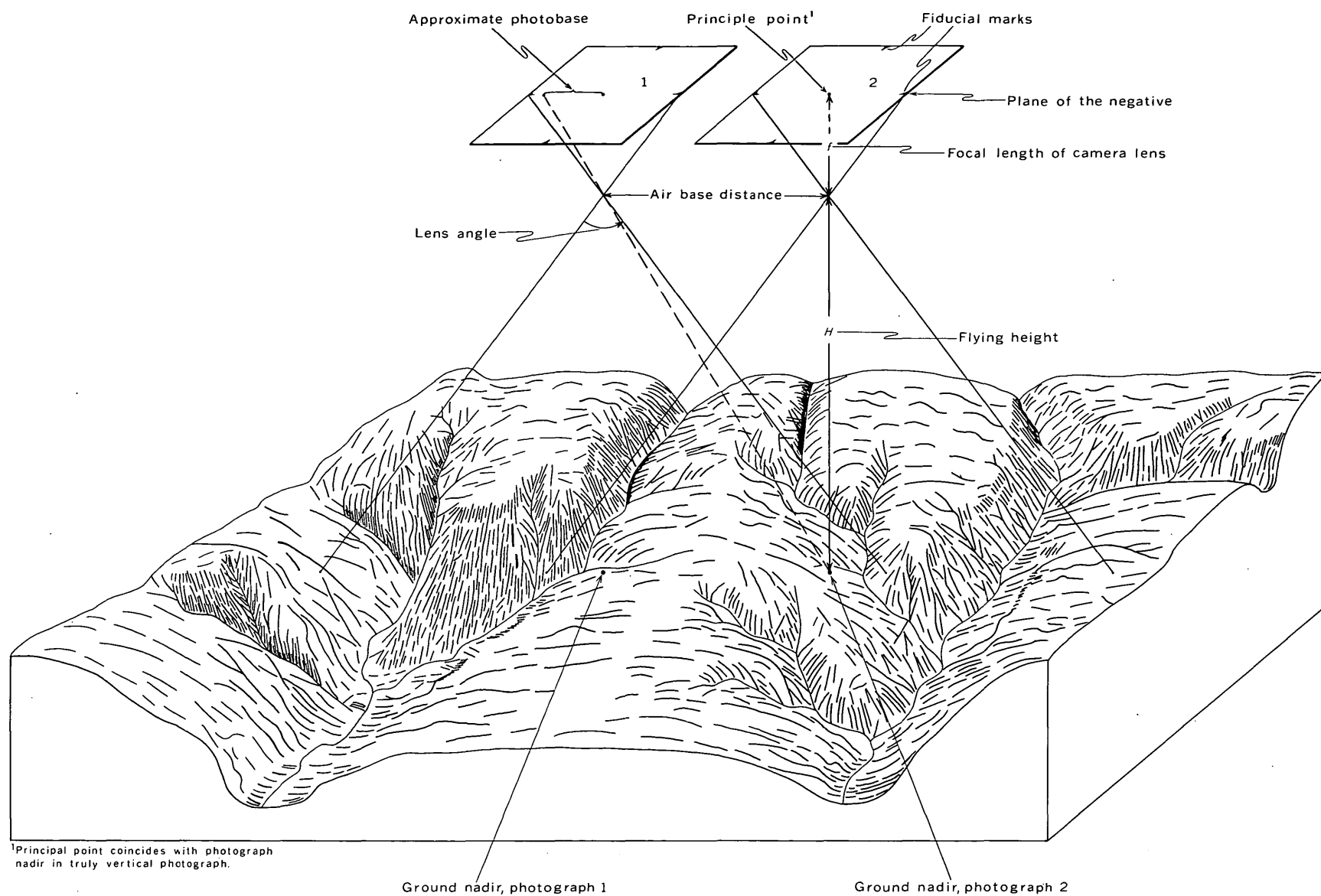


FIGURE 1.—Geometry of the vertical aerial photograph.

Thus, for example, the scale of photographs taken at 10,000 feet above mean terrain with a 6-inch (0.5 foot) focal-length lens is

$$\frac{0.5}{10,000} = 1:20,000.$$

It is evident that as focal length increases, the scale of photographs becomes larger, but as flying height increases, scale of photographs becomes smaller. Therefore, at any given flying height, long-focal-length lenses result in larger scale photographs than short-focal-length lenses. It follows also that at a given flying height a greater number of photographs are necessary to cover a given ground area when long-focal-length lenses are used. Doubling the focal length of the lens, for example, will quadruple the number of photographs required to cover a given area at a given flying height.

It should be noted that if a photograph is enlarged or reduced, the "effective" focal length for that photograph is also changed in direct proportion to the amount of enlargement or reduction. Thus, if photographs taken with a 6-inch-focal-length lens are enlarged two times, the effective focal length is changed from 6 inches to 12 inches. Parallax measurements (see p. 53), used in determining differences in altitude, are increased, but the absolute value for each unit of parallax measurement is decreased. Reducing or enlarging photographs thus has a significant effect with respect to choosing appropriate measuring and plotting instruments, and in measuring differences in altitudes.

For determining scale from the formula $S = f/H$ the effective focal length must be used where photographs have been reduced or enlarged. Particular note should be made in the use of transformed low-oblique photographs, in which the effective focal length is almost always less than the focal length of the camera.

FILM AND FILTER COMBINATIONS

The appearance of the photographic image may be controlled to marked extent by the sensitivity of the film and by the light transmission of the filter employed. The sensitivity of a film emulsion may be controlled when the film is manufactured so that all or only selected parts of the visible spectrum are recorded, or so that part of the invisible spectrum, such as infrared light, is recorded. Also, the wave length of light reflected from an object and actually recorded may be controlled in part by filter combinations. The recording of selected wave lengths of light, controlled by filters or type of film, or by combinations of film and filters, affects the photographic image, primarily by affecting the photographic tone. Conventional pan-

chromatic aerial film is generally exposed through a minus-blue filter and permits the recording of blue-green, yellow, orange, and red light. When color film is used the entire visible spectrum is commonly recorded and a greater number of color differences can be distinguished than on conventional black-and-white film. Special color film or color film used with filters may distort the color of the objects photographed, but if differentiation of geologic features is permitted, then lack of color fidelity may not be detrimental to interpretation. Ideally, film and filter combinations may be used to accentuate specific features for a given type of interpretation (see p. 7-8).

LENS ANGLE

The angle of the camera lens—that is, the apex angle of the cone of rays passing through the lens—is important indirectly in relation to radial displacement and parallax measurements, which are in turn significant with regard to photogrammetric applications in geologic interpretation. Characteristically, long-focal-length lenses (greater than 6 inches) have a narrower lens angle than short-focal-length lenses (6 inches or less). Thus, to maintain a given scale and format size, photographs taken with a narrow-angle (long-focal-length) lens requires flying at a higher altitude than with a wide-angle (short-focal-length) lens. Under these conditions, radial displacement (also termed "relief displacement") of similar image points is less when narrow-angle lenses are used, but only because of the greater flying height required by the narrow-angle lens to maintain the given scale and format size. The parallax difference for an object of specific height is in turn affected as a result of the difference in flying height, the parallax difference decreasing directly with increased flying height for a given focal-length lens (see p. 53). Thus it can be said that lens angle indirectly affects parallax measurement. When a constant flying height is maintained, however, lens angle does not affect parallax measurements of similar image points. Image distortion at the margins of photographs taken with a wide-angle lens may be greater than on photographs taken with a narrow-angle lens and this is considered by many to be detrimental to photointerpretation, especially in high-relief terrain.

VIEWING OF PHOTOGRAPHS

Photographs may be viewed singly, as mosaics, or as stereoscopic pairs. Most commonly stereoscopic pairs of paper prints are viewed in reflected light with simple lens, prism, or mirror stereoscopes, notes are made directly on the prints or on transparent overlays, and information is later transferred to a base map or

mosaic. Many paper prints can also be viewed with transmitted light, which may be helpful in revealing photographic detail. If vertical measurements are made from paper prints a separate measuring device must be commonly employed with the stereoscope. In recent years double-projection instruments, employing the anaglyph principle in forming the stereoscopic model from glass-plate diapositives, have been used increasingly in geologic interpretation.

When photographs are viewed singly or in a mosaic, a two-dimensional view is obtained. The single photograph or mosaic is normally viewed along a line generally perpendicular to the photograph surface, but for some subtle linear features, an oblique view of the surface with a reflected light source moved to different positions may reveal photographic details otherwise difficult or impossible to see (see Lattman, 1958, p. 575). Many valuable relations of geologic and associated features can be observed, particularly as a result of the overall view permitted by mosaics or single prints of small scale, but a two-dimensional view reveals only part of the data available to the interpreter; the value of three-dimensional, or stereoscopic, examination of aerial photographs in contrast to studying the two-dimensional view cannot be overemphasized. Conspicuous geologic features are commonly visible on single aerial photographs or mosaics of aerial photographs, but the wealth of information seen in stereoscopic view is many times greater. Details, such as fine lines or textural differences not readily seen on single photographs—or even on the ground—commonly are shown clearly in the stereoscopic model. Such clarity is in many places a direct result of the common association of fine lines and textures with relief changes, which are exaggerated in most stereoscopic models. To take advantage of the exaggerated vertical dimension, which is so helpful in photointerpretation, aerial photographs should of course be viewed stereoscopically. It may be desirable also to view the photographs pseudoscopically by reversing the print positions so that hills appear as valleys and vice versa. In pseudoscopic view, stream patterns or anomalies may stand out (see fig. 95), or because of the unnatural view other features may be accentuated. Aschenbrenner (1954, p. 401) demonstrated by the use of a seemingly random distribution of dots, which may be likened to silver grains of a photographic emulsion, that information not visible on a single picture can be clearly seen in stereoscopic view.

INTERPRETATION

Interpretation was defined broadly by Summerson (1954, p. 397) as the prediction of what cannot actually be seen; and thus geologic interpretation of aerial

photographs is not unlike certain geologic interpretations of field-observed data. Colwell (1952, p. 535; 1954, p. 433) defined interpretation as “* * * the act of examining photographic images of objects for the purpose of identifying the objects and deducing their significance.” However, geologic interpretation, more often than not, is a result of combined deductive and inductive reasoning, based on the principle of cause and effect. For example, certain features easily identified on aerial photographs, such as terminal moraines and kettle holes, are inductively concluded to have resulted from glaciation, and this in turn may lead by deductive reasoning to the specific identification of less readily recognizable features, such as certain kame terraces. Further deduction may lead to conclusions concerning the type of material present in these terraces. On the other hand, interpretation may be directed mainly toward understanding the geologic significance or history of a broad area, and specific features such as positions of beds and measurements of stratigraphic thicknesses combine by inductive reasoning to reveal the probable geologic conditions that resulted in those features.

Geologic interpretation of aerial photographs can be considered generally a two-step process. The first step includes observation, fact-gathering, measurement, and identification of features on the photographs. The second step involves deductive or inductive mental processing of these data in terms of geologic significance. According to Stone (1951, p. 755) a procedural or methodical approach to interpretation should be used because “The establishment of procedure prepares the way for orderly and complete analyses of complex subjects.” A procedural or methodical approach appears to be especially applicable to the observational phase of a photogeologic study, and it will give a firm basis on which the interpretive phase is dependent.

Observational data, also termed “first-order” information (see Hopkins, Karlstrom, and others, 1955, p. 142), may be subjected to either the empirical or rational method of processing (Smith, H. T. U., 1953, p. 9-10). According to Smith (1953, p. 9) the empirical process is largely mechanical rather than perceptive, and involves matching images of a photograph with similar reference images; reasoning is largely by analogy and this “Reasoning by analogy alone is notoriously deceptive, unless extreme care is taken to make certain that the analogy is truly complete.” Smith (1953, p. 9) also made the particularly significant statement that “Nature is not always so obliging as to provide the desired simplicity and uniformity of conditions” that would permit the ready application of empirical methods. Indeed, much in nature is com-

plex and nonuniform, many terrain features are poly-genetic, and thus interpreting the geologic significance of observational data is dependent largely upon a thorough understanding of the principles of the sciences that explain the observational data. "The physical conditions of a particular terrain change, and the adjustment to that change is a gradual one, allowing all manner of intermediate forms and combinations between the norm for the old situation and that for the new" (Summerson, 1954, p. 396).

Surface expressions of geologic features—the observational data—range from the very obvious to the very subtle. Sorting those data that are significant to a particular problem and properly relating these features one to another provide a measure of the ability of the individual interpreter. Where more than one plausible explanation of observational data is possible, the experience as well as the fundamental geologic ability of the interpreter become especially significant. Thus a rational processing of observational data will yield the most meaningful interpretive results. This does not imply that an empirical method of processing observational data, exemplified by the numerous photointerpretation "keys," may not yield satisfactory results in certain geologic problems and terrains, but the logical, scientific approach demands a rational processing of observational data, particularly where inferences based on subjective interpretations are required.

If observational data cannot be rationally interpreted, they may still be of some empirical value. For example, an interpreter may recognize two zones of vegetation on aerial photographs. Without knowledge of plant ecology, he may infer that a geologic contact exists between the two vegetation types. But a knowledge of plant ecology, permitting a rational interpretation, might well have allowed a further inference that one type of rock or soil was likely to be highly permeable in contrast with the other, thus revealing information with regard to certain physical characteristics of the rock or soil, which in turn may suggest something of the lithologic character. Thus " * * * the understanding of any particular terrain requires more than the knowledge of the geology * * *" (Summerson, 1954, p. 397). The greatest understanding will be by individuals grounded in the natural sciences and who understand, as a result, the various factors that contribute to a particular region. Because any geologic terrain is normally a complex that also includes features of fundamental interest to the botanist, forester, soil scientist, and others, photogeologic interpretation must take cognizance of these related sciences. The combined use of vegetation, soils, and geologic

features to interpret geology is an example of what has been termed the "convergence of evidence" principle (Colwell, 1952, p. 566).

Interpretation, then, begins with the observation, identification, and measurement of features on photographs. One of the most obvious features is that of landform, and it has been stated by Johnstone (1953, p. 265) that analysis of landforms constitutes the basis of photogeology. Smit Sibinga (1948) also pointed out the importance of landform, or geomorphic expression, in interpreting the lithologic character of rocks; but analysis of landform, however important, cannot be the complete basis for photogeologic interpretation, for there is additional "first-order" information such as vegetation patterns, soil patterns, and stream patterns; photogrammetric measurements also provide first-order data. Features other than landform may actually be more important for certain structural interpretations. For example, vegetation may grow along and mark the location of a fault. Thus, interpretation is based not only on landform but also on photographic tone differences, color differences, drainage patterns, erosion patterns, soil patterns, vegetation patterns, and any other surface expression of underlying geology. It is fundamental that photointerpretation is only applicable to those geologic features that do develop such surface expressions.

The many features of surface expression used in photogeologic interpretation are identified on the basis of recognition elements—characteristics of the photographs that result from the scale selected; the color of the rocks, vegetation, and soils of the terrain photographed; the kind of film and filters used; the processing of the film; and related factors. The most significant recognition elements are relative photographic tone, color, texture, pattern, and association of features. Shape is important in identifying many constructional landforms. Finite size as a recognition element for geologic interpretation has been used very little, although relative size is commonly considered by the interpreter. The increasing use of photogrammetry in geologic interpretation, however, portends an increasing importance for size, not so much as a recognition element in the usual sense of the word, but as an interpretation element (see p. 13). Shadows may help in distinguishing certain tree types, which in turn may have geologic significance.

INTERPRETATION FACTORS

RECOGNITION ELEMENTS

PHOTOGRAPHIC TONE

Photographic tone is a measure of the relative amount of light reflected by an object and actually

recorded on a black-and-white photograph; it is fundamental to all other recognition elements, except color. Tones on conventional photographs are usually shades of gray, but may be black or white. Because of the ability of the human eye to differentiate subtle tone changes, relative photographic tone is a significant asset in geologic interpretation of aerial photographs. However, photographic tone is subject to wide variation and there are limits to its usefulness as a recognition element because of the many factors that can influence it.

Photographic tone depends on light reflectivity, which in turn depends on location of an object with respect to the sun; thus the time of day and month of year are influencing factors. Haze strongly scatters light, particularly at the short or blue end of the spectrum and hence affects photographic tone unless corrective filters are used. Geographic latitude, angle of reflected light, sensitivity of film, light transmission of filters, and processing also may exert considerable effect on photographic tone. Hence a standardized tone scale (Daehn, 1949, p. 287) would appear to have little usefulness unless relative photographic tones on different photographs could be equated in terms of the tone scale. It is probable that the use of a densitometer to measure relative photographic tone in terms of the density of the negative would be a satisfactory measure of tone, even though many factors influence the density. Particularly in quantitative studies the use of a densitometer to measure relative photographic tone may prove very worthwhile in differentiating certain geologic features (Ray and Fischer, 1960).

Photographic tone, despite the many factors that may affect it, can be a particularly useful interpretation element; its usefulness depends on the problem under consideration and on how tone is used in conjunction with other recognition elements. For example, if the fracture pattern of an area were studied and it were known that a lush and dark-toned vegetation grew along the fractures because of concentration of moisture, the relative photographic tone probably would be a significant recognition element regardless of the limiting factors mentioned above. On the other hand, as a means of distinguishing between two types of trees that reflect similar amounts of light but which might signify differences in the underlying geology, photographic tone might be of little value unless used in conjunction with other recognition elements, such as crown texture.

Raup and Denny (1950, p. 120), in work along the Alaska Highway, considered photographic tone the least satisfactory criterion in identifying and interpreting vegetation. But Tator (1951, p. 717) consid-

ered tonal contrasts to be major keys for recognizing landscape features of low relief in the coastal region of the Gulf States, such tonal differences resulting mainly from soil and vegetation differences. Schulte (1951, p. 697) pointed out, with regard to pure stands of trees, that at large scales photographic detail is more important, but at small scales tone becomes relatively more important.

Because the analysis of photographic tone is highly subjective it has been suggested that photographic tone might not be as useful as other recognition elements in interpretation. Because of differences that may arise from position, angle of reflected light, processing, and other factors, Stone (1956, p. 125) stated that photographic tone in interpretation probably has been overemphasized. This is true if the factors that affect tone prevent photographic distinction of images that might otherwise be made. But if changes in relative photographic tone are present on a photograph, the interpreter should expect that these changes might be geologically significant. Indeed, photographic tone is probably the most used recognition and interpretation element, although it is generally used in conjunction with one or more other recognition elements. The absence of photographic-tone changes, as a result of processing and other factors, where such tone changes might normally be expected, does not detract from the possible usefulness of tone changes on other parts of a photograph. It merely suggests that the potential of photographic tone differences has not been accomplished for the photographs in question.

It is worthy of note that in interpretation strong tonal contrasts are generally desirable. Yet modern automatic dodging devices commonly used in printing photographs generally reduce overall tonal contrasts, although locally, as in darkly shaded areas or brightly lighted areas, automatic dodging may strengthen tonal contrasts. Because most aerial negatives are slightly lighter in the corners than in the center, hand dodging is commonly necessary if automatic dodging is not employed in making prints. However, undodged or hand-dodged prints are probably the best for general photointerpretation.

For special interpretation problems it may be possible to enhance tonal contrasts within a limited range of the tone scale by film intensifiers or other photographic processes, such as use of selected filters. Ray and Fischer (1960) used selected filters in photographing weathered samples of the Bernal and San Andres formations of New Mexico. The Bernal formation is a red thin-bedded shale and shaly siltstone; the San Andres limestone is primarily a grayish limestone. Spectral reflectance curves, based on spectrophotome-

ter studies, show significant differences for these two formations (fig. 2). Particularly at the short or blue end of the spectrum a strong difference in intensity of reflected light is present; the San Andres limestone reflects almost twice as much light as the Bernal formation. A noticeable difference is also present at the long or red end of the spectrum. But the spectral reflectance curves of the Bernal and San Andres formations within 500 to 675 millimicrons—the wave lengths generally recorded on conventional black-and-white aerial photographs—show that the overall light reflectance from these two formations would average out to be generally similar and little photographic distinction should be expected within this range. It is significant that strong reflectance differences which exist in one part of the spectrum may be masked by reflectance characteristics in another part of the spec-

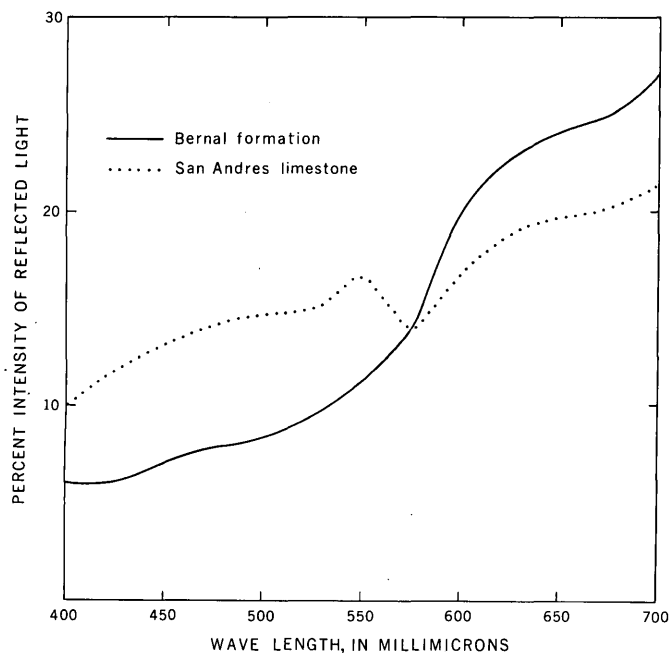


FIGURE 2.—Spectral reflectance curves of weathered samples of Bernal formation (red thin-bedded shale and shaly siltstone) and San Andres limestone (primarily a grayish limestone), New Mexico.

trum, and therefore to achieve photographic distinction of two features, it would probably be necessary to record a restricted part of the spectrum. Photographs of the Bernal and San Andres formations taken through filters that permit recording only of reflected light at the short or long end of the spectrum show a marked photographic distinction of the two formations.

COLOR

Color as a recognition element could be one of the most useful, if not the most useful, criterion for interpretive purposes (see Kent, 1957; Ray, 1958; Fischer,

1958; and Minard, 1960). The significance of differences within a photograph is interpretation and the greater the number of differences, such as color contrasts, the greater is the potential for detailed interpretations. It is a well-established fact that the human eye can differentiate about 1,000 times as many tints and shades of color as it can tints and shades of gray, characteristic of black-and-white photographs, and hence it may be concluded that color aerial photographs will permit a greater amount of detail to be recognized and interpreted. However, it is possible that two rock types of similar color might be differentiated more easily on certain black-and-white photographs than on color photographs because of mineralogic, chemical, or other differences that may permit significant contrasts in reflected light to be recorded when selected films and filters are used.

Petrusevich and Kazik (1955, p. 5, 8) reported that where color contrasts of rocks are not strong, boundaries between these rocks are more clearly seen on black-and-white photographs than on color photographs. Where color contrasts are strong, interpretation is facilitated in areas where individual beds are rather thick and the color of formations is retained for considerable distances along the strike. Petrusevich and Kazik (1955, p. 8) also reported that "A comparison of aerial color photographs of scales 1:15,000; 1:10,000; 1:8,000; and 1:5,000 for the same area, taken under the same conditions, shows that * * * the practical use of aerial color photography for geological purposes should be limited to a scale of 1:10,000 and larger." This conclusion was based on a study of photographs taken with an 8.25-inch lens. Recently developed short-focal-length lenses (3.5 inches and 6 inches) now permit useful color aerial photography to be achieved at a scale smaller than 1:10,000.

Aerial color negative film may prove particularly useful in photointerpretive studies. Unlike positive transparencies (reversible-type color film), which require use of filters during exposure of the film, negative-type color film is processed with filters inserted during the printing process. It is thus possible to vary the color contrasts through the simple medium of printing, with the possible advantages that certain features of geologic significance, such as alteration zones, may be emphasized. Petrusevich and Kazik (1955, p. 5) noted that a greater contrast often can be obtained in a black-and-white print from a color negative than in a print from the corresponding black-and-white negative. Fischer (1958, p. 546) in turn stated that black-and-white positive prints from Ektachrome aero positive transparencies also show stronger tone

contrasts between various rock units than the conventional black-and-white photographs.

TEXTURE

Texture was defined by Colwell (1952, p. 538) as " * * * the frequency of tone change within the image * * * [and] * * * is produced by an aggregate of unit features too small to be clearly discerned individually on the photograph." The scale of the photographs thus has an important bearing on this definition of texture. For example, a network of fine lines described as a texture on one scale of photographs may well be recognizable as a network of joints on a larger scale of photographs; this bears out Schulte's statement (1951, p. 697), made with regard to plant distribution, that at large scales photographic detail is more important, whereas at small scales tone becomes relatively more important. Such a texture, due to tone change within the image, may be called a "photographic texture" (figs. 43, 56, and 85). Photographic texture is therefore a comparative feature within any one general scale of photography. Although photographic tone is a fundamental element of photographic texture, the photographic conditions that affect tone may vary and yet permit such a texture to be a diagnostic recognition element. This is due to the fact that texture in the photographic sense is really a composite of several fundamental characteristics, namely photographic tone, shape, size, and pattern, and, of these elements, slight variations of tone would least significantly affect the recognition of a given texture.

Photographic textures have been described by various workers (Spurr, 1948; Raup and Denny, 1950) as coarse, fine, rough, and fluffy, but such descriptive terminology would seem to have very limited use unless accompanied by photographic illustrations. Furthermore, unless these descriptive terms are themselves clearly defined, comparisons of photographic textures with specific commonly known objects might be more useful. It may also be suggested that because photographic textures are normally considered as two dimensional, the use of a densitometer in conjunction with a coordinatograph-type instrument to determine tone changes per millimeter within the image might permit mathematical classification of such textures. However, such a classification might fail where a strong textural fabric prevailed, for two textures differing primarily because of shape or preferred orientations within the image might well be assigned to the same mathematical classification.

In addition to the use of the term "texture" as described above, texture has other meanings, as in reference to soils. The application of aerial photographs to soils and engineering geology studies has resulted in

the introduction of "soil texture" in some photogeologic literature; the obvious distinction between photographic texture, which can be directly observed, and soil texture, which must be interpreted from other recognition elements, must of course be made. Texture also has been used in relation to the density of a drainage network; wide spacing of streams results in a "coarse" texture of drainage and close spacing of streams results in a "fine" texture of drainage (figs. 3, 42, 49, 51, 62, 63, 79, and 106). Unless quantitative meaning is given to drainage texture, the term must be used on a comparative basis within any one general scale of photography. Horton (1945, p. 283-284) defined drainage density in quantitative terms but little use has been made of this classification by geologists.

Topographic texture has been used to describe the degree of dissection of the land surface (see Smith, K. G., 1950, p. 655-668). Like texture of drainage, topographic texture may be described as fine or coarse (figs. 39, 51, 62, 75, and 106). Quantitative study of topographic texture, based on map study, has shown that the texture ratio, a mathematical expression of the dissection of the ground surface, bears a logarithmic function relation to drainage density (Smith, K. G., 1950, p. 667-668). Therefore, because drainage density can be determined readily, aerial photographs may be useful in a comparative study of erosional topographies.

When texture is used to designate drainage density or erosional characteristics of the terrain, rather than to designate a photographic texture, the use should be so qualified as to make the definition clear. Although textures are commonly considered in terms of the two-dimensional plan view, it is important to note that erosional texture may well be significant or at least more readily recognized when viewed from the third dimension of the stereoscopic model (see fig. 39).

PATTERN

Pattern, as used herein, refers to the orderly spatial arrangement of geologic, topographic, or vegetation features. The spatial arrangement of pattern is normally considered by interpreters to be a two-dimensional or plan-view arrangement of features, but it may also be a three-dimensional arrangement. If features that make up a pattern become too small to identify, as on small-scale photographs, they may then form a photographic texture.

Patterns resulting from particular distributions of gently curved or straight lines are common and are frequently of structural significance; they may represent faults, joints, dikes, or bedding. But a single line, or lineation, is also an illustration of pattern; it

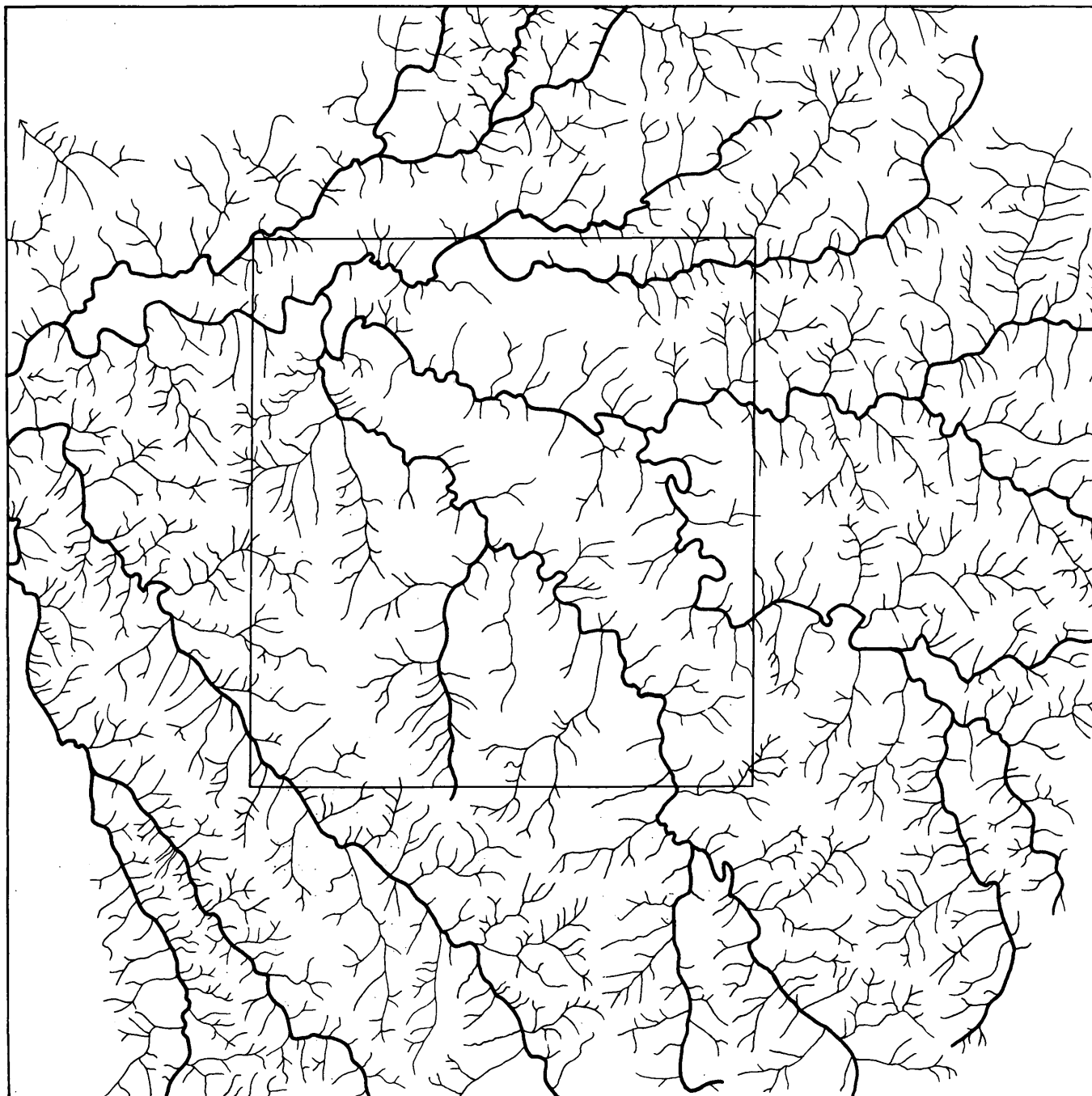


FIGURE 3.—Drainage map of large area in vicinity of ring dike shown in figure 54.

A separate tracing of drainage over a large area in the vicinity of the ring dike of figure 54 shows a marked decrease in drainage density within the ring-dike area. The contrast in drainage densities inside and outside of the

ring dike is more readily seen on a separate tracing of drainage than in the stereoscopic model. (See also fig. 9.) Inset shows area of figure 54.

may result from an orderly arrangement of stream segments, trees, depressions, or other features (figs. 74 and 84). This arrangement may be a continuous alinement of geologic, topographic, or vegetation features, but more commonly it is a discontinuous alinement. Because lineations are especially important as expressions of fractures they may indicate areas of considerable economic significance.

Drainage patterns are an important element in geologic interpretation of aerial photographs (figs. 48, 94, and 96). In bedrock areas these patterns " * * * depend for the most part on the lithologic character of the underlying rocks, the attitude of these rock bodies * * * and the arrangement and spacing of the planes * * * of lithologic and structural weakness encountered by the runoff" (Tator, 1954, p. 412). Stream patterns thus reflect the control exerted by underlying structure and rock type. But stream characteristics may be influenced by thickness and kind of surficial material where structural control is at a minimum. Under these conditions the drainage may reflect differences in surficial materials that are significant to the engineering geologist. (See Belcher, 1945, 1948; Jenkins, Belcher, Greeg, and Woods, 1946; Frost, 1946; Frost and Woods, 1948; Hittle, 1949; and Parvis, 1947, 1950.) In areas where resistance to erosion may be more or less uniform, as in many surficial deposits or in bedrock without pronounced structure, the drainage pattern is commonly dendritic or modified dendritic (see figs. 70, 77, and 106). Where structures are well developed, as in folded mountains, characteristic trellis, annular, or other drainage patterns may develop (see fig. 64).

Because the sensitivity of drainage to strike and dip directions is pronounced, changes in a drainage pattern, or deviation from an established norm, may be as important or more important than interpretation of any one stream pattern. "It is therefore important that relatively large areas be examined so that local drainage patterns [or anomalies] may be readily differentiated from regional drainage patterns" (Alliger, 1955, p. 180). A change in drainage may thus have significant structural implications (see figs. 9, 94, and 96). But a difference in stream pattern may also suggest variations in lithologic character of the underlying rocks.

Patterns of vegetation are also commonly of geologic significance and may reflect structural conditions or lithologic character of rock types (see figs. 40, 43, 54, 72, and 85). Woolnough (1934a, p. 213) suggested that a distinction be made between two types of vegetation distribution which he called "blocks" and "alinements;" the former occurs on extensive outcrops of

rock of uniform character, the latter along narrow rock bands, faults, or similar limited features. Alinements further may be subdivided as linear, parallel, and curved (see Woolnough, 1934a, p. 213). It is suggested that narrow linear or parallel alinements of vegetation may represent fractures (figs. 50, 60, 71, and 101), whereas wide, curved alinements may signify the distribution of outcrop of low, moderately or even steeply dipping beds (figs. 40 and 72); where curved alinements form closed loops they generally represent horizontal or nearly flat lying beds (figs. 61 and 77).

The term "pattern" has also been used in the literature in quite a different sense than described above. In the study of surficial materials the term "soil pattern"—a poorly chosen term—refers to the combination of surface expressions, such as landform, drainage characteristics, and vegetation, that are used in the interpretation of ground conditions (see p. 34–37). Thus pattern as defined above may be included as an element of the broad term "soil pattern," commonly used in engineering geology descriptions. Soil patterns may reveal information of direct use in engineering geology studies, as in the location of granular materials (figs. 52, 88, 104, and 108; and p. 34–37); in addition soil patterns may be important in suggesting the distribution of certain rock types; this distribution in turn may reflect geologic structures (see figs. 4, 48, and 81).

RELATION TO ASSOCIATED FEATURES

The relation of one feature to its surroundings is commonly important because a single feature by itself may not be distinctive enough to permit its identification. The significance of this relation may be spatial or genetic. For example, depressions may be identified as kettle holes because of their location near readily identified terminal moraines, and because of their genetic association with glaciated terrain. With regard to spatial association this recognition element has also been called the "site factor" (Colwell, 1952, p. 540); it may be particularly useful in determining the significance of vegetation with respect to the underlying geology. For example, certain tree groups growing on topographically high areas in interior Alaska suggest well-drained underlying materials. The landform, especially, in combination with the vegetation characteristics suggests stabilized sand dunes (fig. 56). The relation of associated features may thus permit specific identifications and inferences concerning surficial materials or rock types.

Photograph scale may be important in the interpretation of associated features; that is, a geologic feature on small-scale photographs may be interpreted because of its position with regard to other features,

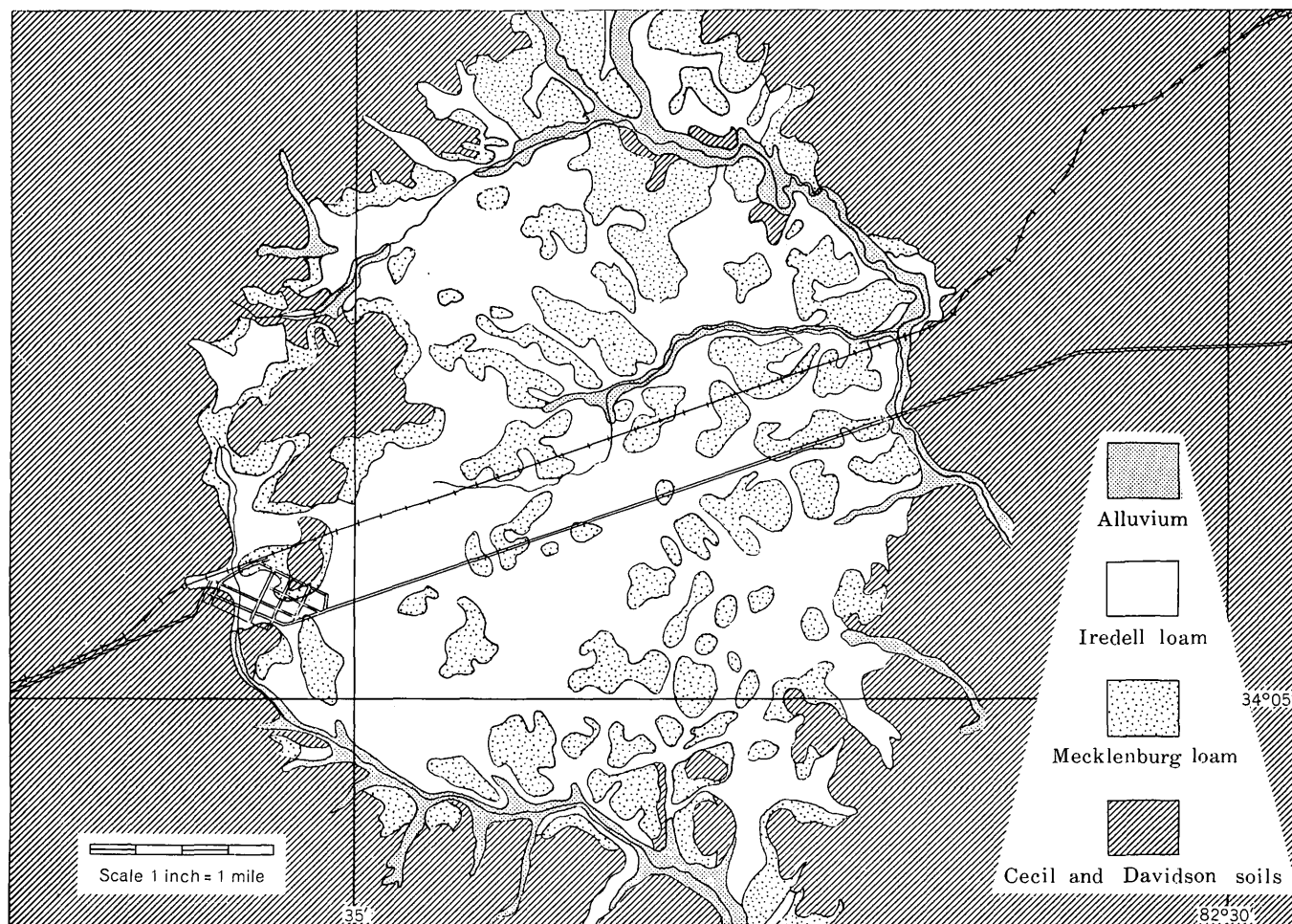


FIGURE 4.—Generalized soil map of area shown in figure 48 (modified from soil survey map of Abbeville County, South Carolina).

The circular area underlain by Mecklenburg loam and Iredell loam is conspicuous. These soils delimit an area of mafic intrusive rocks from a surrounding area of silicic rock types. Particularly where outcrops are sparse or lacking, soil maps may provide significant geologic information, espe-

cially in areas of residual soils. The soil maps may provide structural or lithologic data with respect to underlying rocks, or they may provide pedologic data concerning the surficial materials that is useful to the engineering geologist.

all of which can be seen at the same time (fig. 55), whereas on large-scale photographs direct identification might be made because photographic details are visible. The usefulness of association as a recognition element also will vary not only with photograph scale but with the objective of the study. The engineering geologist may be confronted with the immediate identification and location of kames as a source of gravel near a proposed highway route, whereas the geologist mapping the entire area would be interested in the identification, orientation, and distribution of all kames, with respect to geologic history of the area.

SHAPE

Shape as a recognition element in geologic interpretation is significant primarily only in its broadest defi-

nition, which involves relief or topographic expression. In this regard shape is very important in recognizing constructional landforms, such as volcanic cones, sand dunes, river terraces, and certain glacial features (figs. 41, 55-58, 60, and 104); it is also useful in differentiating rock units where one formation is expressed in bold cliffs and overlies a second formation that shows a lesser angle of slope (figs. 62, 84, and 91), or where adjacent rocks show significant differences in topographic relief (fig. 65). Rectilinear depressions may be expressions of faults (figs. 60, 85, 86, 99, and 103). The general surface configuration, as in the "beehive" weathering of some massive sandstones, also may be regarded as an expression of shape that is useful in recognition. According to Belcher (1945, p. 140-141)

shapes of gully cross sections are important to the interpretation of surficial materials for engineering purposes. However, in its strictest definition, as "a spatial form with respect to a relatively constant contour or periphery" (Webster's New International Dictionary, 1950) shape has been of little importance as a recognition element because nature may reveal the same geologic feature in an infinite number of different shapes, and because common scales of photography (1:20,000) restrict an interpreter's ability to see details of shape. Where local field criteria have been established, shape may be useful, for example, in the interpretation of patterned areas (fig. 53) or in the study of gully cross sections, particularly when large-scale photographs are available (fig. 88).

Shadow as a recognition element is primarily a use of shape and photographic tone. Because vertical aerial photographs are commonly used for interpretation, shadows may permit an effective side view of some features. For example, shadows may be useful in interpreting tree types, such as conifers, which generally have pointed tops; the type of tree in turn may have a relation to underlying geologic materials and particularly to soil-moisture conditions (Stoeckeler, 1952, p. 4). For interpreting most natural features, however, the shape of shadows probably contributes little in direct identification. Insofar as shadows contribute to textures and patterns, they are of course of great importance. Even slight topographic breaks may be accentuated by shadows (figs. 88 and 97).

SIZE

The quantitative element of size, as it relates to surface or volume dimensions of an object, has been little used in recognition of geologic features from aerial photographs, although relative size has been useful as an interpretation aid. Size as an interpretation element is being used increasingly with the adoption of photogrammetry as a fundamental part of photogeology; it is most appropriately considered in relation to interpretations based on thickness of strata, amount of offset along faults, or other finite measurements (see p. 56-63). Geologically significant measurements may be directly related to topographic expression; that is, measurements between topographic positions may yield direct information such as stratigraphic thickness. But generally other influencing factors, such as dip of beds or other structural elements, must be considered just as in field measurement (see p. 56-58). If the thickness of a formation is known, it may aid in location of formation contacts on aerial photographs, because measurements may be made from known points that would permit the positioning of the obscured contacts (fig.

39); or it may aid in correlation of beds across fault zones. Determining the range of thicknesses over a broad area may be essential to understanding the regional geology of that area (see p. 59-60).

Studies in quantitative geomorphology suggest that size, in terms of finite measurements, may be an extremely important parameter of geologic interpretation of aerial photographs. Measurement of geologic data can be expected to become an even more important part of photogeology in the future as techniques of quantifying geologic information become more widely used.

COMBINATIONS OF RECOGNITION ELEMENTS

The usefulness of recognition elements, of course, is enhanced where they may be used in combination. Indeed, photographic tone, useful alone as a recognition factor under some conditions, is a fundamental photographic characteristic without which there could be no recognition elements at all on black-and-white photographs. As mutually supporting recognition elements an association of photographic tone, topographic expression, and texture may permit the interpretation of bedding, even in areas of sparse or no outcrops (fig. 40). Faults are commonly expressed as straight or gently curved lines; they may be further identified by an abrupt photographic tone change on opposite sides of these lines as well as by a pronounced offset of recognizable rock types (fig. 83). Surficial materials are commonly identified on the combined basis of stream patterns, shapes of gully cross sections, texture, and photographic tone as well as by their relation to associated features (see p. 34-37).

VERTICAL EXAGGERATION

In addition to those recognition elements that are based on factors, such as film and filter used and processing, that directly affect the photographic image, certain other factors are important in interpretation. Especially significant is vertical exaggeration—the exaggeration of vertical distances with respect to horizontal distances—which is characteristic of almost all stereoscopic models; this exaggeration makes slopes appear steeper than they are and objects seem taller than they are. Vertical exaggeration is generally present not only in viewing stereoscopic models formed from paper prints but also in viewing projected stereoscopic models formed from glass-plate diapositives in double-projection instruments.

An understanding of vertical exaggeration is fundamental in the study of stereoscopic models, not only because of the exaggerated heights and the somewhat unnatural view that results, but because in many geologic problems the interpreter relies on visual dip

estimations rather than on any measuring devices (see p. 64). The amount of exaggeration of a dip angle in a stereoscopic model is fundamentally related to the tangent of the dip angle; that is, in a stereoscopic model exaggerated 3 times, for example, any true dip angle would be exaggerated to an angle whose tangent function was equal to 3 times the tangent of true dip. Exaggeration of low dips is generally an aid in structural interpretation and in detecting tilt from aerial photographs.

Minor topographic differences, which may reflect underlying geologic structure, are also exaggerated and in turn easily recognized (figs. 40, 88, and 97). The exaggeration of relief in a stereoscopic model of 1:20,000-scale photographs taken with a 6-inch-focal-length lens commonly permits an interpreter to distinguish differences in altitude as small as 1 foot. As a consequence vertical exaggeration then is most important where small but significant differences in altitude may be present in the stereoscopic model.

Vertical exaggeration results from the wide spacing of the camera positions at the time of exposure, as contrasted to the spacing of the human eyes with respect to normal viewing arrangement in examining stereoscopic models. Vertical exaggeration in normal viewing arrangement is fundamentally related to base-height ratio, which is the ratio of the air base distance to the flying height (see fig. 1). As this ratio increases, vertical exaggeration increases. Thus the greater the distance between camera stations (equivalent to air base distance), flying height remaining constant, the greater is the vertical exaggeration. The resulting photographs will have an increasingly smaller overlap area and consequently a lesser area within the stereoscopic model. It should be noted, however, that in normal photographing procedure when flying height is increased for any given focal-length lens, the air base distance is also increased so that a relatively constant base-height ratio is maintained. Under these conditions vertical exaggeration is not affected by flying height. When the base-height ratio is increased through the use of short-focal-length lenses, vertical exaggeration will also increase, the photographs taken with the shorter focal-length lens showing the greater exaggeration. Effective vertical exaggeration may also be increased by moving the two photographs farther apart at the time of viewing, or by increasing the viewing distance.

SCALE OF PHOTOGRAPHS

Small-scale photographs may be advantageous for interpreting some geologic terrains, particularly where reconnaissance information is desired. Small-scale pho-

tographs are normally taken at relatively high altitudes and have scales of 1:60,000 or smaller; their usefulness results chiefly from showing a large area in a single view (approximately 80 square miles on a single photograph having a scale of 1:60,000), which may reveal overall relations, as in geologic structures, drainage patterns, or other features, that could not be readily seen otherwise (figs. 48 and 55). Photomosaics commonly serve this same purpose (fig. 96). The association of features over a large area provided by the small scale is the significant factor to be considered. However, the reduction in image size due to high flying heights or short-focal-length lenses may be detrimental to the identification of some features, and hence make such photographs of little use for some interpretation problems. For example, details of jointing may be entirely lost on small-scale photographs. Also, use of small-scale photographs obtained by using extremely short-focal-length lenses, that is, 2 inches or shorter, may be undesirable, especially in areas of moderate to high relief, because many topographically low areas will be masked from view. Nevertheless, small-scale photographs have definite advantages in qualitative interpretation (Hemphill, 1958b) and may be especially useful if employed in conjunction with large-scale photographs or with instruments that enlarge the photography scale (see p. 47). Where quantitative study is involved, small-scale photographs are advantageous in that less control is needed within a given area than with large-scale photographs; but this advantage may be offset by the decrease in the reliability of measurements (see p. 72-74).

PHOTOGEOLOGY IN GEOLOGIC MAPPING

In geologic mapping maximum use of aerial photographs is attained by closely integrating field and photogeologic studies. It generally is desirable to precede the field phase of geologic study by a study of aerial photographs, which should include the compilation of a preliminary map on which all interpretations, however reliable or questionable, have been noted. Such a preliminary photogeologic study affords several advantages: it may point out areas that must be mapped primarily by field methods; it may eliminate or reduce extensive field surveys in certain areas; it may direct attention to anomalous areas where detailed field study is particularly warranted; and it commonly provides a basis for organizing the geologic plan of field study. In addition, attention is directed to those areas where field study will most likely result in establishing criteria that will permit a refinement of further photogeologic mapping. Also, a preliminary study of photographs gives a geographic familiarity of the area

that would be useful in choosing camp sites, routes of traverse, and optimum locations of instrument survey stations.

Continuing use of aerial photographs during the field phase of geologic study permits a firsthand correlation of geologic features and photographic images, which corroborates or refutes preliminary interpretations and provides information for subsequent detailed photointerpretive study. Refinements in interpretation may be made in the field or in a followup photogeologic study.

The delineation of rock types and structures from aerial photographs may involve mere observation; or more commonly interpretation is involved. In some areas it is possible only to map similar photographic units, as no diagnostic or suggestive criteria as to rock type may be present. Such areas are usually poorly exposed because of heavy vegetation or surficial debris; relief may be very low. But in other areas, where wide expanses of rock crop out, specific formations or rock types may be easily delimited on the photographs; thus much of the routine work of mapping geologic contacts, as well as determining structural measurements, can be accomplished readily by photogeologic methods. Where geologic structures are small and complex, aerial photographs may provide only limited information as contrasted to areas where geologic structures are large and simple. Depending chiefly on factors related to geologic environment, climate, and erosional cycle, the extent to which photogeologic methods can be applied thus may vary widely.

KINDS AND AMOUNTS OF INFORMATION

Geologic information that can be interpreted from aerial photographs may be grouped broadly into two categories: lithologic and structural. In general or reconnaissance mapping the geologist is interested largely in determining the distribution of rock units, including surficial deposits, and in delineating geologic structures. Special studies may require a more rigorous application of photogeologic procedures, which includes quantitative as well as qualitative study of the stereoscopic models. But regardless of the objective of a particular study, the kinds and amounts of geologic information available from aerial photographs will depend primarily on the type of terrain—whether igneous, metamorphic, or sedimentary—the climatic environment, and stage of the geomorphic cycle.

It is generally believed that sedimentary rock areas will yield more information from aerial photographs than igneous rock areas, and that regions underlain by metamorphic rocks will reveal the least information.

Putnam stated (1947, p. 560, 562) that “* * * geologic features * * * tend to be more recognizable where strong differences exist in the erosional resistance of adjacent rocks. Thus, sedimentary rocks, as sandstone, shale, and limestone, are likely to be more apparent than relatively homogeneous rocks like granite, especially if the sedimentary rocks have a moderate dip.” Bentor (1952, p. 162), based on his work in Israel, was of the opinion that “As a whole, air-photographs are much less useful in regions of crystalline rocks than in those composed of sedimentary formations.” With regard to igneous and metamorphic terrains, which are generally believed to be more difficult to interpret than sedimentary terrains, Melton (1956, p. 57) concluded that “Discovery of hitherto unknown or abnormal structures and [mineral] deposits, rather than detailed mapping, will probably be the most rewarding use of aerial photographs * * *.”

Except for high mountainous areas where vegetative growth is restricted by altitude, arid and semiarid regions generally will have the largest areas of rock outcrop, and tropical regions the least; hence the arid and semiarid regions may be expected to yield the greatest amount of geologic information from aerial photographs. In addition to relatively wide areas of rock exposure, the arid and semiarid regions may be expected to show a greater number of significant plant-rock associations than other climatic areas, because weathered material in the arid and semiarid regions is not excessively leached and a close relation of soil to parent formation therefore persists. Where this close association of parent rock and residual soils exists the distribution of different vegetation, reflecting the effect of bedrock on the composition of the soils, may facilitate the mapping of different rock types (see Levings, 1944, p. 27–30). In areas of much precipitation, under temperate or tropical climatic conditions, soils tends to be leached of salts, and there is a further tendency for soils from different parent formations to become more similar at maturity (Murray, 1955, p. 104). Murray stated (1955, p. 104) that under tropical conditions where rainfall is abundant, the ratios of potassium, sodium, and calcium to aluminum, which are widely different in silicic and mafic rocks, become smaller on weathering and are nearly equal in mature soils. Thus differences in vegetation as related to specific formations might be less well developed in tropical areas, except for those plant associations that may depend primarily on physical characteristics of the soil rather than chemical. Grantham (1953, p. 329) noted that in semiarid areas of Africa the soils reflect geology through vegetation differences more strongly than in wet temperate areas.

Sedimentary terrains yield a greater amount of lithologic and structural information than igneous and metamorphic areas because of the generally nonhomogeneous nature of sedimentary terrain, which results in marked differential erosion characteristics that stand out on aerial photographs. Sedimentary rocks of strongly differing physical characteristics commonly crop out within short distances whereas plutonic rocks, particularly, are likely to be relatively homogeneous over wide areas. Locally, diagnostic landforms, such as volcanic cones, may be important in study of igneous terrains, especially where extrusive rocks prevail. Metamorphic terrains, on the other hand, may reveal the least amount of information from aerial photographs because of the very nature of the metamorphic processes, which tend to destroy the erosional and landform characteristics of sedimentary and igneous rocks from which the metamorphic rocks are derived.

In any area where vegetative cover is dense and where surficial debris is widespread, aerial photographs generally can be expected to yield more structural information than lithologic information. The amount of structural information in turn generally will be greater, for any one type of terrain and climatic environment, during the mature stage of the geomorphic cycle, at which time streams show their greatest adjustment to and reflection of structure, and at which time a greater third dimension of the terrain is visible for study in the stereoscopic model. Where the lithologic character of rocks is interpreted on geomorphic or landform expression, maturely dissected areas may reveal the greatest amount of information.

Although the extent to which photogeologic procedures contribute to the geologic mapping of an area depends on the climatic and geologic environment, as well as the stage of the erosional cycle, some generalizations may be stated with regard to differentiating and interpreting sedimentary, igneous, and metamorphic terrains. These generalizations are grouped into two categories: lithologic character of rocks and geologic structure.

LITHOLOGIC CHARACTER OF ROCKS SEDIMENTARY ROCKS

Consolidated.—The presence of bedding in most sedimentary rocks is fundamental to their interpretation from aerial photographs. Because of differential resistance to erosion of sedimentary beds the typical banded patterns of these rocks are seen on aerial photographs. This is a result of what Rich (1951, p. 189) termed the "etching concept" wherein more resistant beds are brought into relief and less resistant beds

lowered as a result of weathering and removal of materials largely by sheet wash and creep (figs. 87, 91, and 97). Back slopes of steeply dipping beds, especially, may contrast strongly because they commonly expose to erosion within a given area a wider variety of lithologic types than dip slopes of gently dipping beds. Although topographic expression is thus important in recognition of bedding, banding due to vegetation or soil differences, expressed by photographic tone may likewise delineate beds, in absence of topographic expression or in combination with it (figs. 40 and 81). Bedding is especially prominent in the mature stage of the geomorphic cycle, particularly in terrain underlain by interbedded hard and soft sedimentary rocks that are tilted. However, bedding may be masked by the massive character of some sedimentary rocks, such as certain sandstones, in which case the sedimentary rocks may appear to be homogeneous and similar to some metamorphic rocks or intrusive igneous rocks as seen on aerial photographs (contrast figs. 71 and 92). A notable exception is massive limestone in which sinkholes have developed (fig. 68).

As seen on aerial photographs shales and similar fine-grained sedimentary rocks tend to have relatively dark photographic tones, a fine-textured drainage, and relatively closely and regularly spaced joints (figs. 49, 62, 63, and 91). Coarse-grained clastic rocks, in contrast, tend to have relatively light photographic tones, a coarse-textured drainage, and relatively widely and regularly spaced joints (figs. 42, 91, and 92). These generalizations are probably most applicable to marine sedimentary rocks. However, some fine-grained clastic rocks may be light toned and some coarse-grained sedimentary rocks, such as the continental red beds, may be dark colored rather than light colored and be expressed as relatively dark photographic tones on aerial photographs. Drainage density in a given climatic area is related primarily to resistance of a rock to erosion; drainage density increases with decrease of resistance to erosion. Resistance to erosion in turn is fundamentally related to permeability; generally resistance to erosion is less in rocks of low permeability. Hence, fine-grained clastic rocks commonly have a fine-textured drainage (fig. 79).

Physico-chemical precipitates are in many places closely associated with fine-grained clastic sedimentary rocks; where these rocks are interbedded the drainage texture and joint pattern both may be fine, as with fine-grained clastic rocks alone, but photographic tone of physico-chemical precipitates may commonly be relatively light, as with some fresh-water limestone, rather than dark, despite the fine grain size.

Although fine-textured drainage commonly characterizes nonresistant fine-grained sedimentary rocks and coarse-textured drainage suggests resistant coarse-grained sedimentary rocks, drainage is probably more significant as an indicator of structure than it is of lithology. Drainage characteristics may suggest broad rock groupings, but no one drainage pattern is diagnostic of sedimentary rocks, although annular and trellis drainage generally suggest sedimentary rocks or close metamorphic equivalents. The association of specific drainage characteristics with rocks of certain lithologic or physical characteristics presents an interesting field of study; quantitative study of stream data measureable from aerial photographs, such as drainage density, may indicate certain drainage-lithology relations.

The type of vegetation may be useful in differentiating specific rock types (see figs. 43 and 61). Hemming (1937) noted that striking vegetation differences were exhibited by limestone and quartzite in northern Rhodesia where the trees *Acacia* and *Albizzia* grew on limestone and *Brachystegia* and *Isoberlinia* grew on quartzite.

Unconsolidated.—Most surficial deposits—the unconsolidated sedimentary rocks—are readily distinguished on aerial photographs from consolidated rock types, although thin veneers of surficial material may be difficult to identify. Many recognition criteria are used in identifying and interpreting surficial deposits from aerial photographs, but the most significant criterion is probably landform. Landform is significant because many surficial deposits, particularly those useful to the engineering geologist, are transported materials that have diagnostic topographic form. The importance of landform is seen in the identification of sand dunes, eskers, kames, alluvial fans, river terraces, and similar constructional geologic features (figs. 52, 55, 56, 58, and 104). On the other hand extensive deposits of surficial debris, such as the drift plains of north-central United States, may show little or no diagnostic landform, but their general makeup may be inferred from drainage characteristics, photographic tone, analysis of slope, and related criteria (fig. 107). These criteria are discussed more fully under uses of aerial photographs in engineering geology studies (p. 33–37).

IGNEOUS ROCKS

Extrusive rocks.—Extrusive igneous rocks commonly have diagnostic landforms (figs. 41, 60, and 76) in contrast to the intrusive igneous rocks, which are revealed on aerial photographs primarily by other recognition features such as drainage, texture, massive

character of the rock, and crosscutting association with country rocks.

In addition to landform certain other criteria may be useful in identifying extrusive rocks, if the terrain is relatively undeformed. The structural relation of flows to associated rocks, for example, may be diagnostic in little-deformed areas, but where flows have been strongly tilted, folded, or otherwise disturbed, recognition and interpretation from aerial photographs may be extremely difficult or impossible. Only those relatively undeformed flows, mainly of Tertiary age and younger, are readily identified from aerial photographs without some knowledge from ground surveys. The ground plan of flows showing lobate patterns of vegetation and topography, especially at the terminations of suspected flows, is commonly diagnostic (figs. 76, 85, and 113), and association with volcanic cones makes misinterpretation difficult (figs. 41, 60, and 76). Locally flow channels may be visible. The surface of a flow may be rather hummocky and irregular, in contrast to surfaces of sedimentary strata, and where several flows have piled up, present topography may show several terracelike forms with irregular surfaces. The unconformable contact between flows and underlying rocks may aid in recognizing extrusive rocks (fig. 87), and where flows cascade down over older topography their identity is obvious (fig. 60). The basaltic or mafic flows may show dark photographic tones on conventional photographs, particularly in well-exposed areas, whereas rhyolitic or silicic flows may have light photographic tones. Locally distinctive patterns are present on mafic flows (fig. 53), and in some areas erosional characteristics permit differentiation of flows and associated rocks (fig. 69).

Where flows have been extruded over deformed igneous and metamorphic terrains, a low-dipping surface associated with lobate patterns of vegetation and topography is suggestive of extrusive rocks, and in some areas faults in the underlying rocks are seen to terminate abruptly at the edge of a lava flow (fig. 85).

Intrusive rocks.—Intrusive igneous rocks have a wide variety of structural relations to surrounding rocks that commonly aid in their identification from aerial photographs. Dikes may be revealed on aerial photographs as rectilinear or curved ridges that stand up because of greater resistance to erosion than surrounding rocks (figs. 81, 82, 87 and 90); they may also contrast in photographic tone with the surrounding rocks either because of the difference in rock types (fig. 90), or because of distinctive vegetation that covers dikes in some areas (Mogg, 1930, p. 662 and 668, pl. 5). Dikes may follow fractures in other igneous rocks and contrast in photographic tone with the host

rock. Where dikes are less resistant than the country rock, they may be expressed as rectilinear depressions that appear similar to fault expressions.

Because sills occur parallel to bedding in sedimentary rocks, they may be difficult to interpret as igneous from aerial photographs, even though strong tonal contrasts of the sills and sedimentary rocks are present. Mogg (1930, p. 656) pointed out that the diabases of Pretoria, South Africa, although relatively hard rocks, weather easily to deep soils that support distinctive deep-rooted vegetation, but the vegetation type differs from area to area. The tree *Kirkia wilmsii* grows conspicuously and exclusively on diabase sheets in the sedimentary rocks of the Pyramid Hills area of Pretoria (Mogg, 1930, p. 658), but in the Magaliesberg area *Acacia caffra* characteristically marks the diabase (Mogg, 1930, p. 662). Vegetation thus may be important locally as an indicator of rock types, but commonly it must be interpreted with caution because the same rock type may carry a different flora in different areas.

Igneous plugs, laccoliths, stocks, and batholiths, by nature of their mode of origin, commonly tilt the sedimentary rocks which they intrude, and in areas where plutonic rocks are exposed the pattern of dips in surrounding rocks may support other criteria suggestive of igneous rocks. Domal areas due to intrusion may also be reflected in radial drainage patterns (fig. 48), just as are certain folds in sedimentary rocks. But if areas of plutonic rocks are large, the characteristic homogeneous nature of such rocks may result in a dendritic drainage pattern, unless drainage is controlled by a fracture system (figs. 51, 70, 71, and 86). Because of the generally homogeneous nature of plutonic rocks as contrasted to sedimentary rocks they will have a massive appearance on aerial photographs, and banding typical of sedimentary and some metamorphic rocks will generally be lacking (figs. 59, 70, and 71). Also because of the homogeneous character of many igneous bodies, elements essential to plant growth may be distributed more or less uniformly throughout the mass (Murray, 1955, p. 103) and significant differences in vegetation can be expected to be absent from any one plutonic rock mass (fig. 70), except for those differences controlled by altitude or by structural conditions, such as faults that may trap an abundance of moisture (fig. 71).

In addition, topographic and erosional characteristics may aid in the interpretation of some igneous terrains. Granite at low altitudes in some tropical areas is expressed in hummocky, rounded topography on which a uniform type of vegetation is present; dendritic drainage may characterize this terrain.

Similar rounded topography may also be present at high altitudes, but where glaciers have been active all rocks may stand out in sharply angular topography. Regardless of surface expression, however, a crisscross pattern of joints, nearly always present in igneous rocks, commonly can be seen not only in the well-exposed areas (see figs. 70, 71, 100, and 103) but also in many vegetation-covered areas (fig. 72). Topographic expression of most plutonic rocks, as with other rock types, is dependent in large part on climate and stage of the erosional cycle, although within an area underlain by different igneous rock types difference in resistance to erosion may be significant and specific rocks may stand topographically high (see fig. 82). The homogeneous character of many intrusive rocks and characteristic jointing, on the other hand, are related primarily to the rock type and its mode of occurrence, and are independent of climate and erosional cycle.

METAMORPHIC ROCKS

The identification and interpretation of metamorphic rocks from aerial photographs is commonly difficult because large-scale distinguishing characteristics are generally lacking. Bedding, so necessary to structural interpretation, may be difficult or impossible to recognize because of physical changes brought about by metamorphism, including the superposition of metamorphic structures of small scale. Indeed, many structural trends that can be interpreted from aerial photographs represent foliation rather than bedding (figs. 73 and 74). Where exposures are good, differences in photographic tone offer the best clue to recognition of bedding, especially where the metamorphic rocks are derived from thin-bedded sedimentary rocks of contrasting lithologic makeup (fig. 103). Thick formations of quartzite and marble might readily retain the photographic characteristics of the original sedimentary beds, however, because the metamorphic changes of induration of sandstone and recrystallization of limestone would likely have little effect on the gross physical appearance of these rock types as seen on aerial photographs. It is possible, however, that talus from quartzite ledges might take the form of large blocks in contrast to smaller chunks of rubble at the base of sandstone cliffs. The preference of vegetation for one rock type such as limestone, as a result of its chemical makeup, might well persist, even if the formation were metamorphosed to marble; but vegetation that might show a preference for sandstone because of its physical makeup, especially its high porosity, might well be lacking on its metamorphic equivalent, quartzite.

Strong parallel alignments of ridges and intervening low areas may be due to regional cleavage, foliation,

or fold axes, and thus the "topographic grain" of an area may suggest underlying metamorphic rocks (figs. 73, 76, 100, and 102), but in glaciated areas this evidence must be used with caution (fig. 67). In an area where a pronounced regional trend, or "topographic grain," is shown on the aerial photographs, the likelihood that metamorphic rocks are present is supported by the occurrence of widely spaced lineations at right angles to the regional trend. These lineations commonly represent regional cross joints and may be reflected in abrupt deflections of drainage along conspicuous straight stream segments of major streams (fig. 74) or in the development of tributary streams along these joints (figs. 73-75). Where bedrock is well exposed the profuse fractures in certain metamorphic rocks may be visible (figs. 46 and 99). Cady (1945) pointed out that in some areas in central Alaska talus slopes are developed much more extensively where the peaks are of metamorphic rocks rather than of granitic rocks; this distinguishes these two rock types locally (fig. 103).

STRUCTURE

FLAT-LYING BEDS

Flat-lying or nearly horizontal beds are most easily recognized where different sedimentary rock types exhibit contrasting photographic tones expressed as bands that extend along the topographic contour (figs. 77 and 78). Where both resistant and nonresistant rocks are present slope characteristics commonly are suggestive of horizontal strata—the resistant rocks have steep slopes or vertical cliffs, and the nonresistant rocks have a lesser angle of slope; the significant changes in slope between two beds extend generally along the topographic contour (figs. 77 and 78). Photographic tone and slope characteristics are associated in many places as mutually supporting evidence of flat-lying beds.

Because of the uniform resistance of one rock type to erosion, particularly in a horizontal direction, the drainage on flat-lying beds is generally dendritic unless controlled by joints or faults (figs. 42, 61, and 77). However, dendritic drainage alone, although suggestive, is not necessarily diagnostic of flat-lying sedimentary rocks; other rock types, such as granite, also may be uniformly resistant to erosion and may also exhibit dendritic drainage.

DIPPING BEDS

Numerous expressions of dip of sedimentary beds may be seen on aerial photographs. Dip direction is readily apparent where topographic surfaces coincide with bedding surfaces (figs. 87, 90, 92). Even in heavily vegetated areas the direction of dip commonly

stands out as a result of the overall view afforded by the aerial photograph, which shows the tree crowns to fall in a dipping plane (fig. 89). In those areas where dips are very low, the aerial photographs are advantageous, if the beds are clearly expressed, because vertical exaggeration, which is present in most stereoscopic models, permits low dips to be readily interpreted (see fig. 91 and p. 64). The degree of dip may be estimated from the stereoscopic model by experienced photointerpreters or it may be measured photogrammetrically.

Where bedding is expressed by bands of differing photographic tone or by topographic breaks in slope due to resistance of beds, the rule of V's may be applied to determine the direction of dip; that is, where the trace of a bed intersects a stream valley a V in the outcrop pattern will point in the direction of dip (figs. 80, 81, and 98) unless the direction of dip and direction of streamflow are the same and the stream has a gradient greater than the amount of dip (fig. 59).

In many areas, particularly those of low relief, where beds are obscured by surficial materials or vegetation the direction of dip may be inferred from drainage characteristics. Where dips are gentle the relatively long tributary streams commonly flow down the dip slopes (Lattman, 1954, p. 361-365), whereas short tributary streams will characterize back slopes (figs. 5, 7, and 74). It is interesting to note that the relation of short and long tributary streams may be reversed where dips are steep, that is, about 45° or more (fig. 6). Other photorecognition criteria, such as distribution of photographic tones, should be sought to indicate whether dips are gentle or steep; or scattered field observations may provide sufficient information for making an analysis of dip direction based on stream characteristics. In such an analysis it may be desirable to trace all streams, however small, on a separate overlay (fig. 7). This is best done from the stereoscopic model. Exact positioning of tributaries is not essential to this technique of determining dip direction, but lengths of tributaries must be sketched carefully as the length relations of updip to downdip tributaries is significant. Viewing the stereoscopic model pseudoscopically (fig. 95) may be helpful in delineating the drainage.

FOLDS

Folds are commonly expressed as obvious features on aerial photographs especially where a fold is shown in its entirety within a single view and an orderly structural arrangement of beds is discernible (fig. 90) or where erosion has exposed a cross section of the

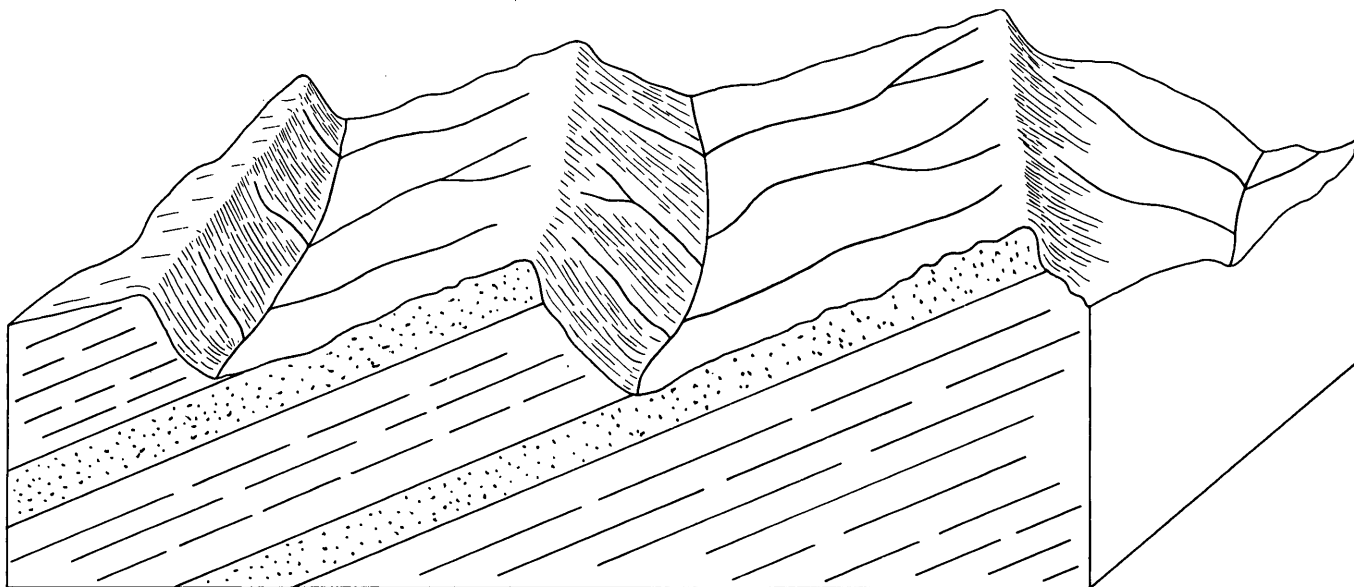


FIGURE 5.—Sketch showing long tributary streams on updip side of strike valley in area of low dips.

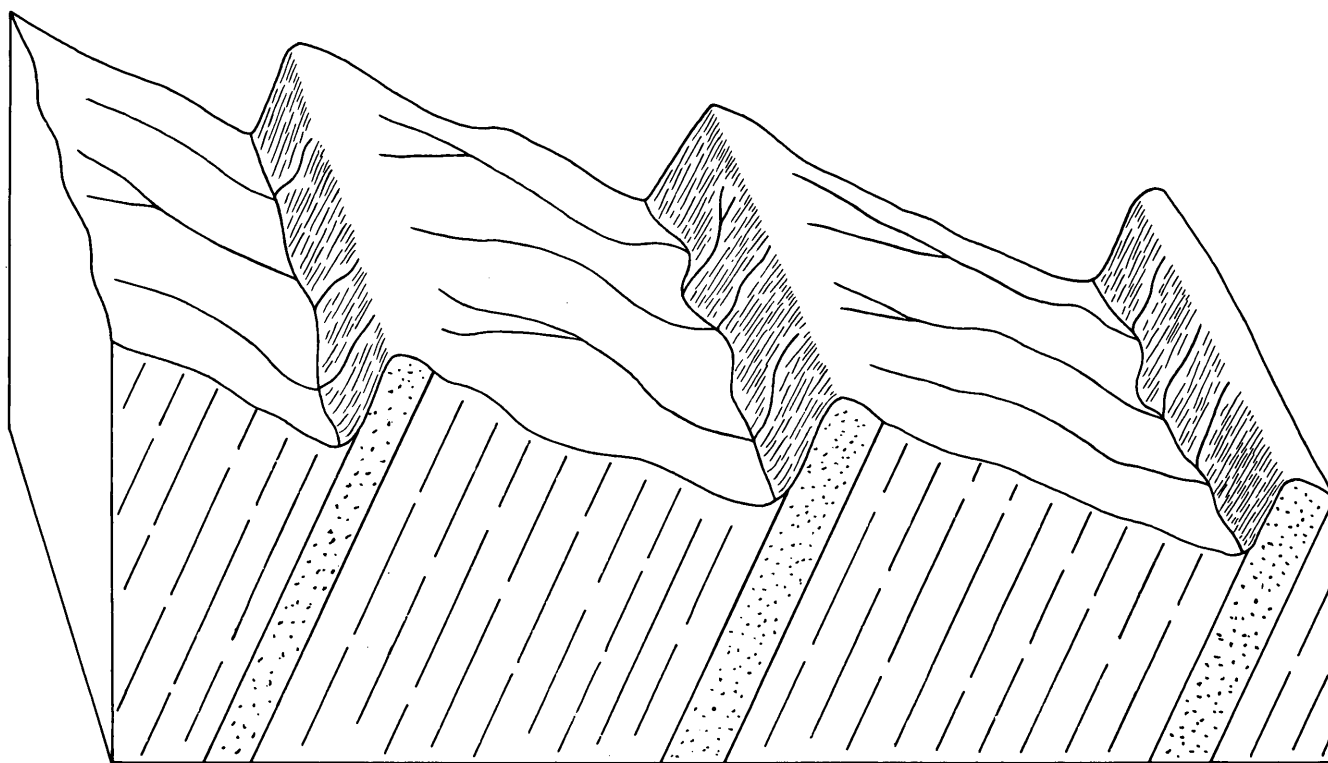


FIGURE 6.—Sketch showing long tributary streams on downdip side of strike valley in area of steep dips.

structure (fig. 91). Drainage characteristics may also aid in recognizing and delimiting the fold. Wengerd (1947, p. 596) noted that in parts of northern Alaska streams flowing in synclinal valleys were sluggish and meandering, and had low banks and swampy border areas with meandering tributaries; in contrast, streams flowing in anticlinal valleys were steep walled and less meandering. Wengerd also noted that dip slopes and back slopes in some areas commonly exhibited different drainage densities (fig. 79).

Where folds are plunging, major streams commonly curve around the nose of the fold; the convex side of the curve indicates the direction of plunge of anticlinal folds (figs. 81, 89, and 90). However, in areas where relief is low or bedrock is obscured by vegetation or surficial materials, drainage patterns or drainage anomalies may be the primary expression of folds (see figs. 9, 94, and 96; and p. 26-27). Drainage patterns or anomalies generally are best seen on small-scale photographs or mosaics where segments of streams combine to form significant patterns when observed in a single view (fig. 96). The significance of drainage characteristics may not be immediately apparent when large-scale photographs are viewed.

FAULTS

One of the advantages in study of aerial photographs is that of delineating high-angle faults or suspected faults. This advantage is a direct result of the aerial view, which allows a large area and the gross features within it to be seen at one time. For example, many alinements that are inconspicuous on the ground are readily seen on aerial photographs (figs. 74 and 83). Although many alinements are conspicuous because of their independence of stream valleys or ridges and uplands which they cross (see Barton, 1933, p. 1198), alinements of stream segments and small drainage courses are probably the most common indicators of faults. Most high-angle faults are expressed on photographs as straight or gently curving lines, and this characteristic is probably the most important clue that a fault may exist. All linear features should be examined with care even though other criteria are needed to prove the existence of faults.

Lines indicative of faults may be expressed as alinements of vegetation, straight segments of stream courses, and waterfalls across streams; alinements of lakes, ponds, and springs; conspicuous changes in photographic tone or drainage and erosional texture on opposite sides of a linear feature, or tone change along a linear feature because of vegetation which may appear darker; alinements of topography, including saddles, knobs, or straight scarps; rectilinear depres-

sions; or any combination of these. Faults may also be expressed by horizontal or vertical offsets of beds or recognizable rock units (figs. 50, 60, 62, 74, 79, 80, 82-84, 86, 98, 99, 101, and 114). Where bedrock is well exposed the actual physical break may be seen. In some places a lineament, or broad linear depression, may be conspicuous but not distinct. Where such areas of possible faults occur, beds on one side of the general lineament should be examined for change of dip and strike as well as abnormal stratigraphic position with respect to beds on the other side (see fig. 80). Commonly in sedimentary terrain, offsets on opposite sides of a linear feature are easily detected, owing to the vertical exaggeration which is inherent in most stereoscopic models and which generally assists in the identification of correlative beds (figs. 83 and 84).

Suspected faults should be examined carefully because other features may be represented, at least in part, on aerial photographs in the same manner as faults, particularly if a single photograph is being viewed. In some areas jointing in one direction within a formation may be prominent and where an apparent offset is present owing to the occurrence of an erosion scarp along a joint plane, the scarp line may be misinterpreted as a fault trace. Where channels have been cut in sedimentary formations, and a rock type of different lithologic character now occupies the channels, a distinct lineation between the channel filling and the original sedimentary rock, now truncated, may suggest a fault trace. A line between two distinct types of vegetation, although possibly reflecting the presence of a fault, may well be due to differences in underlying rock types in normal sequence, or to the moisture content of the soil, or even to manmade features. In some areas the simple erosion of dipping strata may result in an alinement of topographically high points that suggests a fault. Or vegetation and drainage alinements may be present along easily eroded dikes. The need for caution in interpreting faults from aerial photographs is thus dictated by the very presence of numerous other geologic features that are expressed photographically in a similar manner.

Low-angle faults are more difficult to interpret from aerial photographs than high-angle faults. Discordance of structures within different rock types combined with strongly curving or irregular traces of the fault contact of the rocks involved offer the best clue to the presence of low-angle faults. Angular unconformities may show similar photographic expression.

In a study of azimuth, frequency, and length measurements, Gross (1951) demonstrated that in some covered areas of the Canadian Shield certain lineations very likely represent faults. The study involved the

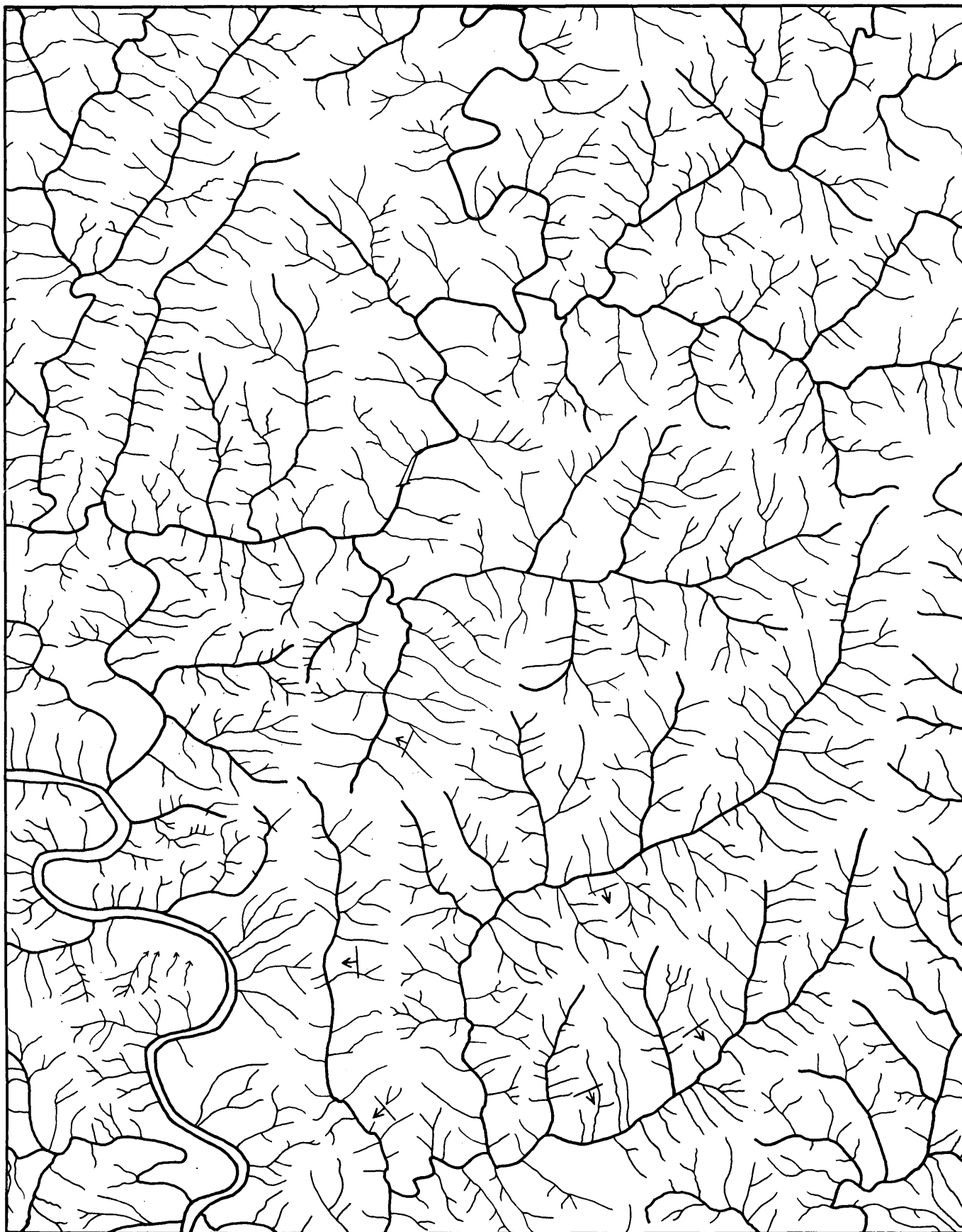


FIGURE 7.—Drainage map of area shown in figure 74 and vicinity. (Strike and dip positions based on analysis of stream-length relations.)

The separate drainage tracing allows a study of drainage characteristics divorced from the abundant imagery of the photograph. Patterns and tributary stream-length relations, for example, are readily observed on the separate tracing. Relative lengths of tributary streams at many places might easily be overlooked in the stereoscopic model. However, a study of the plani-

metric disposition of streams must be considered a supplement to a study of the stereoscopic model in which significant features in the third dimension, such as elongate hills or other features that may represent structure, are seen.

construction of histograms in which the length and frequency of topographic lineations as seen on aerial photographs were plotted against geographic orientation within 10° segments of the compass. Similarly, histograms were plotted from a sampling of field data of strike of strata, schistosity, dikes, glacial striae, faults, and other features considered to have a bearing on the configuration of the topography. One peak on the histograms compiled from aerial photographs was found to represent a direction of prominent faulting.

JOINTS

Joints, like faults, are most commonly expressed on aerial photographs as linear features. In flat-lying or gently folded sedimentary rocks, most joints are steeply dipping or vertical, evenly or regularly spaced, and commonly consist of two prominent sets that are expressed on aerial photographs as lines intersecting approximately at right angles, which gives a blocky appearance to the topography (fig. 42); however, joints may be well developed in only one direction, which gives a strong linearity to the fracture plan (fig. 92). In fine-grained clastic rocks the joints are generally more closely spaced than in coarse clastic rocks. Joints may become widened through weathering and erosion processes and appear as particularly conspicuous linear features; the similarity of these joints to faults is superficially striking, especially where well-developed regional cross joints have formed in metamorphic rocks and other criteria of faulting are lacking. Identification of many joints is enhanced by the presence of vegetation along them, due perhaps to greater moisture along these lines. Lattman and Olive (1955, p. 2087) described the use of solution-widened joints in Texas as a guide to indicate steepening of dip and to locate changes in dip direction. Joints more nearly parallel to the dip direction were widened by solution of meteoric water. Rubble, soil, and water trapped in these joints gave rise to dense vegetation expressed on aerial photographs as conspicuous, even-spaced parallel lines. A good clue to the identification of joints in relatively undisturbed sedimentary rocks is the general abundance of short lineations on a photograph, and a more or less uniform trend of these lineations within a given area of a few square miles extent.

Lattman and Nickelsen (1958) described azimuth-frequency measurements from aerial photographs in a study of fracture traces in western Pennsylvania. The fracture traces are expressions of natural linear features that consist of topographic, vegetation, or soil

alinements exposed continuously for less than 1 mile. The term "fracture trace" is used by Lattman (1958, p. 569) to differentiate these alinements from natural linear features exposed continuously for at least 1 mile or more, called "lineaments." A histogram of frequency and orientation of the fracture traces showed maximums closely corresponding to those of prevailing directions of joints as seen in the field, with the exception of one fracture-trace maximum which had no counterpart in exposed rocks of the area (Lattman and Nickelsen, 1958). This one maximum of frequency and orientation of traces, however, was found to correspond with joints in underlying coal beds; the joints apparently were reflected through an overlying thickness of shale and sandstone to be expressed at the surface in a manner discernible on aerial photographs but not in routine field-mapping procedure. The close correspondence of fracture traces and joint directions in the test area suggest that aerial photographs may be used to extend mapping of joints into nearby areas of no outcrop.

Joints in igneous rocks are likely to be seen readily on aerial photographs (figs. 70, 71, 100, and 103). Commonly three and sometimes four prominent joint sets are developed. Where these joints are primary joints, dips may be low, moderate, or steep, depending on the orientation of flow structures within the igneous mass; this contrasts with the generally steep dipping joints of little-disturbed sedimentary rocks. Because of the wide range of dips of joints in igneous rocks, and because at least three joint sets are almost always developed, the surface traces of these joints, shown as lineations on aerial photographs, intersect at widely varying angles. The resulting crisscross pattern is distinctive of intrusive rocks in many areas. Joints in igneous rocks also may be irregularly spaced in contrast to those in sedimentary rocks.

Joints in metamorphic rocks may not be as conspicuous on photographs as joints in sedimentary or igneous rocks. Joints previously formed in igneous or sedimentary rocks may be destroyed by metamorphic processes and much of the energy of metamorphism spent in development of schistosity, fracture cleavage, or other small-scale metamorphic structures, rather than conspicuous joints. This is particularly true of metamorphic rocks formed from fine-grained clastic rocks, which comprise more than 50 percent of the sedimentary rock group. Where metamorphic rocks are recognizable by strong lineations that represent fold axes or trend of foliation, widely spaced regional cross joints perpendicular to the fold-axes direction may be prominent; streams developed along the cross joints accentuate these structures (figs. 8, 73, and 74).

CLEAVAGE AND FOLIATION

Cleavage or foliation, which is almost universally present in metamorphic rocks, especially in those that were originally shale or other thin-bedded clastic rocks, is difficult to differentiate on most aerial photographs. The "grain" of metamorphic terrain as expressed on aerial photographs by stream and vegetation patterns, as well as by parallel ridges and gullies, however, may well reflect pronounced cleavage or foliation (figs. 76 and 100). Turner (1952) pointed out that prominent topographic alinements in the schists of central Otago, New Zealand, are clearly expressed on aerial photographs. These alinements, generally parallel to the trend of *b* lineations, are believed to have resulted from differential weathering controlled by cleavage, foliation, and other elements of the schist fabric.

UNCONFORMITIES

Unconformities are generally difficult to interpret from aerial photographs. An angular unconformity may be inferred from the discordance of bedding, either in strike, dip, or both, at a contact line that has an irregular trace across a wide area. But discordance alone does not prove the presence of a stratigraphic unconformity since a discordance of bedding may be due to faulting, or locally to crossbedding. The areal distribution of rocks or structures as seen on small-scale photographs or mosaics, or after plotting geologic data over a large area, may also suggest the presence of an unconformity. On a local scale, the separation of unconsolidated, nearly horizontal, river gravel from the truncated, underlying strata is a good example of an unconformity (fig. 88). Pediment gravel that overlies truncated bedrock (fig. 45), or channel-fill deposits that truncate the underlying bedrock (fig. 44), may be clearly expressed on aerial photographs.

INTERPRETATION OF AERIAL PHOTOGRAPHS IN PETROLEUM GEOLOGY

Aerial photographs have been widely used by geologists of the petroleum industry particularly in the mapping of many large-scale geologic structures, which are readily recognized on aerial photographs because of direct surface expressions of dipping beds. The use of photogeologic techniques in the search for structures that may contain oil is continuously increasing. However, as the obvious and well-exposed structures in many areas have long been discovered, considerable attention is now being given to indirect, or geomorphic evidence of subsurface structures. In addition, photogrammetric methods for making measurements needed to compile structure contours and to



FIGURE 8.—Drainage map of area shown on left half of figure 73.

The regional cross-joint trend, expressed by the main streams on figure 73, is strongly brought out on the drainage map. Note tributary streams flowing at right angles to the main streams. Stream trends are obscured com-

monly by the abundant imagery of the photograph and it may be desirable to compile separate drainage maps when stream characteristics are used to interpret lithologic or structural features of an area.

determine strike, dip, stratigraphic thickness, and closure are being used increasingly.

The indirect evidence yielded by photointerpretive studies is based on the premise that subsurface structures may be reflected in surface expressions of various kinds, such as stream or vegetation patterns or anomalies. Indirect evidence is particularly useful in the interpretation of areas of few or no outcrops, such as areas of low relief, or areas of dense vegetation. Commonly in such areas, the evidence points not directly to a structure, but to an anomaly, such as a variation in drainage characteristics from the norm established for a local region. The anomaly in turn suggests a possible subsurface structure. Thus even though surface evidence alone may not be conclusive in the interpretation of subsurface structure, it may provide clues and stimulus for exploration (Alliger, 1955, p. 183). However, Wheeler and Smith (1952, p. 112) cautioned that " * * * strong deformation, periodically rejuvenated, is restricted to the mobile belts * * *," and structures farthest away from maximum deformation are " * * * therefore more difficult to infer from physiographic abnormalities at the surface * * * that without the genetic background of those events in the geologic history of the tectonic province responsible for surface and subsurface indications of structure, photogeology may be unfavorably speculative."

FOLDS

Folds may be expressed on aerial photographs by the distribution of bedding, by drainage characteristics, by topography, by distribution of soils, or by combinations of these criteria. The surface manifestations of folded or domed structures thus may range from obvious, where direct surface expression of dipping beds is present, to subtle, where subsurface structures are reflected only indirectly by physiographic criteria.

BEDDING

Many folded structures can be delineated readily because bedding is clearly expressed at the surface. Particularly in areas where rocks are well exposed and structural deformation has been mild, beds may be clearly defined by photographic tone together with topographic relief or hogback landform (figs. 90, 91, and 92); strike and dip of beds are easily determined and the structure delineated from the distribution of beds (see also p. 19).

In areas where bedding may be obscured by low plant and grass vegetation, differences in vegetation together with slight topographic relief changes, enhanced by vertical exaggeration of the stereoscopic model, may permit bedding to be delineated and struc-

tures to be structure contoured (see fig. 40 and p. 6).

DRAINAGE

In areas where bedding is largely obscured, for example by vegetation or surficial materials, stream patterns, anomalies, or textures may be helpful in determining dip slopes and outlining folds. In some areas dip-slope streams have a coarse-textured arrangement in contrast to the fine-textured arrangement of back-slope streams (fig. 79). These textures probably reflect coarse-grained and fine-grained rocks, respectively. The distributions of such textures in turn may suggest the location of structural axes.

In many areas stream adjustment to structure will result in a sweeping curve of the stream particularly across a structural axis and around the nose of a plunging fold; the convex side of the curve indicates the direction of anticlinal plunge (figs. 81 and 90). But such curves may also develop on dip slopes and thus not be indicative of the location of a structural axis. This situation may prevail where anticlinal structures are breached into softer material. Streams developing on the more resistant dip slope of the structural flank may curve on that flank and along soft interbeds, and not across the axis of the structure (fig. 93). Such a condition would probably be most pronounced during the mature phase of the geomorphic cycle. In geomorphically young areas streams may not have had sufficient time to adjust to folded structures, and may have a tendency to follow joints or preexisting faults (Howard, 1940, p. 195). In areas where stream pattern or anomaly is the primary surface reflection of underlying structure, as in some jungle-covered areas, other criteria, such as vegetation pattern, should be sought to corroborate the location of a structural axis suggested by stream characteristics.

Stream patterns or anomalies are undoubtedly the most useful indirect evidence of subsurface structures in many areas. This is especially true for coastal areas of low relief, many interior basins, or areas of dense vegetation or other surficial cover. Tator (1951, 1954) and DeBlieux (1949) discussed the structural significance of drainage anomalies in the coastal region of the Gulf States; in these low, swampy areas of aggradation it is important to establish the drainage norm by studying the drainage characteristics over a large area. Deviations from this norm may give the first indication of a structural anomaly. DeBlieux (1949, p. 1259) described abrupt locally restricted changes in drainage considered to be the result of subsurface structure. Over the Lafitte field in Louisiana a relic tributary of the Mississippi River forms two

sharp meander bends, although for miles upstream and downstream from this area, the stream channel is simple and straight. Over the Scully dome " * * * two relic distributaries of Bayou Lafourche followed simple courses, but suddenly changed to an anastomosing pattern over the dome, then resumed simple courses south of the structure." (DeBlieux, 1949, p. 1259.)

Structural implications of stream pattern or anomaly may be corroborated by other geomorphic evidence. Over the Lafitte field the presence of distinct remnants of natural levees on either side of the channel, the only such ridges over the length of the relic course of the stream, was considered significant supporting evidence of underlying structure (DeBlieux, 1949, p. 1259). The levee-ridge remnants presumably were held up by subsurface structure as surrounding areas subsided.

In a study of tonal and textural anomalies in west-central Texas DeBlieux and Shepherd (1951) described anomalous compressed meanders over structural highs. In the same area annular and radial drainage patterns and stream deflections in the flank areas were important criteria that supported an interpretation of subsurface structure (fig. 94). The importance of abrupt changes in direction of streamflow in relation to possible subsurface structures has recently been emphasized by Buttorff (1958) and Elliott (1958), based on work in the Powder River Basin, Wyoming. Such deviations from the norm for an area commonly stand out when a separate drainage map of an area is studied (see fig. 9) or when stereoscopic models are viewed pseudoscopically (see p. 5 and fig. 95).

In areas of aggradation and active subsidence it is to be expected that abnormal drainage characteristics rather than any specific drainage pattern might be indicative of subsurface structure. The combination of emergence, due to recent rise of salt plugs, and subsidence of the general coastal-plain area is responsible for many of the anomalous drainage characteristics of the coastal area of the Gulf States; such characteristics are anastomosing stream segments, abruptly widened levee ridges, or abrupt changes in direction of streamflow.

In areas of active degradation, patterns of drainage rather than abnormal drainage characteristics can be expected to be indicators of structure. However, Wheeler and Smith stated (1952, p. 82) that the analysis of stream pattern with regard to structure—which they called "creekology"—is somewhat outmoded as a photogeologic procedure; they implied that

anomalies in drainage characteristics may be far more important than specific drainage patterns. However, drainage pattern may actually be anomalous with respect to the drainage norm for an area; such examples of drainage patterns have been found along the northwest coast of Alaska on the Arctic coastal plain. Here, in an area of northward-flowing streams, slight topographic highs have resulted in radial-dendritic drainage patterns, which outline areas of subsurface structure (fig. 96). Commonly no other surface expression of structure is present. Because of low relief, outcrops are few.

TOPOGRAPHY

The presence of topographic highs has been significant in locating subsurface folds or domal structures even in many areas where relief is very slight. Many of the "islands" of the coastal area of the Gulf States are surface expressions of salt domes. Topographic features such as natural levees, which represent areas of higher ground only a few feet or tens of feet above the delta or flood plain, are also significant interpretation criteria in the search for subsurface structure (Tator, 1951). Tator reported (1951, p. 717) that " * * * cheniers and natural levees * * * provide linear patterns of higher ground supporting distinctive vegetation growths." These higher areas are also favored for cultivation. According to Tator (1951, p. 717) "Tonal contrasts in the photographs are the major keys used for recognition of landscape features of extremely low relief, such tonal variations being largely the result of soil and vegetation differences." The significance of low relief, is shown by DeBlieux's description (1949, p. 1254) of Felicity Island, a 2-mile-long natural levee ridge separated by several miles of marsh from the area where the levees normally could be expected to die out. The preservation of the "island" in an area of active subsidence has been attributed to local subsurface structure. Abrupt widening of levees on one or both sides of a channel, in areas of subsidence, also has been noted over subsurface domal structures (DeBlieux, 1949, p. 1254, and fig. 2, p. 1255); widening of levees may be due to other causes, such as coalescence of two levees, however, and this feature of the flood plain must be interpreted carefully.

In a study in northern Alaska, Fischer (1953) used topography as the principal interpretation criterion in locating the Square Lake anticline. The area is a treeless waste of low relief that is underlain by permafrost; tundra grasses cover the region, and no bedrock is exposed. Fischer (1953, p. 208) reported that the original photogeologic study showed small hills in the area elongate in the same direction as the regional

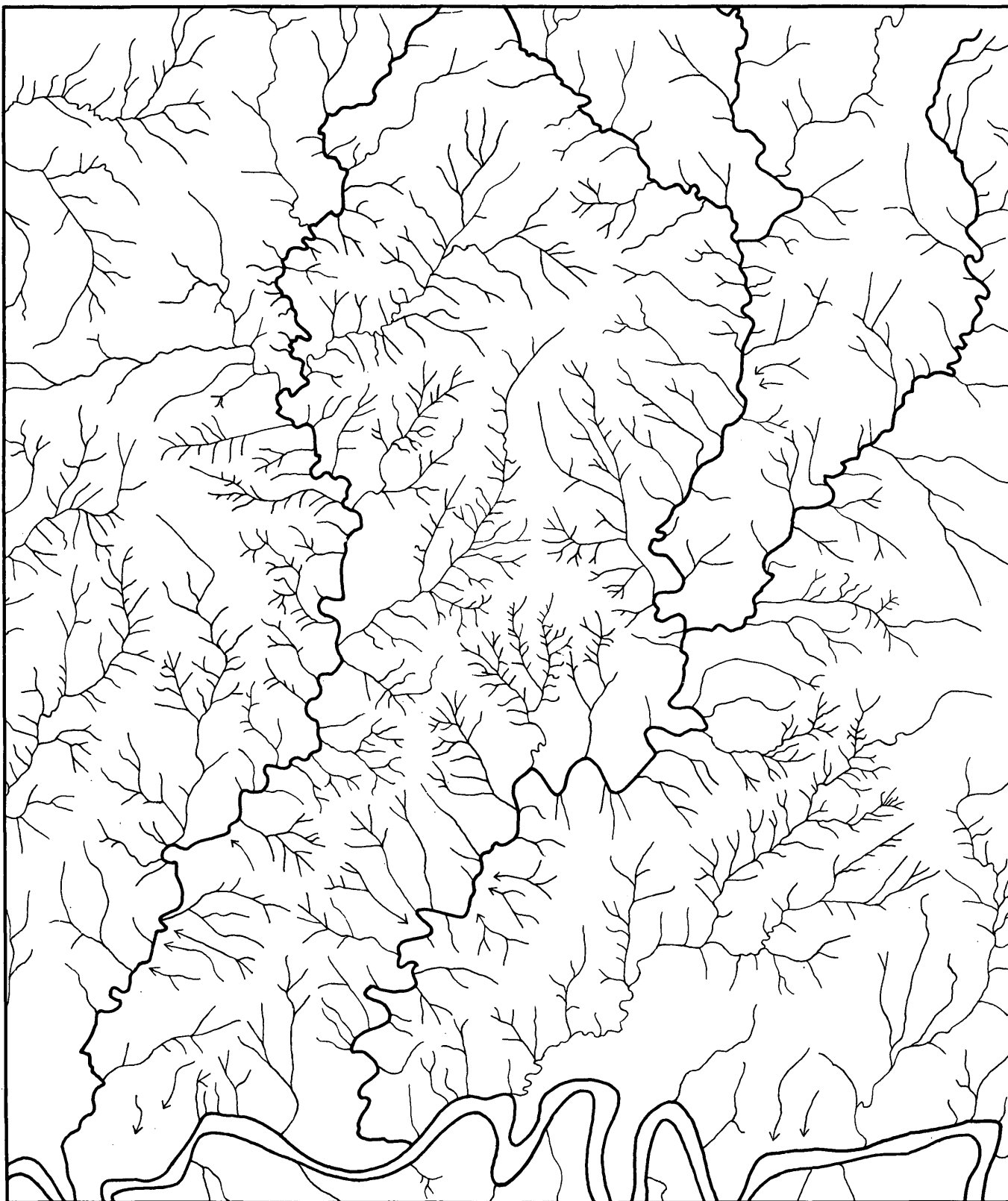


FIGURE 9.—Drainage map of area shown in figure 94.

Radial drainage over structure, *A* of figure 94, stands out on the drainage map which is unobscured by the abundant details of the photograph. Note that the radially draining streams flow into larger streams that have an

nular pattern around the structure. Stream deflections, as at *D* in figure 94, are commonly more readily observed on the separate drainage map or in pseudoscopic view of the model (see fig. 95).

structural trend. Normal to this trend other elongate hilltops sloped in the direction of the inferred dip of beds. Also, streams flowing in the dip direction had a slightly less well developed dendritic pattern than those flowing opposite to the dip direction. There also appeared to be a correlation between slopes of the tops of cut banks and the direction of dip. Plotting of all such data gave a consistent apparent structural pattern—a plunging anticline—of unknown reliability. A subsequent seismic survey corroborated the photogeologic interpretation.

SOILS

In some areas devoid of outcrops, soil patterns or soil distributions may be useful in delineating or suggesting structures. Both Woolnough (1934b, p. 221, 224) and Christensen (1956, p. 858–859) cited examples of the usefulness of aerial photographs in this regard. Wheeler and Smith (1952, p. 106) stated that contrasts in soil tone accentuate unusual drainage relations on the northern flank of a structure in the southwest Maysville area, Oklahoma; and in southwestern Alabama differences in cultivation pattern reflect relief and soil characteristics by which geologic units of Tertiary age beneath younger unconsolidated materials can be differentiated.

DeBlieux and Shepherd (1951, p. 98) described tonal and textural anomalies in west-central Texas that resulted from differences in soil types, soil-moisture content, and erosional characteristics. They cited an anomaly at Salt Fork on the Brazo River where “* * * dark and coarsely hummocky surface strongly contrasts with the lighter color and finer texture of the surrounding surface * * *” (DeBlieux and Shepherd, 1951, p. 98). The anomaly was strikingly similar to that of a reef producer in Scurry County. DeBlieux and Shephard (1951, p. 88) emphasized that how a structure forms is unimportant in a study of tonal, textural and other anomalies, because the surface evidence is identical, whether the structure has resulted from upward movement, differential downwarping, reef or residual topography, or combination of these features; it is important initially that a surface anomaly can be recognized.

FAULTS

Faults are significant in the geologic interpretation of petroleum areas because they may be deep seated and of major importance in localizing oil accumulation. Where faults are genetically related to structures that may be oil bearing the distribution pattern of faults may be of considerable use for interpreting the locations of those structures. The many surface expressions of faults are described above (p. 21).

Desjardins (1952, p. 82) stated that surface fault

and fracture lines, expressed as lineations on aerial photographs, form patterns that bear a definite relation to deep-seated salt domes and to subsurface faults of the Gulf Coastal Plain. Disturbance centers, believed to be underlain at depth by salt domes, may be indicated by the fault patterns, shown on photographs as “Sharply curving lines which are strikingly concentric” or as “Prominent transverse lines radiating usually from some marginal point rather than from the center of the structure” (Desjardins, 1952, p. 82). Desjardins believed that such fault patterns were the result of continuous application of small stresses caused by rising salt masses rather than an accumulation of stresses that would produce large amounts of movement; he also felt that faults probably would form in interdome areas as well as over the domes. The genetic significance of the fault pattern is thus critical if distribution of faults is used as a basis for locating the dome itself. Desjardins (1952, p. 83) made a strong distinction between surface expressions of faults, which he associated with deep-seated domes, and other criteria, such as topographic expression, widening of natural levees, and looping of stream channels, which he associated with shallow-seated domes.

Although most interpretations of faults are based on qualitative characteristics of observed data, such as the dislocation of correlative beds, or the contrast in light and dark photographic tones on opposite sides of a straight line, a quantitative approach to such studies may provide additional useful data. On the basis of azimuth-frequency studies Blanchet (1957, p. 1748) suggested that structural and stratigraphic anomalies in some areas may be located by a statistical analysis of fractures, which he defined as the generally abundant, natural lineations discernible on aerial photographs. The basis for analysis is a comparison of local deviations in the statistical mean direction of fracture sets with regional norms for each fracture set. Regional norms are first established by plotting fracture-azimuth frequency diagrams of the region involved. Then statistical mean directions of fracture sets are determined by analyzing samples within circular areas centered at relatively small horizontal intervals of a few miles. These local mean directions are in turn studied for local deviations which are entered into empirical equations that yield structure-intensity values. These structure-intensity values are then contoured, to form a structure-intensity map, which may reflect structural anomaly. The structure-intensity map is supported by a fracture-incidence map, prepared in contour form, and by an analysis of drainage characteristics of the area in question. Blanchet applied this method to a study of petroleum structures.

FACIES

Although the widest application of aerial photographs in petroleum geology has been with regard to structural traps, a study of aerial photographs may contribute to the location of stratigraphic traps, particularly if photogrammetric measurements of formation thicknesses can be made at many points within the stereoscopic model (see p. 59-60). From a qualitative standpoint it can be seen in figure 97 that a rapid loss of sandy section can sometimes be detected on aerial photographs. Such "shaling" or loss of sandy section due to facies change may be important in the search for stratigraphic traps and in some areas it may be measured photogrammetrically. In other areas well-defined formational units may thin or thicken without facies change, but this also may be significant in regional studies with regard to stratigraphic traps (Christensen, 1956, p. 861, fig. 6). Measurements of stratigraphic sections needed in such studies commonly can be made from aerial photographs.

REGIONAL STUDIES

The significance of aerial photographs in regional petroleum studies is widely recognized, but very little information is present in the literature with regard to this phase of photograph use. Not only may measurements be made from aerial photographs with regard to strike, dip, stratigraphic thickness, and closure, but the regional view of the mosaic or small-scale photographs permits a continuity of photographic criteria that may be of structural or stratigraphic significance. Overall geologic relations are brought together, and areas where detailed study is needed may be indicated. However, the limitations of the photogeologic technique must be constantly borne in mind. As Wheeler and Smith (1952, p. 112) pointed out, the validity of the technique " * * * depends a good deal upon the human element and the utilization of all applicable geologic data." They warned that " * * * the student of photogeology may * * * become overly impressed with geometric design of lines, masses, and tones so that, in the absence of understanding of the tectonic history he may find compatible alignments of stream courses, structurally inexplicable lineations or shapes and soil patterns that are not consistent with the known or expectable products of diastrophism" (1952, p. 112). An emphasis on regional study is indeed justified, however, if maximum use is to be made of aerial photographs, and this is true whether photographs are used in long-range exploration programs, as in reconnaissance mapping of broad basin areas, or in the ultimate study of local structures.

INTERPRETATION OF AERIAL PHOTOGRAPHS IN
SEARCH FOR ORE DEPOSITS

The search for ore deposits, similar to that for petroleum, requires favorable host rocks or structures, or both, and it is therefore necessary to determine the general lithologic character and distribution of rocks and associated structures as a basis for carrying out a mineral survey of an area. Aerial photographs may contribute geologic data not only with regard to the fundamental guides of lithology and structure in ore search, but they also may reveal details of physiography, which may be an important ore guide in the search for placer deposits. Botanical guides to ore bodies may also be detected on aerial photographs of some areas, although little work has been done in this field.

STRUCTURAL GUIDES

Where fractures have been significant in localizing ore deposits aerial photographs may reveal significant structural data relating to trends and offsets of fractures, even in areas where surficial cover is extensive. This is due in large part to the great variety of criteria suggestive of fractures (see p. 21). In many areas it is possible to determine spatial relations of sets of fractures, and to infer the relative ages of the fractures from the aerial photographs, although results of field study are necessary to determine the significance of the patterns.

Aerial photographs are presently most useful in study of those ore deposits associated with fractures. In many mining districts where mineralized fractures form a vein pattern that is repeated throughout the district, an analysis of the fracture pattern and distribution may provide significant data in the search for new ore bodies. Reed (1940) described the use of aerial photographs in a mineral-deposits study of the heavily timbered Chichagof mining district of Alaska where gold-bearing quartz veins are associated with faults and shear zones (see fig. 99). There the faults are commonly expressed as depressions owing to greater erosion of soft material from fault zones (see also Twenhofel and Sainsbury, 1958, p. 1433). Reed (1940, p. 44) stated that many faults of moderate surface expression would probably have been overlooked on the ground, and that many faults of weak surface expression were seen only on aerial photographs. Joliffe (1945, p. 604), in a discussion of photogeologic prospecting in the Yellowknife area of Canada, noted that some of the largest gold-ore bodies " * * * lie in strong shear zones that are marked by rather distinctive gullies in relatively massive, resistant volcanic rocks." Many of these shear zones and other lineaments are conspicuously shown on aerial photographs.

Gross (1951) pointed out that in the glaciated Dryden-Kenora area of northern Ontario and the Goldfields area of northern Saskatchewan, Canada, there are many linear features seen on aerial photographs but that only certain ones represent faults. He devised a scheme of statistical analysis to show the likelihood that certain linear trends were faults (see p. 21). Concentration of prospecting along these linear features in the Goldfields area resulted in discovery of pitchblende deposits.

Because faults commonly are interpreted readily from aerial photographs, photogeologic study may aid in locating extensions of faulted ore bodies. Faults that offset an ore body may show an orderly spatial arrangement, and information regarding direction of displacement may be extrapolated to similar faults whose displacement is masked by vegetation or surficial debris. Willett (1940) found that aerial photographs provide significant information on the location of faults cutting the Invincible Lode, a gold-quartz deposit in the Glenorchy district of New Zealand. The photographs strikingly show the offset of a lode east of the Invincible Lode by a series of parallel faults, which suggest that similar conditions exist at the Invincible Lode where the evidence is not as readily observed because of surficial debris. In the Invincible Lode area one major stream flows parallel to the strike of the faults, and a second stream is deflected along a fault for about 1,000 feet, then bends back to its old course; the direction of deflection also indicates the horizontal direction of displacement of the quartz lode. The pattern of displacement, based on photogeologic evidence together with ground evidence, suggests the location of faulted extensions of the lode.

Major anticlinal and domal structures, readily interpreted from aerial photographs of many areas on the basis of drainage characteristics or strike and dip patterns, are with notable exceptions of relatively little importance in ore search. Where folds have been a factor in localizing ore, as in some metamorphic rocks, they commonly are too small or the geology too complex for existing aerial photographs to provide useful guides in prospecting.

LITHOLOGIC GUIDES

Lithologic guides may be considered from the standpoint of the parent and host rocks, or from the standpoint of mineralized or altered zones, which are more appropriately termed mineralogic guides. Photogeologic interpretation of rock types (see p. 16-19) may outline broad target areas of favorable parent and host rocks (fig. 100). Lueder (1953, p. 823) suggested that various locations can be rated on the basis of

favorable photogeologic evidence; the most favorable area would become the prime target area for further investigation. Where some local field criteria are available, specific ore-bearing formations may be traced on photographs (fig. 98). At Ross Lake, Canada, the fact that rare-earth-bearing pegmatites of small areal extent were recognizable on photographs was a major factor in the discovery of certain tantalite deposits (Joliffe, 1945, p. 604).

The use of color aerial photography will increase many times the amount of lithologic information that can be obtained from a photogeologic study. This additional information will contribute not only to the reliable interpretation of host or parent rocks, but may permit local guides, such as alteration zones, to be readily recognized. In a study of the hydrothermally altered volcanic terrain near Tonopah and Goldfield, Nevada, information obtained from reversible-type color transparencies was contrasted with data obtained from thin sections of rock types. Kent (1957, p. 868) stated that "In both areas a general correspondence between coloration and alteration was observed. Zones of different coloration within a lithologic unit represent different stages of alteration. Colors of rocks in early stages of alteration are useful in recognizing lithology, but highly altered rocks have the same color within several different lithologic units. The colors associated with highly altered rocks are easily recognized on color aerial photographs; thus their distribution and their relationship to structural features can be studied." In addition Ray (1958, p. 37) wrote that "In one area of altered andesites a pale green color on color aerial photographs was found to represent an intermediate stage in the alteration resulting from partial silicification, with pale green chalcedony, and deuteric alteration and later oxidation of iron opaques. A light color in another zone was found to result from brecciation of dacite and attendant alteration to carbonates. A rather intense orange color was indicative of highly altered zones in all localities observed. However, the orange coloration did not indicate the rock type involved nor the type of alteration present, but rather was the result primarily of weathering of iron minerals following their partial breakdown by deuteric alteration."

PHYSIOGRAPHIC GUIDES

Some ore deposits are topographically expressed or are related to structures, rock types, or surficial deposits that are so expressed (fig. 102). Hence, topography may be considered a guide in ore search, although it does not by itself indicate the presence of ore. Because fractures commonly are topographically ex-

pressed as rectilinear depressions, a possible physiographic guide to ore as interpreted from aerial photographs may be said to exist in many areas. Where fractures have been mineralized, and the vein filling stands in relief, topography may be a useful guide in ore search. However, many mineralized veins are poorly resistant to weathering and erosion, and occur as topographically low areas.

Where topography results in a photographic texture it may be possible to delineate areas of favorable host rocks, as the paraschists in Surinam (Zonneveld and Cohen, 1952, p. 155). Grantham (1953, p. 336) pointed out that in the wet Sierra Leone area of Africa, the " * * * sharp change in topography from linearly arranged hills, controlled by schist and migmatite, contrasts with the irregular features of structureless granite."

An analysis of the physiography of an area may provide significant information, particularly in relation to placer deposits. As many placers have a complex history, it may be necessary to work out the alluvial history of a valley or valley system for maximum information in locating placer pay streaks. The arrangement and positions of old stream channels may be interpreted from meander scars, oxbow lakes, and different terrace levels that are commonly seen on aerial photographs. Photographs also may provide gradient measurements of present or past streams; this information may be significant inasmuch as placer concentrations occur especially where stream gradients flatten.

Buried stream channels, also the site of some ore deposits, may be interpreted from photographs of some areas on the basis of topographic expression (fig. 101). In many parts of the western Sierra Nevada, Tertiary stream valleys have been filled and gold-bearing gravel buried by younger lava flows. The greater resistance of the lava flows compared with the surrounding rocks has resulted locally in sinuous cappings of volcanic rocks that stand above the present-day stream system. Table Mountain, California (Loel, 1941, p. 384, 386-387), is an outstanding example of basalt capping auriferous gravel of a buried channel.

The location of stream-channel deposits recently has received wide attention in the search for uranium deposits on the Colorado Plateau in Western United States. There the Triassic Shinarump member of the Chinle formation is thicker in channels cut in the underlying Moenkopi formation, which is also of Triassic age. Some channels can be observed directly on aerial photographs (fig. 44); others may be inferred from isopach measurements, which in some areas may be obtained from aerial photographs. (See p. 58-59). The uranium is associated with carbonaceous materials,

largely plant remains, scattered throughout the channels.

BOTANICAL GUIDES

Much field and laboratory work has been accomplished with regard to plant distribution and plant concentration of certain elements as indicators of ore. Little has been done, however, on plant characteristics or associations that may be observed or interpreted from aerial photographs, and herein lies a field of research that has much potential. There appear to be three aspects of botanical study from aerial photographs that may contribute to the location of ore deposits. These involve (a) color differences in vegetation brought about by concentration of certain chemical elements, (b) species differences or absence of vegetation owing to concentration of certain chemical elements, and (c) distribution of vegetation suggesting favorable structures or rock types. Color differences in vegetation, due to mineral and chemical concentrations, that may be reflected on aerial photographs have received almost no attention, and offer an interesting field of study. Species differences or lack of vegetation has likewise received little attention in ore search, although Walker (1929, p. 50-51) noted that air search was made for "dambos" as indicators of copper deposits in central Africa. Dambos are open spots in the bush cover, where vegetation does not grow because of the concentration of poisonous copper salts in the soils. Walker noted that the Roan Antelope copper deposit was marked by such a dambo, although the deposit extended beyond the limits of open area. Identification of species from color differences due to concentrations of certain chemical elements may be particularly amenable to detection on color or other special aerial photography.

Plant and tree distribution may be useful indicators of structures or of rock types favorable to ore deposition; vegetation distribution may reflect physical characteristics of the rocks, such as porosity or presence of fractures, although some rocks, such as limestone, may be preferentially covered by a certain type of tree because of chemical concentrations in those rocks (see fig. 72) rather than because of physical properties. Or vegetation may grow preferentially or trees grow higher and be aligned along a fault or shear zone, which might in turn be a favorable site for ore deposition (see fig. 71). Such indirect guides in ore search contrast highly, however, with color or species differences, which might suggest more strongly the presence of ore minerals.

Levings and Herness (1953, p. 456-457) stated that heavy timber growth in the Corbin-Wickes area of Montana shows a preference for unaltered quartz mon-

zonite, which has a darker photographic tone than the surrounding andesite and dacite; ore occurs in the volcanic rocks. Zonneveld and Cohen (1952, p. 153) mention that vegetation differences permit photographic differentiation of the clay savannahs and sand savannahs of Surinam, South America. Bauxite production at Surinam's Billeton mine (Hemphill, oral communication, 1958) is from a clay area, and hence it is important to know the distribution of such clay areas.

INTERPRETATION OF AERIAL PHOTOGRAPHS IN ENGINEERING GEOLOGY

Aerial photographs have been used for many years to provide topographic and land-use information in locating routes for pipelines, highways, or other rights-of-way, but only in recent years have photographs attained wide recognition as a source of geologic information for engineering purposes. Many kinds of geologic information for engineering use may be obtained from aerial photographs. These include (a) identification and location of soil materials, particularly granular materials, which would provide suitable foundation sites for industrial and airport developments, or highway rights-of-way; (b) identification and location of clay and clayey silt soils, which would have detrimental properties with regard to building, airport, and highway sites; (c) location of aggregate materials; (d) delineation of areas that may be underlain by permafrost; (e) interpretation of distressed conditions in landslide areas; (f) analysis of structural geology in areas of tunnel, dam, and reservoir sites; and (g) location of sample areas for detailed investigation of soil and rock materials.

SURFICIAL MATERIALS

Surficial materials generally are interpreted in terms of gross physical characteristics, rather than the detailed physical characteristics used by the pedologist. Knowledge of the gross physical properties is sufficient for many reconnaissance studies in engineering geology. Indeed, it is the grouping of several pedologic soil types into a few classifications that permits aerial photographs to be of significant engineering use. In the preparation of soil-engineering maps from agricultural reports of an area in Illinois, Thornburn (1951, p. 91) was able to reclassify 99 different pedologic soil types into 13 engineering groups. Lueder (1951) described the use of aerial photographs as a major tool in preparing soil-engineering maps.

The inability to interpret fine details with regard to physical characteristics of the soil thus does not preclude the use of aerial photographs in many engineer-

ing geology studies. From the standpoint of engineering significance a granular material, for example, which exhibits certain diagnostic photographic characteristics such as coarse-textured drainage, will generally react favorably to drainage, compactability, and other engineering tests, regardless of whether it is a residual granular material that has resulted primarily from weathering in place or whether it is a transported gravel derived from different rock types. However, Jenkins, Belcher, Greeg, and Woods (1946) pointed out exceptions to the general thought that photographic characteristics common to granular materials always signify suitable granular materials for engineering purposes. For example, the soil profile of well-drained limestone has a granular texture due to aggregation of clay particles into lumps. The surface drainage may be coarse textured; but the soils break down on compaction and react as plastic soil material, and not as a granular material (Jenkins, Belcher, Greeg, and Woods, 1946, p. 80).

Where pedologic data are already available they may be very useful to the engineer when interpreted in terms of engineering test data (fig. 4). Indeed, certain soil mechanics tests by the engineer, such as plasticity or soil-texture tests, are similar to those used by the pedologist. Greenman (1951) suggested that the pedologic method can become the nucleus around which aerial photo interpretive and field geologic information can be accumulated. But Eardley (1943, p. 567) pointed out that "In many places conditions unfavorable for the development of a normal soil, such as rugged mountains, wide sandy plains, or swampy basins may cover rather large areas. The important construction materials in such places may be better interpreted as a result of geological processes than from the standpoint of a soil classification * * *."

GROUND CONDITIONS

The interpretation of ground conditions probably has received more attention in recent years than any other engineering geology application of aerial photographs. Much of the literature concerns reconnaissance studies of soils in general and granular materials in particular; granular materials are essential for building sites and highway and airport development (Jenkins, Belcher, Greeg, and Woods, 1946; and Purdue University, 1953). Special attention also has been given to photointerpretation of permafrost conditions in northern latitudes.

With regard to highway engineering, Belcher (1945, p. 144) stated that "* * * the soil problem resolves itself into two parts, one in which the soil in place is satisfactory as subgrade, and the second, where the soil is unsuitable. In areas of unsuitable soils some form

of improvement, by stabilization or insulation, is required. Insulation involves the economic location of granular materials in the form of rock to be crushed, cinders (volcanic), or sand and gravel * * *. Inasmuch as sand and gravel or other granular deposits exist to some extent in nearly every county in the country the significance of soil patterns indicating granular materials is of considerable economic importance to engineers." In fact, a large percentage of construction and maintenance expenses are in the costs of sand, gravel, crushed rock, and similar materials. As a tool for interpreting areas of gravel, sand, silt, and clay, aerial photographs offer an inexpensive and rapid method of reconnaissance, and according to Schultz and Cleaves (1955, p. 370) "* * * planning and exploration for large engineering projects should almost never be undertaken without a thorough study of aerial photographs of the region * * *."

Photointerpretation of surficial materials must consider not only the surface expressions of these materials but also the geologic factors reflecting the origin of these materials. A knowledge of the origin of materials permits inferences as to what kind of materials can be expected in an area, and in what locations with respect to other geologic features. Field-sampling programs also could be based on the analysis of the photo-geologic data, and subsequent mineralogic and related studies by the engineering geologist could provide the soils engineer with information that would eliminate the need for many of the soil mechanics tests now performed as part of the routine laboratory analysis of all soil samples.

ELEMENTS OF SOIL PATTERN

The surface expressions of granular and other soils materials have been termed collectively the "soil pattern." The soil pattern consists of several elements of which the most important ones for nonpermafrost areas are considered to be landform, drainage, erosion, relative photographic tone, and color; vegetation cover and land use may also be significant (Belcher, 1944, 1945, 1948; Jenkins, Belcher, Greeg, and Woods, 1946; Frost, 1946; Mollard, 1947; Hittle, 1949; and Purdue University, 1953). Schultz and Cleaves (1955, p. 371) considered that "interpretation of soils by means of aerial photographs rests largely on the interrelationships of soils and geomorphic features"; consequently landform is considered by some to be the most important element in photointerpretation of soils. Landform, however, is only one element of the soil pattern and it is clearly evident that the association of several elements of the soil pattern will provide the greatest amount of information from aerial photographs.

Landform

Identifying the landform commonly identifies the natural process that formed it, and commonly limits the type of soils or soil characteristics that can be expected. The emphasis on landform is probably valid in reconnaissance soils investigations where broad areas of several different landforms are studied and mapping is at a small scale. But where detailed engineering information is needed, as in foundation studies, it is likely that the area of study will be within one landform, mapping will be on a large scale, and other elements of the soil pattern, such as differences in relative photographic tone, which may reflect soil-moisture content, will be of prime importance.

In small-scale mapping the emphasis on landform is probably warranted particularly for constructional landforms of transported materials, such as sand dunes, river terraces, alluvial fans, and many glacial landforms, all of which have distinctive shapes, although not necessarily unique (see figs. 52, 55-57, and 104); here the transported soil materials make up the landform. In contrast residual soils associated with destructional landforms may be more difficult to interpret from aerial photographs, for here the parent rock makes up the landform, and the significance of soils rests in part on the subjective interpretation of rock types. However, the interpretation of other elements of the soil pattern with regard to physical characteristics of soils are just as valid for residual as for transported materials; the engineering significance of many residual soil areas can be interpreted readily from aerial photographs on the basis of these other elements, such as drainage and erosional characteristics (figs. 63 and 65).

Drainage characteristics

Highly permeable soils will have good drainage regardless of their origin, provided that topographic positions will permit draining. In well-drained soils surface drainage normally will be coarse textured or even absent (figs. 49, 52, 66, 104, 106, and 108); in soils of low permeability drainage will normally be fine textured (fig. 63) or ponds may be numerous (figs. 57 and 66). The presence of fine- or coarse-textured drainage in surficial materials, like that in bedrock (p. 16), is primarily related to the relative resistance of the different materials to erosion, and hence related to permeability and grain size. Coarse materials characteristically are resistant to erosion, are permeable, and have a coarse-textured drainage; fine materials commonly are less resistant to erosion, are impermeable, and have a fine-textured drainage. These relations are significant in the interpretation of engineering soils from aerial photographs because drain-

age texture can be readily observed. However, exceptions to these relations may exist, as with loess, which is commonly characterized on aerial photographs by a relatively fine-textured drainage (see figs. 105 and 106); yet, loess in its natural environment is generally considered well drained internally.

Flow or channel markings, for example on terraces, indicate that the material was deposited by running water and further suggest that the material may be granular. Frost (1946, p. 121) described flow markings in an area in the midwest as consisting of light and dark streaks usually parallel to the direction of flow. The light streaks are ridges of sand or fine gravel that are probably sand and gravel bars; the dark streaks are fine clay or organic material deposited in depressions that once contained standing bodies of water. Frost (1946, p. 121) stated that "The chief significance of such markings lies in the fact that they suggest stream deposition and in order to have stream deposition at such elevated positions and occurring on * * * a large scale, there must have been large volumes of swiftly flowing water. Since swiftly flowing water allows only coarse material to settle, the terrace must contain a large percentage of gravel." It may be debatable that channel markings always indicate swiftly flowing water, but where some doubt exists other elements of the soil pattern may reveal the character of the terrace material.

In broad areas of aggradation, such as the Mississippi embayment, drainage characteristics revealed by aerial photographs are significant to the engineering geologist, as different soil characteristics are associated with the several features of valley alluviation. For example, backswamp areas contain clay and silty clay of high organic content, whereas natural levees consist of silt, silty sand, and some silty clay (Fisk, 1944, p. 18, 20). The levees commonly " * * * provide linear patterns of higher ground supporting distinctive vegetation growths" (Tator, 1951, p. 717). Low areas may be swampy and also contain distinctive vegetation. Graveliferous deposits fill the old valleys and in turn are covered by various other deposits; sandbars contain permeable sand that grades downward into the gravel. The distribution of features of the flood-plain drainage may be significant in analyzing ground conditions and locating favorable engineering materials in highway, railroad, and airport development.

Erosional characteristics

Closely related to the drainage characteristics of a soil are its erosional characteristics; these are important in photointerpretation studies chiefly from the standpoint of gully erosion, which is controlled largely by the physical properties of the soil and especially by

cohesion. The usefulness of gully erosion characteristics in photointerpretation primarily involves the shape of transverse profiles, although longitudinal profiles may provide additional information. According to research workers at Purdue University (1953, p. 15-16) " * * * there are three basic gully characteristics which are associated with three major soil textural groups." Granular soils commonly develop sharp, V-shaped gullies that have short, steep gradients. Nongranular cohesive and plastic soils are generally indicated by uniform gentle gradient of gullies that extend well back into the upland, and by broadly rounded shallow V-shaped transverse profiles. The loess soils and sandy-clay soil exhibit U-shaped cross sections of gullies that have flat bottoms and low gradients.

Although there may be a general adherence of gully characteristics to the major soil textural groups, exceptions are not uncommon. For example combinations of the basic gully characteristics " * * * occur in 'layered soils' or in soils exhibiting a 'strong profile'". (Purdue University, 1953, p. 16), and compound gradients may develop. In addition to the steep or vertical slopes in deep gullies, windblown silt may develop silt pinnacles and catsteps or terracettes (Purdue University, 1953, p. 45). It has been pointed out (Purdue University, 1953, p. 27) that climatic environment under which gullies form is an important consideration; for example, soft clay shale in an arid region where flash floods may occur commonly exhibit abnormally steep slopes in contrast to clay shale in areas of uniform rainfall where such slopes are usually softly rounded. Under certain conditions, such as gravel capping on clay soils in the New Jersey coastal plain (fig. 108), gullies in the underlying clay soils may be steep and deeply incised, in contrast to the usual broad shallow transverse gully profile of the clay soil group in humid regions.

In permafrost areas different materials may yield the same cross-sectional profile. Gravel deposits cemented by ice may have vertical gully walls, or may have gullies that are asymmetric in cross section if one side is preferentially exposed to the sun and thaws at a faster rate than the shadow side. The insulating materials overlying frozen deposits also affect the rate of thawing and hence the erosional characteristics of gullies. Interpreted carefully, however, the erosional characteristics—gully cross section and gradient—may reveal useful information on texture and other engineering characteristics of the soil.

Photographic tone

On black-and-white photographs the significance of color must be interpreted in terms of relative gray photographic tones. Belcher stated (1948, p. 486) that

"Light color tones (grays) are usually associated with well-drained soils, while clays, principally because of their water-retention capacity, appear dark." Frost (1946, p. 122), in describing the mottled soils in Indiana, stated that mottling nearly always indicates gravel. The mottling is due to "dark areas" which are " * * * small clay-like pockets that have been formed by the normal weathering processes of the gravel-sized material" (Frost, 1946, p. 122). These pockets are depressions that " * * * act as small infiltration basins which result in a higher moisture content and a darker color pattern" (Frost, 1946, p. 122). This mottled soil pattern contrasts with that of the drift plains in other areas where light-toned patches of slightly higher and dryer silty soils adjoin lower areas of wet plastic silty clays. Somewhat similar mottled patterns have been described by Gwynne (1942, p. 202-205) from the drift plain in Iowa (see fig. 107). But light photographic tones also may result from lack of moisture, owing to lack of precipitation as in many arid regions, rather than because of good drainage, and thus tone may be of little significance in evaluating soil texture in some areas. Or light tones may be the result of topographic position, and it is probable for example that a " * * * sand dune on a sand plain in a humid region will photograph light in color against a dark background" (Purdue University, 1953, p. 26) not because of differences in soil textures but because of topographic position. Climatic conditions also influence the colors of soils, especially the residual soils, and dark color rather than light color may be associated with well-drained materials, as certain red soils developed from limestone (Jenkins, Belcher, Greeg, and Woods, 1946, p. 84). Yet, provided climatic conditions are considered and provided relative photographic tone is borne in mind, the generalization that light photographic tones suggest good drainage and dark tones poor drainage may be useful in the overall interpretation of soils with regard to moisture content. Where tone is due to moisture, infrared photography will result in strong tonal contrasts between soils of different moisture content.

Color

Color has been cited as a principal element of the soil pattern that may yield information on the texture and drainage character of the soil profile, but to date very little interpretive work has been done with color photography. Belcher (1945, p. 138) briefly mentioned experimental color photography taken in different parts of the United States and stated that "The value of color * * * lies in the added detail that it furnishes with respect to these two elements of the soil pattern" (that is, soil color and details of vegetative cover). It

would seem that color photography would reveal pedologic information significant in engineering evaluation of soils, especially the residual soils, which may be more difficult to interpret in general than transported soils, particularly from black-and-white photographs.

Vegetation

Vegetation as an element of the soil pattern has been considered one of the most difficult to interpret. It is known, for example, that certain trees, such as aspen, are tolerant of many different soils and soil conditions, but some types of vegetation are strongly influenced by soil type. Furthermore, vegetation may be influenced significantly by climatic factors. Where permafrost is close enough to the surface to affect tree and shrub roots the kind of vegetation that will grow may be restricted (see p. 37). Species identification may be difficult in any area unless large-scale photographs are available or unless pure stands are present. Nevertheless, vegetation may reveal significant information in engineering studies provided valid interpretations are made with regard to how vegetation is associated with soil textures, soil-moisture content, and topography; thus a knowledge of plant ecology is necessary if maximum information on soil conditions is to be obtained from aerial photographs. Willows, for example, indicate wet ground, poplar indicates dry ground, and jack pine implies sand and gravel beds (Belcher, 1945, p. 139). However, where abrupt changes in soil conditions exist, it is likely that vegetation changes will also occur (figs. 56 and 72), and areas needing further ground surveys may be easily delineated by inspection of aerial photographs without any basic knowledge of plant ecology. For example, stabilized sand dunes in interior Alaska can be easily delineated because they are marked by stands of dark-toned spruce (see fig. 56), in contrast to light-toned brush and grass of the interdune areas. This relation may be found where the topographically higher, well-drained sand of the dunes contrasts with frozen silty deposits of the interdune areas.

Where phreatophytes—plants and trees that obtain water from the water table—can be delineated (see p. 40), aerial photographs may provide significant engineering data because phreatophytes may choke overflow channels and thus increase the flood potential of some areas. Information pertaining to the downstream de-silting effect of phreatophytes with regard to dams and reservoirs may also be obtained from aerial photographs of some areas (see Robinson, 1958, p. 28-29). However, little interpretative work in this field has been done.

Land use

Land use may also reveal information on the soil conditions of an area. Belcher (1945, p. 142) reported that "Orchards thrive in well-drained locations and therefore, when observed on level ground, good sub-drainage is implied." Shallow drainage ditches in areas of little relief commonly signify plastic, poorly drained soils. Schultz and Cleaves (1955, p. 378) stated that in eastern France and western Germany " * * * rugged topography and associated sandy soils developed on sandstones are generally left in forest; the comparatively level topography and associated clayey soils developed on shales and limestones are cultivated * * *." On the flood plain of the Mississippi River the silty sand of the natural levees is cultivated primarily because of its topographic position above the lower backswamps. In parts of the Valley and Ridge province of Eastern United States the limestone areas commonly are farmed whereas shale areas may be left in forest.

PERMAFROST

Permafrost has a significant effect on engineering characteristics of soils of the far northern latitudes and has received considerable attention in recent years, particularly from the standpoint of photointerpretation (Cabot, 1947; Woods, Hittle, and Frost, 1948; Benninghoff, 1950; Frost and Mintzer, 1950; Frost, 1951; Sager, 1951; Black, 1952; Hopkins, Karlstrom, and others, 1955). Considerable disagreement exists, however, on the significance of photointerpreted data in the study of permafrost areas (see Black, 1952, p. 126-127, 129), although it is generally agreed that aerial photographs can be particularly useful in such studies. The following discussion of ground conditions in permafrost areas is taken from the work of Hopkins and Karlstrom (Hopkins, Karlstrom, and others, 1955), except as noted by specific references.

Muller (1947, p. 219) defined permafrost as "a thickness of soil or other surficial deposit or even bedrock, at a variable depth beneath the surface of the earth in which a temperature below freezing has existed continuously for a long time (from two to tens of thousands of years)." Muller (1947, p. 30) also stated that "From the standpoint of engineering, the content of ice in frozen ground is of paramount importance * * * [because] * * * thawing of this ice produces excessive wetting and undesired plasticity of the ground and renders it unstable and susceptible to settling, caving, and even flowing." Building foundations, highways, railbeds, and airport runways may be considerably damaged unless the presence of permafrost is taken into consideration and measures taken to eliminate or minimize the effect of the thawing that results from

the disturbance of the natural thermal regimen. Where bedrock or thick frozen gravel deposits that contain local drainage channels are the primary foundation materials, permafrost is not normally detrimental to construction.

Although aerial photographs are useful in the interpretation of areas that may be underlain by permafrost, criteria used for interpreting soil conditions of nonfrozen areas apply only to a limited extent to permafrost zones. Gully characteristics of an impermeable gravel deposit cemented by ice, for example, will not necessarily be the same as the characteristics of gullies in impermeable nonfrozen soils. Because of the altered permeability and porosity of soils owing to permafrost, erosional characteristics, as applied to the interpretation of nonpermafrost areas, may have little significance in the perennially frozen regions. Other criteria, such as the common landforms, although suggestive of type of material present, are of limited use in determining the presence or absence of permafrost. Few diagnostic indicators of permafrost appear to exist. More often than not the criteria are suggestive rather than indicative; they include distribution and type of vegetation, polygonal relief patterns, pingos, and features resulting primarily from thawing.

Distribution and type of vegetation

Distribution patterns of trees and shrubs commonly supplement topographic expression in recognizing landforms; these patterns may contribute indirectly to the interpretation of probable permafrost conditions based upon inferences concerning the age of the land surface, climate, and character of the underlying material. In addition, the type of vegetation may be useful in delineating areas where permafrost is likely to be present. Hopkins and Karlstrom (1955) reported that recognition of shallow-rooted species on aerial photographs aids in delineating the areas where permafrost is most likely to occur at shallow depth, and that recognition of deep-rooted species helps delineate areas least favorable for the formation or preservation of permafrost. Thus, black spruce may suggest areas underlain by permafrost at shallow depth, whereas tall willow shrubs and isolated pure stands of balsam popular on river flood plains generally indicate unfrozen ground. The distribution patterns of trees and shrubs, however, are most significant only when evaluated together with other information, such as type of landform, concerning permafrost distribution in the region under study.

Polygonal relief patterns

Polygonal relief patterns commonly can be identified on aerial photographs, but as they may be present

in both permafrost and nonpermafrost areas this criterion is not, by itself, always diagnostic in evaluating permafrost conditions; however, in conjunction with other features it may be very significant. Polygonal patterns may be divided into two broad groups: those formed by frost-stirring and those formed by contraction. The formation of frost-stirred polygons is favored by the presence of permafrost at shallow depth, but these polygons are not necessarily an infallible indicator of shallow permafrost as they are also known to occur where permafrost is absent or is at a considerable depth.

Contractional polygons are subdivided into low-center, high-center, and frost-crack polygons. Low-center polygons, one of the most dependable indicators of permafrost, are commonly found in poorly drained depressions. The presence of pools of water in the centers of some polygons is a diagnostic recognition feature, and it is common to find low-center polygons expressed on aerial photographs as dark-toned centers surrounded by light-toned marginal ridges (figs. 109–112). High-center polygons occur in slightly better drained areas than those in which low-center polygons are found; generally, the centers are relatively level, although they may be domed where frost is extremely active. In contrast to low-center polygons, drainage around high-center polygons is commonly concentrated in marginal trenches, and pools of water are present at trench intersections. Because of the high centers, these polygons are commonly expressed on aerial photographs as light-toned centers surrounded by dark-toned margins (figs. 40 and 109–112). Frost-crack polygons may be difficult to distinguish on aerial photographs, as they are similar to high-center polygons; they may be present in some areas where permafrost is absent.

Other relief patterns in conjunction with vegetation distribution result in striped slopes that are commonly present in permafrost areas (fig. 40).

Pingos

Pingos are rounded or elliptical steep-sided hills formed by the “downward freezing of a body or lens of water or of semi-fluid mud” (Muller, 1947, p. 59). They may be as much as 300 feet high. Fissures may develop along the axis of a pingo or radiate from the crest. Pingos usually are found in poorly drained areas and normally are readily distinguished on aerial photographs by their distinctive local landform (figs. 110 and 111); they are almost always a reliable indicator of permafrost, although locally they may be confused with erosional knolls or hills.

Features resulting from thawing

Two features associated with thawing are suggestive of the presence of permafrost. These are thaw lakes (sometimes called thermokarst lakes) and beaded drainage. Thaw lakes occur in frozen fine-grained sedimentary deposits that generally contain clear lenses and masses of ice whose volume is greatly in excess of the porosity of the unfrozen material. As this ice melts the ground subsides and forms a basin in which a thaw lake may accumulate (figs. 110 and 111). When caving is progressing, banks are ragged and steep or overhanging. Tilted trees known as “drunken forests,” along the margins of such lakes are indicative of active caving. In treeless areas active caving may be indicated by tension cracks parallel to the banks. Other indications of thawing, such as serrated margins of lakes, also may be present (figs. 109–111). The usefulness of thaw lakes as permafrost indicators, however, is limited by the difficulty of distinguishing on aerial photographs between active thaw lakes, relict thaw lakes, and similar-appearing lakes that are in no way related to permafrost.

Beaded drainage occurs particularly in perennially frozen peat and silt containing ice wedges; it is characterized by small pools connected by short water-courses that may be sharply incised (figs. 40 and 112). The pool banks commonly are steep as a result of thawing and caving of frozen materials.

Absence of permafrost

In areas of discontinuous permafrost it is not only desirable for the engineer to know where permafrost is present, but it may be equally important to determine where permafrost is absent. Certain hydrologic phenomena and elements of the soil pattern commonly indicate or suggest the absence of permafrost. For example, subterranean drainage in unfrozen zones within permafrost may be detected on aerial photographs of some areas. The recognition criteria are in part similar to those applied in evaluating soil conditions in nonpermafrost areas of the world. That is, streams may disappear into the bottoms of closed depressions or by percolating into a gravel-covered surface. In addition, the presence of dry depressions in permafrost areas may indicate locally well-drained areas, inasmuch as there is generally a source of water during the summer months. Such areas contrast with other areas of the earth's surface where dry depressions may be due to absence of precipitation or other immediate source of water. Locally unfrozen zones within permafrost areas may also be suggested by springs, which are commonly indicated by flood-plain icings; shown as flat, white surfaces on some aerial

photographs, or indicated by more luxuriant vegetation along a pronounced lineation or within a dark-toned area on low hill slopes. These unfrozen zones may be favorable as a source of ground water. In addition, because permafrost generally causes soils to be impermeable, drainage characteristics indicative of permeable materials (see p. 34) may be interpreted to mean lack of permafrost, at least in the immediately underlying materials. Certain tree species may also suggest absence of permafrost (see p. 37).

EROSION, TRANSPORTATION, AND DEPOSITION

LANDSLIDES

Natural movement or potential movement of materials is a significant consideration in many construction engineering problems. Foremost in this regard is the movement of soils and rock materials by landslides. Ritchie (1958, p. 67) stated that "All landslide investigations must start with recognition of a distressed condition in the natural or artificial slope * * *." Distressed conditions are commonly interpretable from aerial photographs. "The evidence for distressed conditions that may be present, or that may be induced, lies chiefly in evidence of movements, minor or major, that have already taken place or of geologic, soil, and hydrologic conditions that are likely to cause movement in the future" (Ritchie, 1958, p. 67). Geologic, soil, and hydrologic conditions signifying potential landslide areas include the presence of unfavorable geologic structures and rock type, prevalence of fine-grained materials, and an abundance of water or conditions that would permit access of water to fine-grained materials.

Because remedial measures for landslides or prevention of landslides are generally not only difficult but costly, avoidance of landslide areas is important in highway route layout. Existing landslides are commonly identified on the basis of landform (figs. 46 and 113). Liang and Belcher (1958, p. 70) stated that some landforms are more susceptible to landsliding than others, and thus identifying the landform is highly important. "Potential slides of the rockfall and soilfall type can commonly be foreseen simply by recognizing geologic conditions that are likely to produce overhanging or oversteepened cliffs" (Ritchie, 1958, p. 51). Basalt cappings underlain by easily eroded shale (figs. 53, 87, and 113) illustrate a condition where rockfalls may occur as a result of failure and slump in the underlying materials.

Movement of unconsolidated materials by flowage is likely to produce the most damaging landslides. Existing flows and slides (figs. 46 and 113) commonly have a "hummocky" surface. Landslide scars, where

soils and vegetation have been stripped off the bedrock, may be easily recognized on aerial photographs by the light photographic tone of the bedrock in contrast to darker tones of surrounding areas. Areas of potential flow of unconsolidated materials may be revealed by tension cracks or crevices, or suggested by the presence of seepage zones or springs, shown by dark tones of dense or luxuriant vegetation or by dark tones of the soil.

Ritchie (1958, p. 50) warned, however, that although aerial photographs are of significant help in developing the setting for detailed studies, they seldom contain the detail needed by the engineer to carry out preventative or remedial measures. The prime application of aerial photographs in landslide studies appears to be in interpreting ground conditions to determine areas that should be avoided in highway route layout and similar problems.

BEACH EROSION

In a shoreline study in California, Munk and Traylor (1947) showed that variation in wave height and refraction of waves along the shore was controlled in part by sea-floor topography. Where refraction causes a convergence of waves the rate of shoreline erosion may increase. Krumbein stated (1950, p. 203) that "Refraction diagrams are becoming an essential part of any study concerned with shore processes, and graphic methods have been developed for preparing them from hydrographic charts or aerial photographs." Photographs taken periodically of shoreline areas would also provide information, both qualitative and quantitative, in studies of erosion and deposition, which might thus be useful in planning remedial action against the eroding currents. In a study of shoreline erosion by the U.S. Army Corps of Engineers (U.S. Beach Erosion Board 1946, p. 13) aerial photographs taken in 1941 were compared with land surveys of 1836 to obtain rates of erosion along the shore of Lake Michigan. The rate of erosion plays a significant part in planning corrective measures for eroding currents.

BEDROCK

GEOLOGIC STRUCTURE AND TYPE OF ROCK

Because of the influence that faults may have on construction design and costs, it is important that faults be located and studied in the beginning stages of an engineering project. Aerial photographs may provide significant information in this regard as some faults are recognized from subtle expressions on photographs but are identified only with difficulty on the ground. The usefulness of photographs in mapping a proposed damsite in southeastern Alaska is shown in a

study of the Swan Lake area (fig. 114) where faults stand out in aerial view as conspicuous lineations, which are primarily reflections of rectilinear depressions on the ground. In a damsite study in Malaya, Alexander and Proctor (1955) used large-scale aerial photographs taken 750 feet above the ground. These photographs showed clearly the attitude and distribution of faults and joints in granitic country rock. In connection with the San Jacinto tunnel project in California, Henderson (1939) noted that aerial photographs revealed indications of unsuspected faults and corroborative evidence of those previously suspected. Fault locations underground were found to be close to that predicted from study of photographs.

In addition to showing faults, aerial photographs commonly shown dipping beds that are important in some foundation studies for pier and abutment location. Or dipping beds may indicate potential rock-slide conditions where the dip is in the same direction as the hill slope.

Lithologic characteristics of bedrock materials are also significant in many engineering problems, as in foundation work, or in locating road metal sources. Criteria useful for interpreting the general lithologic character of rock types from aerial photographs are discussed on pages 16-19.

INTERPRETATION OF AERIAL PHOTOGRAPHS IN HYDROLOGIC STUDIES

LOCATING POTENTIAL GROUND-WATER SOURCES

Little has been written on the interpretation and uses of aerial photographs specifically in hydrologic studies, although photogeologic techniques offer both practical and research applications in this field. Practical application of aerial photographs in hydrologic study are at present confined largely to assisting the geologic mapping in ground-water investigations, particularly in areas covered by surficial materials. As an aid in ground-water mapping, elements of the soil pattern are evaluated in terms of ground conditions, just as in many engineering geology studies (see p. 34-37). Thus, for example, coarse-textured drainage or absence of drainage may signify highly permeable materials (figs. 52, 66, 88, 104, and 105B; and p. 34-35) or the landform (figs. 52 and 104) may suggest the kinds of materials that compose it, which permits an evaluation of permeability and porosity and potential as a water reservoir. In addition, aerial photographs may reveal information directly suggesting the presence of water, such as a preferential distribution of vegetation at the margins of a gravel cap (see figs. 104 and 108). The type of vegetation in turn may permit inferences with regard to the general quality

of water. For example, salt cedar is tolerant of relatively high content of salt in water, whereas cottonwood trees are intolerant. Howe (1958) described briefly the use of aerial photographs with specific reference to locating possible water-bearing formations.

WATER-LOSS STUDIES

In a study of water loss caused by phreatophytic plants and trees, which take their water from the water table, Turner and Skibitzke (1952) used aerial mosaics and contact prints for delineating areas of different densities of phreatophytes. The areas were then measured by planimeter and used in conjunction with vertical foliage density, determined by field methods, to arrive at volume density to which water loss by transpiration for specific species could be equated. Data pertaining to tree species and heights were determined by ground methods. Turner and Skibitzke (1952, p. 67) stated that "The comparison between results obtained by air and by ground mapping led to the conclusion that the former offers a much faster and more accurate method, particularly in areas of dense growth." Further use of aerial photographs in collecting basic data for studies of water loss by phreatophytes could probably be made. For example, it may be possible to determine tree or plant species, especially when large-scale black-and-white photographs are available or where color photographs have been taken. In addition, for many areas where the ground surface can be observed through the trees, photogrammetric measurements may provide rapidly those height measurements needed in water-loss studies. For areal measurements of differing vegetation types or densities a simple dot-templet method may be useful (Wilson, 1949). Like many other studies, however, where vegetation and ground features must be observed, measured, and plotted, maximum use of aerial photographs will result from combined use of field and photogeologic methods.

OTHER APPLICATIONS

Aerial photographs as a tool in hydrologic studies provide a medium for obtaining basic data, such as cross-section profiles, linear, areal, slope, and volume measurements. Some of the suggested uses of photogrammetric techniques in hydrologic studies are: (a) for definition of channel size and shape of cross section to be used in studies of the effect of channel geometry in flood characteristics of streams; (b) for determining channel storage capacity used in flood-frequency correlations; (c) for definition of the three-dimensional sinuosity of natural channels to be used in studies of the rate of energy loss; (d) for definition of the geometry of bed roughness of alluvial channel

models (Thompson, 1958); (e) for measuring topographic characteristics of drainage basins such as stream slopes and drainage density; and (f) for determining areas of lakes and swamps in water-storage studies.

INSTRUMENTATION

Instruments in photogeologic study serve three objectives, namely, interpretation, measurement, and plotting of data. The instruments used thus may be photogrammetric or nonphotogrammetric—photogrammetry is the art of making reliable measurements from photographs. Usually different instruments are used for attaining each of the three objectives, as, for example, in using a stereoscope, parallax bar, and radial planimetric plotter, respectively. But all three operations may be combined in a single piece of equipment, such as the Kelsh plotter (fig. 18). Whether interpretation is done with a simple stereoscope and paper prints or with a precision stereoplotting instrument using glass-plate diapositives, the criteria of recognition, described in the first part of this paper, remain the same except insofar as scale and resolution of photographic details are involved. Both measurement and plotting are here considered as mechanical aids that provide quantitative information to be further used in geologic interpretation of an area, and instruments are discussed primarily with this objective in mind.

Measurement involves (a) the determination from aerial photographs of vertical and horizontal distances, which in turn are used to compute stratigraphic thicknesses, angles of dip, and other quantitative data of geologic use; (b) the direct determination of inclined distances, commonly the stratigraphic thickness of a formation; (c) the direct determination of angles of slopes or beds; and (d) other quantitative determinations of possible significance in geologic interpretation, such as light-transmission measurements.

Plotting primarily involves the orthographic positioning of geologic data from aerial photographs to base maps or compilation sheets. It also involves direct plotting of geologic data in cross-sectional views, and may include positioning data such as geologic contacts, which are not directly recognizable in the stereoscopic model, by use of the floating dot or spatial reference mark that is found in many photogrammetric instruments.

KINDS OF INSTRUMENTS

Many different photogrammetric instruments are available for making measurements and plotting geologic data to base sheets or cross-sectional profiles (see Fischer, 1955; Ray, 1956; Pillmore, 1957; and Hemp-

hill, 1958a). Certain instruments permit only the measurement of altitude differences, others permit only the orthographic positioning of geologic data, but many instruments are used for both measuring and plotting. Most measuring and plotting devices are designed to accommodate standard 9- by 9-inch photographs; enlarged photographs can be used with only a few instruments, such as the overhead projector, in transferring data to a base sheet.

MEASURING DEVICES FOR USE WITH PAPER PRINTS

One of the most commonly used and widely available types of instrument for determining altitudes from paper prints of aerial photographs is the stereometer or parallax bar. Several varieties of stereometers are available for use with either the lens or mirror-type stereoscope (see fig. 10); they consist of two small plates, usually of glass or plastic, that have inscribed dots, or other targets, that can be centered over conjugate image points in a stereoscopic pair of photographs. The plates are attached to a supporting bar along which they may be separated horizontally. The supporting bar generally has graduated readings in millimeters or inches and a slow-motion adjustment drum that permits readings of hundredths of millimeters or thousandths of inches. All stereometers are based on the "floating-dot" principle, where two target dots, one seen with each eye, are fused stereoscopically into a single dot that appears to float in space within the stereoscopic model. The apparent height of the single fused dot, used as a reference mark in determining altitude differences, is related to the horizontal separation of the individual dots being viewed. Thus by measuring the horizontal separation between individual dots when the fused dot in the stereoscopic model is placed at the top of an object (such as a hill or cliff) whose height is to be determined, and subtracting from it the measurement of the horizontal separation between individual dots when the fused dot is placed at the bottom of that object, a measure of the height, called differential parallax, is obtained. Differential parallax is converted to feet by simple mathematical calculations (see p. 53). Stereometers are thus merely devices that permit reliable measurement of differences of horizontal distances between two or more pairs of conjugate image points as seen on two photographs that form a stereoscopic pair.

Parallax ladders also may be used for determining differences in altitudes from aerial photographs. Like the stereometer, the parallax ladder is based on the floating-dot or floating-line principle. The instrument may consist of two diverging rows of dots on plastic or glass arms; thus, a series of pairs of dots exist with

different horizontal separations, and this in turn results in several floating dots all at different altitudes within the stereoscopic model (see fig. 12). Or the instrument may consist of two diverging lines with intercepts of specific horizontal separations ticked off; thus a single plunging line would be seen in stereoscopic view. The instrument, oriented at right angles to the flight line, is used by sliding it over the stereoscopic model until a pair of dots or line intercepts—seen stereoscopically as a single dot or cross in space—appears to fall on the base of the object whose height is to be determined. A reading of the horizontal separation of the two dots or intercepts is then made. The parallax ladder is moved until a different pair of dots or intercepts—also seen stereoscopically as a single dot or cross in space—appears to fall on the top of the object whose height is to be determined. Again a reading of the horizontal separation of dots or intercepts is made. The difference in readings obtained is then used in a simple formula to determine the difference in altitude of the two points (see p. 53). A direct-reading parallax ladder that eliminates the need for most of the mathematical computation has also been devised. The differences in horizontal separation of pairs of dots has been calculated by the manufacturer in terms of heights in feet for different flying heights and photobases, and this permits a direct reading of relative altitudes within the stereoscopic model.

Also for use with paper prints is a stereo slope meter, designed primarily for determining degrees or percentage of slope. The instrument consists of two transparent disks each scribed with eccentric circles of specific diameters (fig. 11). These disks are mounted in a frame so as to be movable horizontally in a fashion similar to the dots of the stereometer. In stereoscopic view the two sets of eccentric circles appear as a cone that is divided into several zones. By proper horizontal spacing of the two disks, the resulting cone seen stereoscopically can be raised or lowered so that some two circles will rest on the slope or grade to be determined. By appropriate simple calculations the slope can be determined. Center dots present on each of the transparent disks also permit relative altitudes to be determined just as with a stereometer.

PLOTTING DEVICES FOR USE WITH PAPER PRINTS

Instruments have been designed specifically for plotting information from paper prints to base maps or control sheets. An instrument widely employed in the past is the sketchmaster (fig. 13), which uses the camera-lucida principle in transferring data from the photographs to the base sheet. The sketchmaster

allows the operator to view a single photograph image superposed on the base map. Adjustments for scale changes in the perspective photograph permit coincidence or near coincidence of photograph control points and base-map control points. Geologic detail is sketched directly on the base map. This instrument can be adjusted to remove small amounts of tilt inherent in some vertical photographs, but like any direct-reflecting projector, large amounts of radial displacement due to relief cannot be effectively removed.

The radial planimetric plotter has been devised especially for transferring photographic detail to a base map or control sheet. Unlike the sketchmaster, this instrument is designed to eliminate displacement due to relief. The plotter consists of a mirror stereoscope mounted above two photograph tables (fig. 14). A transparent plastic arm with a centrally scribed line extends from and pivots around the center of each table. These arms are linked to a pantograph attachment. Because the plastic arms radiate from different centers they cross each other in stereoscopic view to form the so-called plotting cross.

In operating the radial planimetric plotter a pair of vertical photographs is oriented on the photograph tables for proper stereoscopic viewing, and control points on the photographs are oriented to control points on the base manuscript by means of the radial arms and pantograph. Movement of the pantograph attachment moves the plotting cross over the stereoscopic model and permits tracing of photograph detail on the base manuscript. Inasmuch as the radial arms that intersect a terrain feature on each photograph represent azimuth lines from known points on the base manuscript, the intersection of these two arms will represent the true map position of that feature, just as will the intersection of two azimuth lines shot from different instrument stations in the field. Thus the relief displacement of a feature on a photograph is effectively removed; this is one of the chief advantages in using the radial planimetric plotter. However, the radial lines do not intersect along the principal line—or flight-line direction—between photographs, and the photograph tables must be shifted to their alternate centers before the central area of stereoscopic model can be delineated. Because the photograph tables are mounted in a horizontal position, the instrument does not permit removal of tilt that may be present in the photographs, but tilt is usually small in present-day photography and generally does not cause significant errors in horizontal positioning of geologic data.

The multiscope is a combination of mirror stereoscope and camera lucida that has received limited use

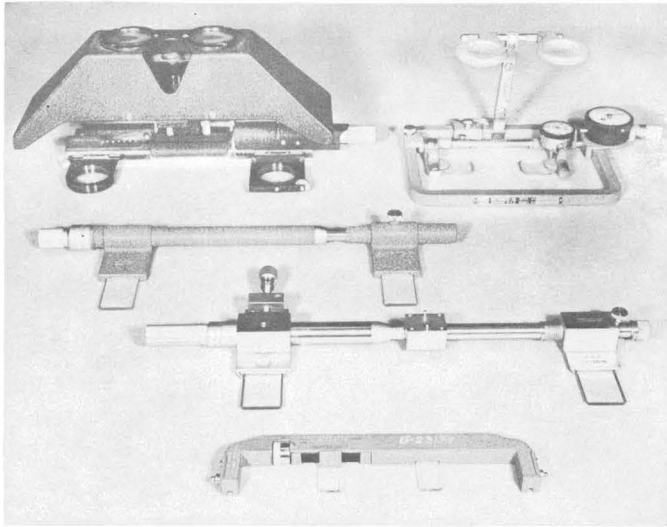


FIGURE 10.—Stereometers.

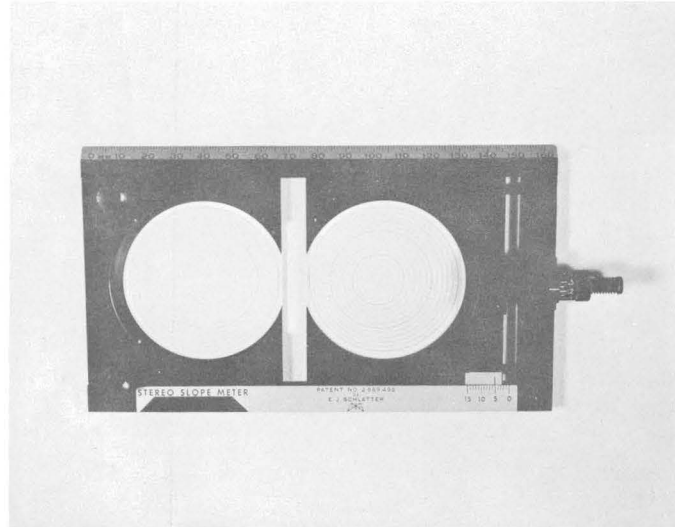


FIGURE 11.—Stereo slope meter.

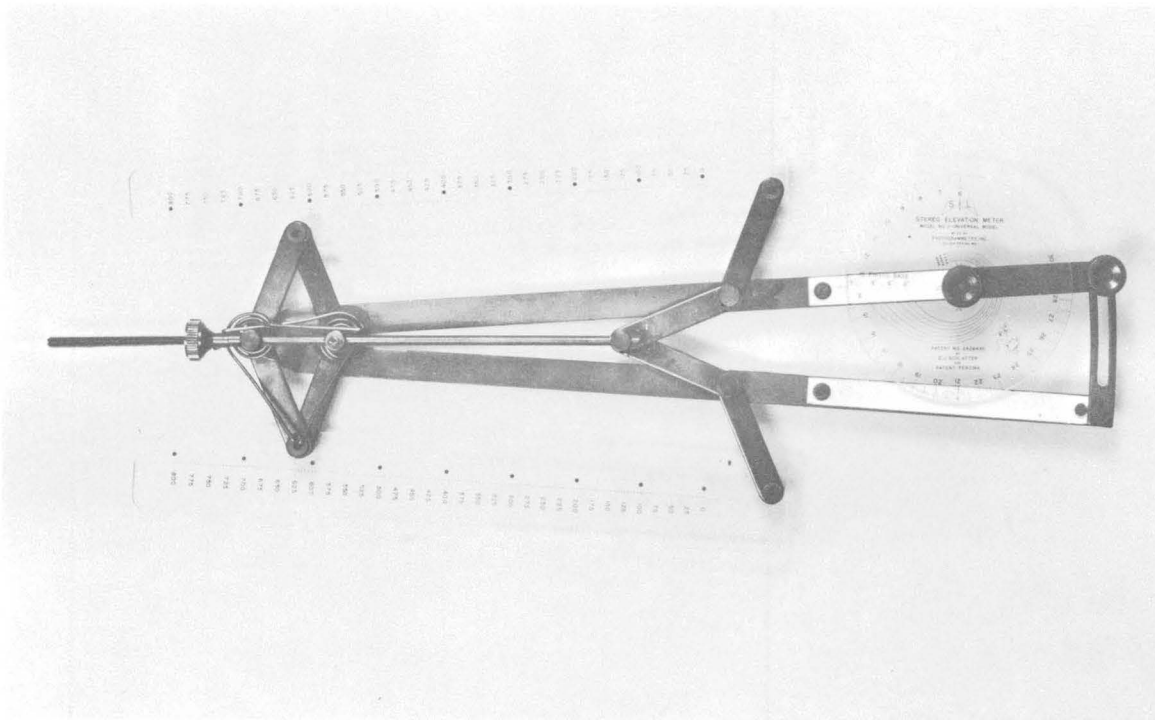


FIGURE 12.—Parallax ladder.

MEASURING INSTRUMENTS FOR USE WITH PAPER PRINTS

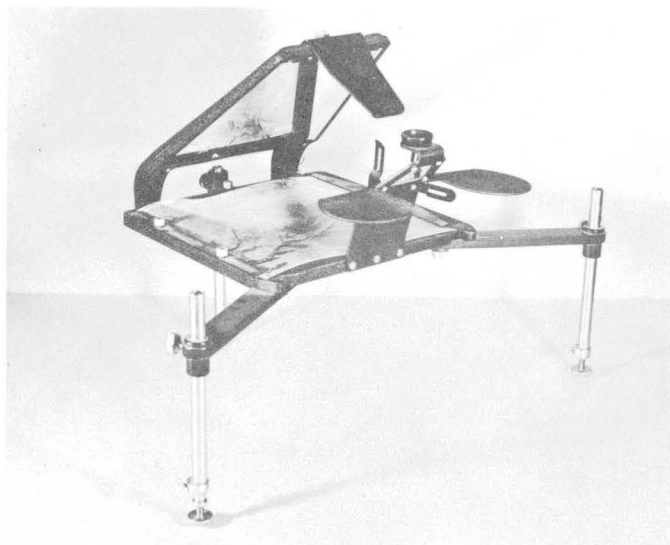


FIGURE 13.—Sketchmaster.

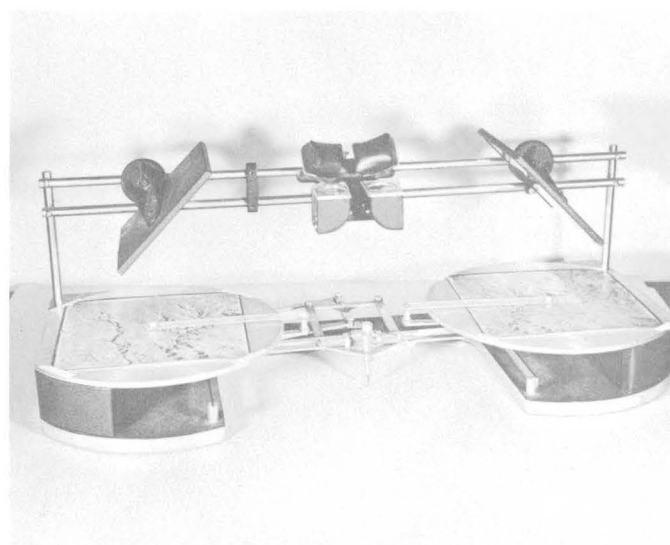


FIGURE 14.—Radial planimetric plotter.

PLOTTING INSTRUMENTS FOR USE WITH PAPER PRINTS

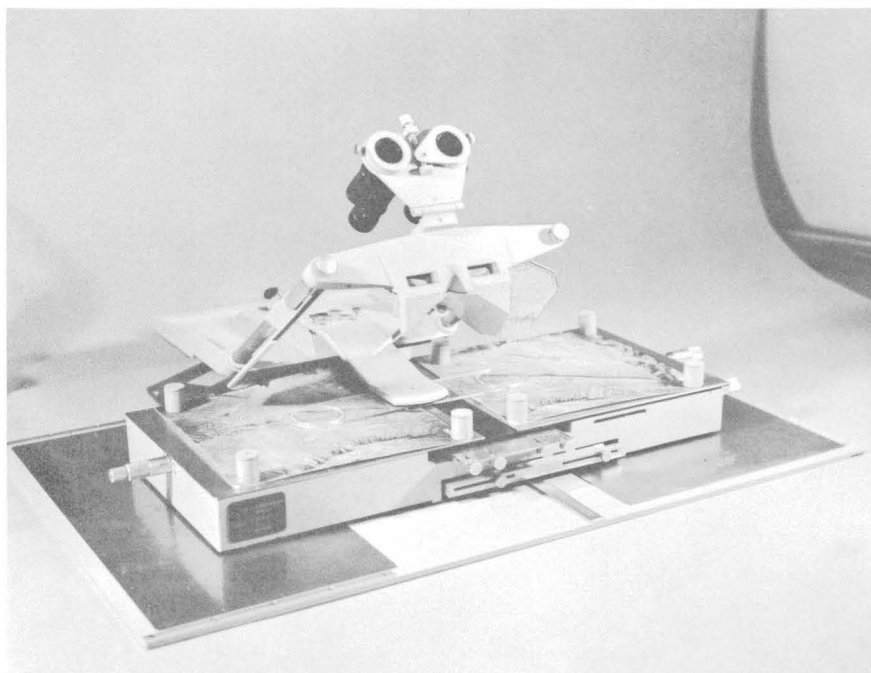


FIGURE 15.—Stereotape.

COMBINED MEASURING AND PLOTTING INSTRUMENT FOR USE WITH PAPER PRINTS

in plotting geologic data from photographs to base maps or control sheets. Photographs are mounted on movable photograph plates that permit small adjustments for tilt. The viewing assembly is constructed to allow the insertion of one or two half-silvered mirrors in the eyepiece, so that in operation either the image of a single photograph or the stereoscopic model may be superposed optically on the map or control base. Although the stereoscopic model may be seen at all times, use of only one half-silvered mirror permits the eye to see only the image of one photograph superposed on the map base; the resulting plot is similar to that from the sketchmaster—or reflecting projector—no errors due to relief displacement are removed. If, however, two half-silvered mirrors are used, appropriate manipulations permit true orthographic plotting of detail from the stereoscopic model. Scale adjustments between photographs and map base are made by interchanging special lenses in the viewing assembly together with changing manually the distance of the viewing assembly above the map base. The instrument is said to permit measurement of altitudes when coupled rotary prisms are inserted under the half-silvered mirrors, or when a device similar to the multiplex tracing table is placed in the field of stereoscopic view (Spurr and Brown, 1945, p. 177).

MEASURING AND PLOTTING DEVICES FOR USE WITH PAPER PRINTS

Some instruments have been designed both for measuring altitudes and for plotting data from paper prints of aerial photographs. These instruments are commonly termed "paper-print plotters" and include the KEK plotter, the Mahan plotter, and the stereotape.

The KEK plotter consists of a stereoscope, two photograph tables, floating-dot assembly, and drawing attachment. The plotting cross of the radial planimetric plotter is replaced in the KEK plotter by the fused dot floating in space. By raising or lowering the photograph plates the fused dot is positioned on the ground in the stereoscopic model. Vertical motion of the photograph plates is linked to a drum scale on which relative altitudes can be read directly in feet. Movement of the pantograph drawing attachment allows geologic detail to be sketched directly on the map base, but during this sketching the fused dot must be held on the ground in the stereoscopic model by simultaneous vertical movement of the photograph plates. The photograph plates may be tilted to make an approximate correction for tilt that may be inherent in the photography. Because the floating-dot assembly lies above and is physically separated from the photograph tables, small amounts of extraneous paral-

lax and significant amounts of horizontal shift in the map position of a point may result by moving one's head in viewing the stereoscopic model.

The Mahan plotter is generally similar in principle to the KEK plotter but differs slightly in operation. The floating dot is positioned on the ground in the stereoscopic model by vertical motion of the disks on which the dots are scribed, whereas in the KEK plotter the position of the disks containing the scribed dots is fixed and the photograph plates are moved vertically in order to position the floating dot at a particular level in the stereoscopic model. The stereoscope of the Mahan plotter is adjustable, which permits very nearly the recovery of the perspective from photography ranging in focal length from about 8.25 to 12 inches. As with the KEK plotter, a shift of the viewer's head when viewing the model may cause horizontal positioning errors and the presence of small amounts of extraneous parallax. The stereoscopic model of the KEK and Mahan plotters may be effectively leveled, in absence of vertical control, by visual reference to certain physiographic features of the terrain (see p. 55).

A somewhat different paper-print plotter is the stereotape. The instrument consists of a stereoscope with binoculars of $\times 4$ magnification mounted over a photoholding assembly that contains a parallax bar and attachments for pantograph hookup, as well as a mechanism, when vertical control is available, for effectively leveling tilted models, for correcting errors of horizontal position, and for orthographic plotting of geologic data (fig. 15). The stereotape is an elaborate instrument that corrects for tilt by mechanical linkages within the photoholding assembly. No physical tilting of the photoholders takes place and thus the instrument differs significantly from the KEK and Mahan plotters. In addition, the targets of the stereometer attachment for altitude determinations are in contact with the paper prints, and no extraneous parallax can be introduced by movement of the operator's viewing position. In the absence of vertical control, which permits tilt correction through mechanical linkages, the stereotape as a measuring device must be used as a simple parallax bar.

MEASURING AND PLOTTING DEVICES FOR USE WITH GLASS-PLATE DIAPOSITIVES

The Kelsh plotter, multiplex, and ER-55 plotter, all of which require glass-plate diapositives, are used in the United States both to measure quantitative geologic data and to plot geologic detail to base maps or control sheets (figs. 16-18). These double-projection precision-plotting instruments are designed to accom-

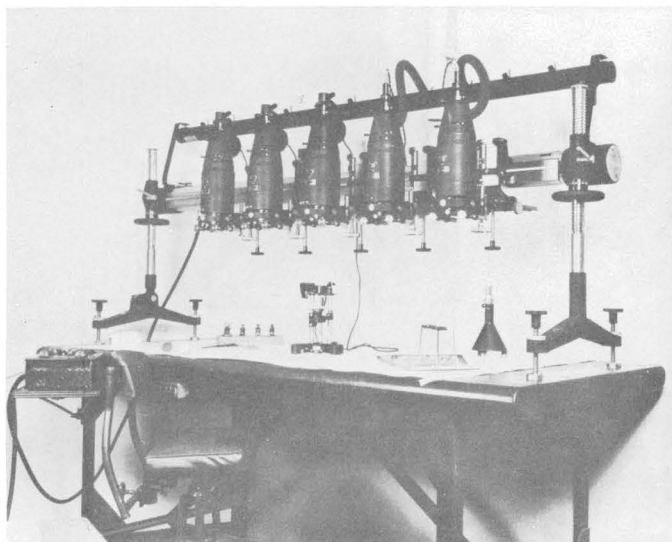


FIGURE 16.—Multiplex.

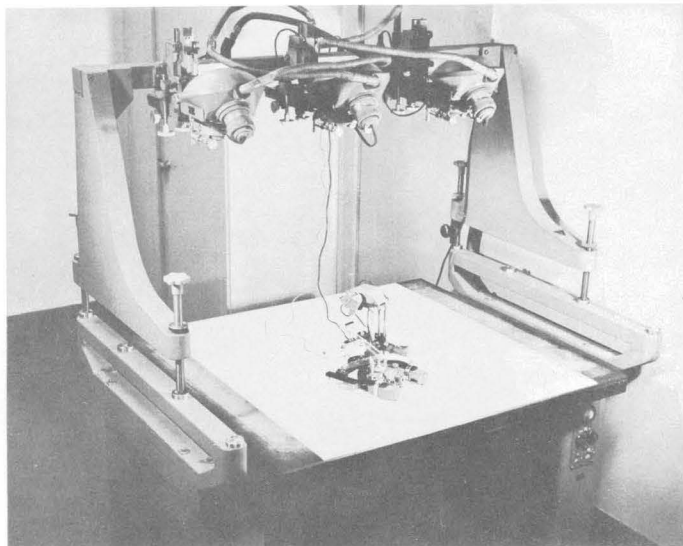


FIGURE 17.—ER-55 plotter.

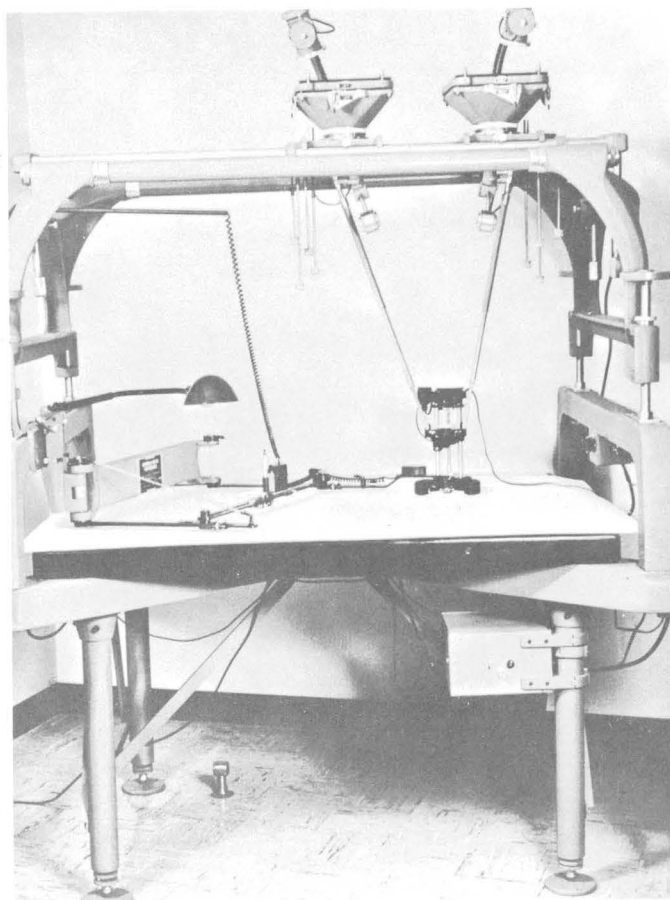


FIGURE 18.—Kelsh plotter.

COMBINED MEASURING AND PLOTTING INSTRUMENTS FOR USE WITH GLASS-PLATE
DIAPOSITIVES

moderate photography of specific focal lengths, usually 6 or 8.25 inches. All utilize the anaglyph principle of projection of light of complementary colors, red and blue-green, through glass-plate diapositives to create the third dimension. The stereoscopic model is viewed through glasses of the same color as the filters used in the light-source projectors. Because double-projection, or anaglyphic-type, stereoplotting instruments simulate in miniature the spatial relations of the camera stations at the time the photographs were taken, all features of the terrain are optically re-created in the stereoscopic model in essentially true relation with respect to the measuring mark or floating dot. Where sufficient vertical control is available any tilt inherent in the photography can be removed so that accurate measurements of altitudes can be made and true orthographic positioning of detail obtained. Without vertical control the stereoscopic model of many terrains commonly can be leveled within 1° of the horizontal datum by visual reference to certain physiographic characteristics of the terrain (see p. 55); under these conditions approximate orthographic positioning may be obtained, but significant errors in vertical measurements may result (see p. 69-75).

The stereoscopic model is usually viewed on a small white-surfaced table called a platen, which may be raised and lowered so that an illuminated floating dot in its center is kept in contact with the surface of the ground, as seen in stereoscopic view. Vertical motion of the platen is transmitted to a scale reading in millimeters of vertical measurement, or, on some instruments, to a scale that converts readings directly to heights in meters or feet. Geologic features are traced orthographically on the base map by a pencil located directly beneath the illuminated dot on the platen, or by a reduction pantograph attached to the tracing table. Interpretation, measuring, and plotting can be carried out in one continuous operation.

The Kelsh plotter is designed to accommodate glass-plate diapositives the same scale as the original photography. For many geologic problems film positives may be substituted for the more expensive glass-plate diapositives. The scale of the projected stereoscopic model is usually about 5 times that of the original photography. Only that part of the stereoscopic model appearing on the platen is illuminated; this results in a concentration of light and a brightly illuminated model but prevents viewing of the entire model at one time. Because the glass-plate diapositives are the same scale as the original photography the resolution of the stereoscopic image is excellent.

The multiplex uses glass-plate diapositives on which the original 9- by 9-inch negative is reduced about

5 times. The small diapositive image is then enlarged approximately 12 times in projection of the stereoscopic model. The projected stereoscopic model is about 2.5 times the original photography scale. As a result of the large amount of reduction of the original photograph negative, some of the photographic detail is lost and fine details of terrain, important in geologic interpretation, may not be visible. In multiplex projection the entire model area is illuminated, and if the terrain being viewed has only low or moderate relief the stereoscopic model may be observed in its entirety by substituting a large white surface for the platen. This overall view of the stereoscopic model is often of considerable use in geologic interpretation, because of the association of geologic features that can be seen at one time. The overall view is generally accomplished by projecting the stereoscopic model to the multiplex table slate; no plotting or measuring can be done when the model is viewed on this surface.

The ER-55 plotter uses glass-plate diapositives on which the original 9- by 9-inch negative is reduced about 2.8 times; this amount of reduction does not seriously affect image resolution. The projected stereoscopic model is about 3.5 or 5 times the scale of the original photographs, depending on the projector model. Ellipsoidal reflector-type projectors result in a brightly illuminated model in which terrain detail has a high degree of resolution. Like the multiplex, the ER-55 plotter permits viewing the entire stereoscopic model at one time. In addition to accommodating vertical photography the ER-55 projectors are adaptable to twin low-oblique photography taken with the camera axis inclined 20° from the vertical position.

Geologic study of stereoscopic models in double-projection plotters has numerous advantages over the study of paper prints. The ability to interpret, measure, and plot in one continuous operation has already been cited. In addition, the geologist works with an enlarged stereoscopic model that ranges from about 2.5 times to 5 times the original photography scale, depending on the instrument used; thus small-scale photography commonly may be used. A higher degree of image resolution is maintained on glass diapositives than on paper prints, and results in more detail that can be observed in the double-projection stereoscopic models, except for the multiplex, in which some resolution needed in qualitative and quantitative interpretation is lost in the projected model. Because all features of the terrain are optically re-created in essentially true relation, reliable measurements for structure contouring, for drawing isopach lines, for computing strikes and dips, and for determining fault displacements can be obtained for many areas with stereo-

scopic plotters; measurements can be made rapidly and hence economically (see Pillmore, 1957).

OTHER INSTRUMENTS

Other photogrammetric instruments such as the stereoplanigraph and autograph permit precise measurements from aerial photographs, but these heavy plotters are generally unavailable to the geologist. Beside permitting precision of measurement, these instruments are designed to accommodate different sizes of diapositives and photography taken with different focal-length lenses.

Certain modifications or additions to existing instruments have been made specifically for geologic purposes; and some new instruments, described below, have been designed expressly for geologic study.

EXAGGERATED-PROFILE PLOTTER

The exaggerated-profile plotter is a device attached to the tracing table of double-projection plotters, such as the Kelsh, multiplex, and ER-55 plotters, for drawing terrain profiles. As the tracing table is moved along the line of profile and as the platen of the tracing table is moved vertically a pencil attachment records the profile on a vertical tracing board. Profiles exaggerated as much as 5 times may be plotted. An arm on the tracing table slides in a groove along the base of the tracing board so that a selected cross-section direction is maintained. Two models of the exaggerated-profile plotter have been developed. One is based on the lever and fulcrum principle (fig. 19); the other is based on the pantograph principle (fig. 20). The exaggerated-profile plotter was first developed to aid in solving a specific geologic problem in correlating thin and closely spaced intraformational sandstone beds in rocks of Cretaceous and Jurassic age in Wyoming (Pillmore, C. L., oral communication, 1958). The plotter may be very useful also in quantitative geomorphic studies or in studies involving the qualitative correlation of shape characteristics of terrain.

INTERVAL-MEASURING DEVICE

A floating-dot instrument that permits the maintenance of a desired vertical interval between two floating dots in a stereoscopic model from paper prints, as well as serving as a conventional stereometer, also has been developed in the course of photogeologic study (Hackman, R. J., oral communication, 1959). Two floating dots, representing different altitudes in the stereoscopic model, may be useful for example in positioning an obscured formation contact when other contacts are readily observed and formation thicknesses are known. The instrument consists of two transparent circular disks mounted on a frame with two worm

screws, one of which permits separation of the disks in the x direction, and the other of which permits both disks to be rotated equally but in opposite directions (see fig. 21). A series of dots, evenly spaced, are arranged in a straight line so as to pass through the center of each disk. One dot coincides with the center of each disk and can be moved only in the x direction, as in most stereometer-type instruments. The other dots may also be moved in the plane of the disk by rotating the disk, thus providing a parallax ladder as seen stereoscopically. By proper adjustment a pair of dots, one on each disk, can be separated by rotation of the disks to provide a direct-reading parallax ladder, or the dot separation may be referred to millimeters of parallax and differences in altitude calculated in the usual manner (see p. 53). The center dots of each disk can be floated in the stereoscopic model at a desired point and the distance above or below this point measured merely by rotation of the disks. Scales graduated to record hundredths of millimeters of parallax permit readings of separation of the center dots of the disks as well as reading of total x parallax resulting from rotation or x motion of the disks.

UNIVERSAL TRACING TABLE

Some research in development of instruments carried out to date has centered around the modification of existing instruments. Important in this group is the universal tracing table (fig. 22), which is a multiplex tracing table that has been modified in design by R. H. Morris and C. L. Pillmore of the Geologic Survey. It is used for direct measurement of inclined distances, such as stratigraphic thickness of dipping beds, in stereoscopic models from double-projection plotters. The platen and underlying assembly can be tilted as much as 45° . A separate worm-screw drive on the tilted assembly distinct from the conventional worm-screw drive for vertical movement, permits movement of the platen in an inclined direction perpendicular to the surface of the platen. A scale on this auxiliary worm-screw-drive assembly permits the reading of measured intervals in hundredths of millimeters; conversion to feet is made in the usual manner for double-projection stereoscopic models (see p. 54-55). A series of holes drilled through the platen to the underlying light source provides a plane of floating dots in the stereoscopic model.

MEASUREMENT

PRINCIPLES OF VERTICAL MEASUREMENT

Vertical measurements of altitude differences provide by far the greatest amount of quantitative information in geologic interpretation from aerial photographs. Differences of altitudes are generally deter-

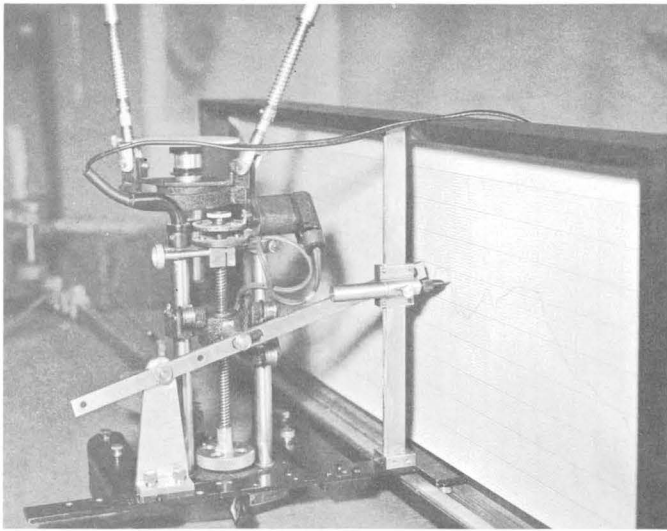


FIGURE 19.—Lever and fulcrum type of exaggerated-profile plotter.

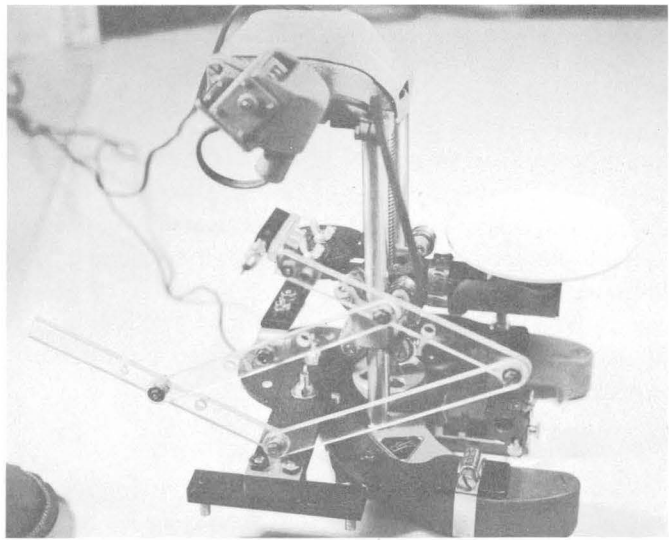


FIGURE 20.—Pantograph type of exaggerated-profile plotter.

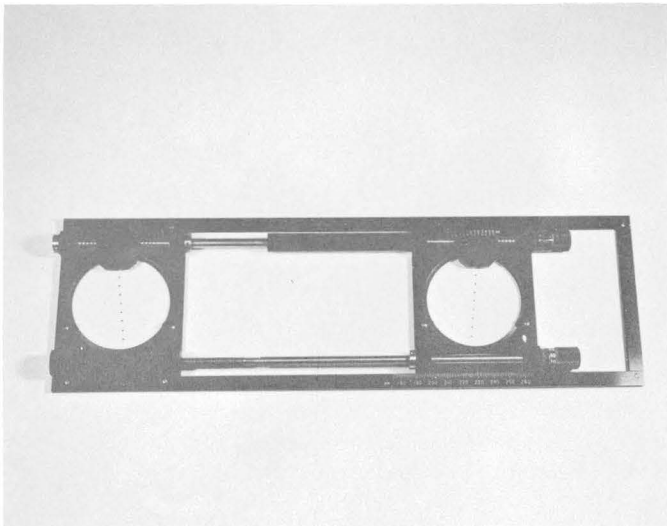


FIGURE 21.—Interval-measuring instrument.

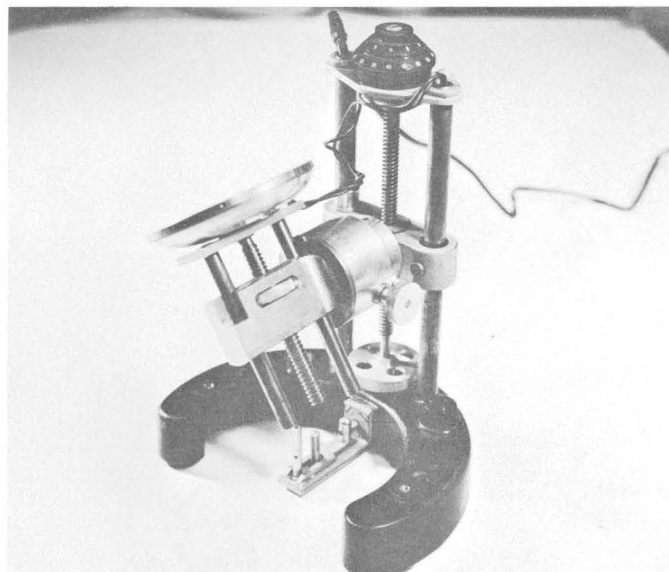


FIGURE 22.—Universal tracing table.

INSTRUMENTS DESIGNED OR MODIFIED FOR GEOLOGIC USE

mined from overlapping aerial photographs, although they may under special circumstances be determined from a single photograph. When overlapping prints are used, the altitude difference between any two points is determined by measuring the horizontal linear parallax difference between the two points and relating it to appropriate geometry of the stereoscopic model. Altitude determinations from glass plates in double-projection plotters require the measurement of actual vertical distances within the stereoscopic model. In the uncommon circumstance when a single photograph may be used, altitudes are determined by measuring relief displacement and relating it to appropriate geometry of the aerial photograph.

DETERMINATION OF ALTITUDE DIFFERENCES BY THE PARALLAX METHOD

When an object is viewed or photographed from two different positions, as on two overlapping vertical aerial photographs, an apparent shift in the position of that object takes place, which is known as paral-

lactic displacement. On overlapping aerial photographs this is a measurable linear distance that is directly related to the height of the object. In photogrammetric terms parallax of an image point appearing on two overlapping photographs is called absolute stereoscopic parallax and is represented by the algebraic difference, parallel to the flight line, of the distances of the conjugate image points from their respective principal points (see fig. 23). The difference in absolute stereoscopic parallaxes between two different image points is a measure of the distance one point is above the other. On overlapping paper prints the parallax difference may be measured reliably by using a stereometer-type instrument, based on the floating-dot principle; parallax difference may also be measured with a ruler, although this procedure is rarely used because of inaccuracy of measurement.

In double-projection stereoplotters (Kelsh, multiplex, and ER-55 plotters) an actual vertical measurement of altitude difference is made within

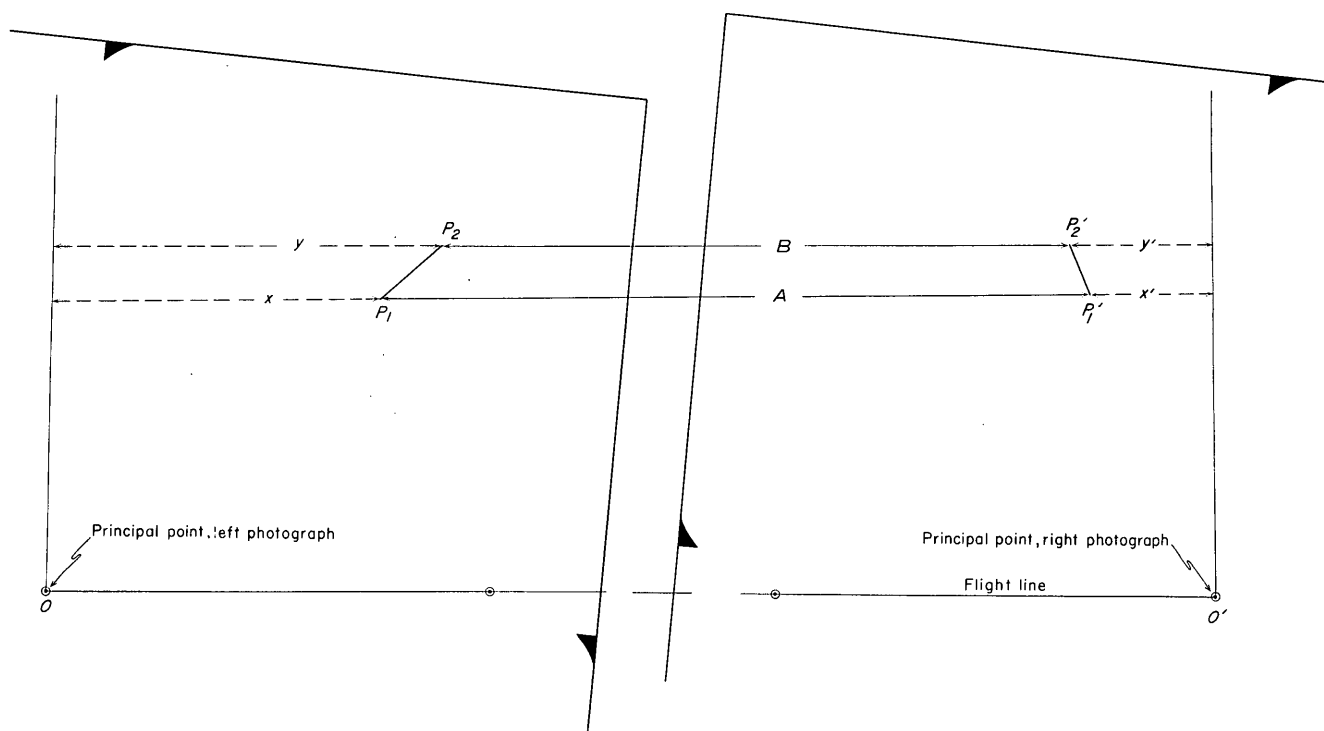


FIGURE 23.—Diagram showing relation between absolute stereoscopic parallaxes and horizontal distances actually measured with stereometer-type instruments in determining differences in altitude from paper prints.

Let images $P_1'-P_2'$ and P_1-P_2 represent the photographic expression of a pole on the left and right photographs of a stereoscopic pair. The absolute stereoscopic parallax of the base of the pole is $x - (-x') = (x + x')$. The absolute stereoscopic parallax of the top of the pole is $y - (-y') = (y + y')$. (Distances measured to the right of the principal point are positive, to the left, negative). The parallax difference between the top and bottom of the pole then is $(y + y') - (x + x')$.

From the figure:

$$\begin{aligned} y + y' + B &= x + x' + A \\ y + y' - x - x' &= A - B \\ (y + y') - (x + x') &= A - B. \end{aligned}$$

Thus the difference in absolute stereoscopic parallaxes is equal to $A - B$. The distances A and B are the actual distances measured with stereometer-type instruments, generally in hundredths of millimeters, in determining altitude differences from paper prints.

the stereoscopic model; the linear parallax recorded on the photograph is translated into a vertical distance as a result of angular parallax in the viewing arrangement. Figures 23 and 24 show diagrammatically the distances that are actually measured when stereometer-type instruments and double-projection instruments are used respectively in altitude determinations.

USE OF STEREOMETER-TYPE INSTRUMENTS

When paper prints of aerial photographs are used in conjunction with a stereometer-type instrument and a stereoscope, two linear horizontal distances must be measured to obtain the parallax difference between two different image points. These distances are simply A and B as shown on figure 23. They can be measured with a finely graduated ruler but more commonly a

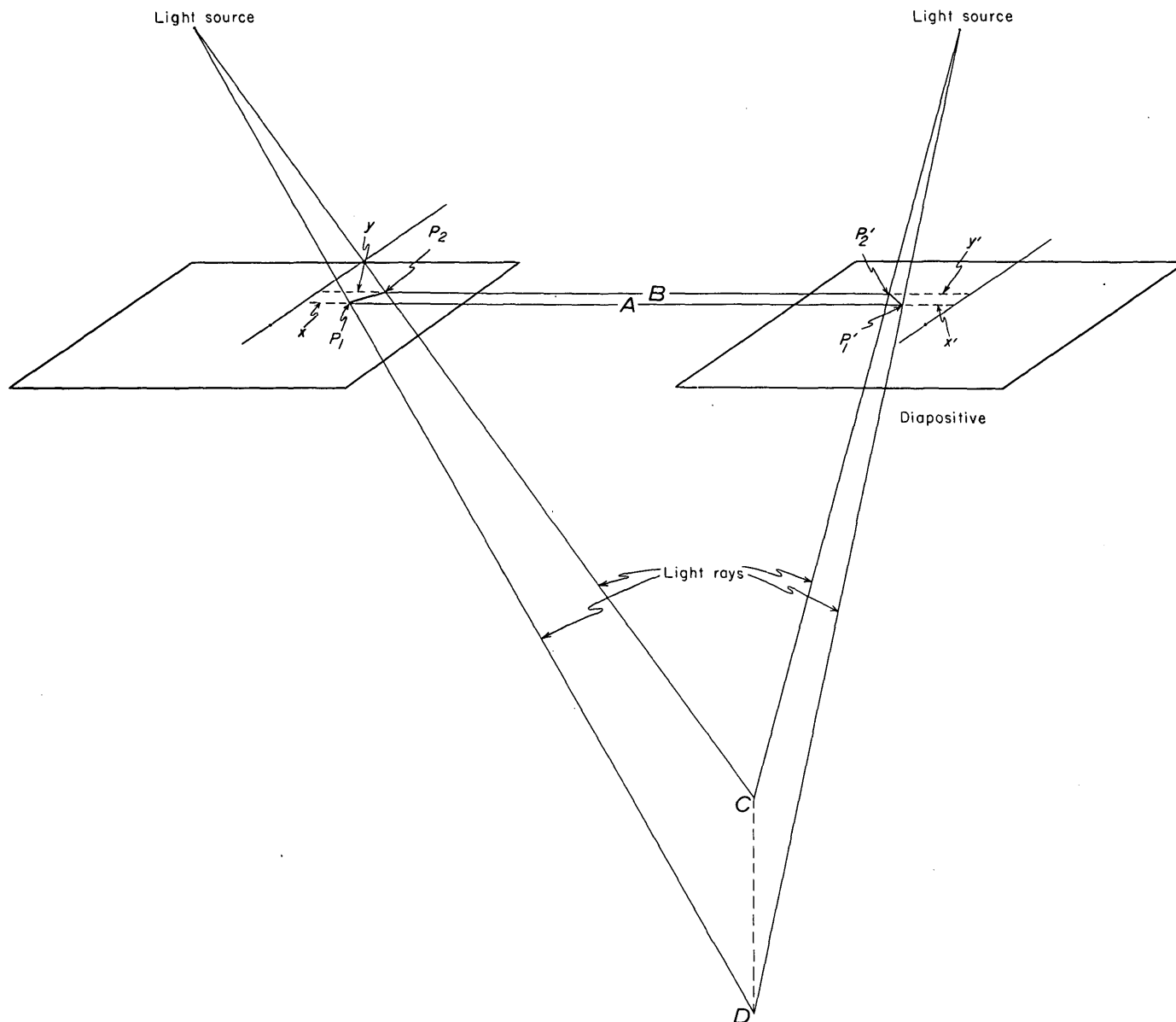


FIGURE 24.—Diagram showing relation between absolute stereoscopic parallaxes and vertical distance measured with double-projection type instruments in determining differences in altitude from glass plates.

The absolute stereoscopic parallaxes of the top and bottom of a pole represented on the left photograph by P_1 - P_2 and on the right photograph by P_1' - P_2' are $(y + y')$ and $(x + x')$, as in figure 23, and differential parallax between the top and bottom of the pole is $(y + y') - (x + x')$ or $A - B$. With double-projection instruments the vertical distance CD is actually measured, rather than the horizontal distances that are measured on

paper prints. The distance CD , measured generally in tenths of millimeters, is converted to feet by multiplying by the K factor, which represents the number of feet on the ground per 0.1 millimeter in the stereoscopic model. Points C and D represent the intersections of those light rays that pass through the top and bottom of the pole respectively.

stereometer-type instrument or parallax bar is used because it permits more consistent readings of smaller increments of length than a ruler. Stereometers are generally constructed with a principal scale graduated in millimeters and a subordinate drum scale calibrated in hundredths of millimeters for recording parallax measurements; a few instruments are designed to record in inches.

To make parallax measurements from aerial photographs it is first necessary to orient the photographs properly for stereoscopic viewing. This is accomplished by aligning the photograph centers and conjugate centers along a straight line—the equivalent of the flight-line direction—and separating the photographs for comfortable viewing (fig. 25). Photograph centers are located by marking the intersections of lines drawn between fiducial marks at the opposite sides of each print. Each center is then transferred stereoscopically to the other photograph of the stereo-

scopic pair and its conjugate image point marked. Parallax measurements are then made in the so-called x direction, parallel to the flight line. Measurement is accomplished by adjusting the separation of the dots of the parallax bar until a single fused dot, seen stereoscopically, appears to rest on the ground at the first point selected. The instrument reading is recorded and the procedure is repeated for the second point selected. The difference in readings is the parallax difference between the two points. In making parallax measurements the fused dot will be seen readily when it floats above the apparent ground surface of the stereoscopic model but will appear to split into its two component dots as it is lowered below the ground surface. If the fused dot, as it is being lowered, appears to split at some point just above the ground surface, a slight change in the separation of the photographs may be necessary to permit simultaneous viewing of the floating dot and the stereoscopic model.

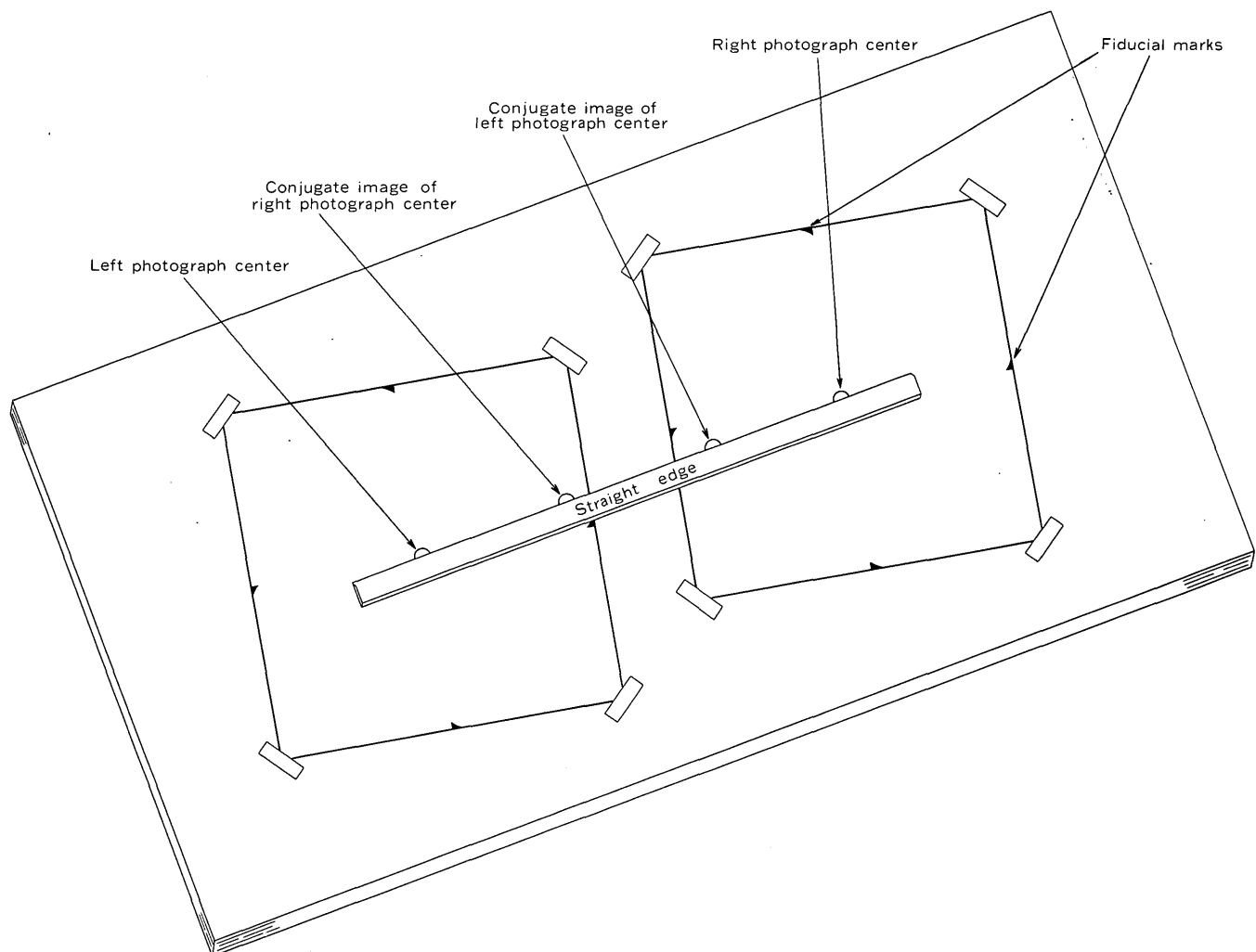


FIGURE 25.—Sketch showing correct orientation of photographs for stereoscopic viewing.

To obtain the height of an object or difference in altitude between two points the difference in parallax must be related to the geometry of the stereoscopic model. For measuring heights from paper prints this relation is best expressed by a formula which, in its simplest terms, is

$$h = \frac{H}{b} \cdot \Delta p \quad (1)$$

where h = height of the object, in feet, or difference in altitude being determined;

H = height of airplane, in feet, above mean terrain (determined from specifications of photographic mission or relation $H = f/S$, see below);

b = photobase (commonly determined by averaging the distances between the center and conjugate center of each photograph of the stereoscopic pair); units of measure may be millimeters or inches but must be the same as Δp ;

and Δp = parallax difference, in millimeters or inches, as determined with stereometer-type instrument (distance $A-B$ of figure 23).

It will be noted that as H increases, the measure of Δp for any given vertical interval will decrease; however, the absolute value for any one unit of Δp will increase correspondingly. On the other hand, if focal length is increased and flying height remains constant the measure of Δp for a given vertical interval will increase but the absolute value for any one unit of Δp will decrease correspondingly.

The above formula (1) may be used without any appreciable error if relief in an area is low; Δp will be small. If relief in an area is high one of the following two formulas, (2) or (3), should be used:

$$h = \frac{H'}{ab + \Delta p} \cdot \Delta p \quad (2)$$

where h = height of the object, in feet, or difference in altitude being determined;

H' = height of airplane, in feet, above the lower of the two points whose parallax difference has been measured;

ab = photobase adjusted to the lower of the two points whose parallax difference has been measured (commonly determined by measuring the distance between photograph centers— $O-O'$ of fig. 23—and subtracting from it the distance between conjugate image points at the lower altitude—distance A of fig. 23); units of measure may be millimeters or inches but must be the same as Δp ;

and Δp = parallax difference, in millimeters or inches, measured with stereometer-type instrument (distance $A-B$ of figure 23);

$$\text{or} \quad h = \frac{H'}{ab - \Delta p} \cdot \Delta p \quad (3)$$

where h = height of the object, in feet, or difference in altitude being determined;

H' = height of airplane, in feet, above the upper of the two points whose parallax difference has been measured;

ab = photobase adjusted to the upper of the two points whose parallax difference has been measured (commonly determined by measuring the distance between photograph centers— $O-O'$ of fig. 23—and subtracting from it the distance between conjugate image points at the upper altitude—distance B of fig. 23); units of measure may be millimeters or inches but must be the same as Δp ;

and Δp = parallax difference, in millimeters or inches, measured with stereometer-type instrument (distance $A-B$ of figure 23).

Formula (2) is used when H' and ab are determined by referring to the lower of the two points whose altitude difference is desired, as in measuring upward from the base to the top of a cliff. Formula (3) is used when H' and ab are referred to the upper point, as in measuring downward from the top to the bottom of a cliff. Most commonly the lower of two points is selected as the reference point and measurements are made from that point to some higher point in the stereoscopic model; thus formula (2) is more widely used than formula (3).

Parallax differences generally can be read within small tolerances (see p. 73), and errors in computing differences in altitude result mainly in the determination of flying height and photobase, assuming photographs have little or no tilt. It is therefore generally desirable to determine flying height (H') and adjusted photobase (ab) carefully because a given percentage error in one of them may cause a similar percentage error in the computation of altitude difference. In addition, failure to use formula (2) or (3) when parallax difference (Δp) is large will also cause a considerable error in the final result even though the adjusted photobase (ab) has been carefully determined.

For calculation of absolute heights as is necessary, for example, in determining stratigraphic thickness or displacement on faults, the factor H' may be determined from a base map of known scale or from other control using the relation $H' = f/S$. If the altitude difference between some two points, A and B , is desired

and if neither A nor B falls in a convenient map position for scaling a distance and determining H' for one of them, it may be necessary to make parallax measurements with respect to some selected third point, C , for which the flying height (H') can be readily calculated.

Where altitudes are to be used for computing angles of dip it is not necessary to know the absolute height of H' ; the tangent relation of angles

$$\text{Tan angle of dip} = \frac{\text{vertical distance}}{\text{horizontal distance}} \quad (4)$$

involves only relative horizontal distances and relative differences of altitudes, and thus any value may be assumed for H' when measuring parallax difference and determining the scale of the photograph to be used in computing dips. In photogrammetric terms this relation may be expressed as

$$\text{Tan angle of dip} = \frac{\text{flying height (feet)} \times \text{parallax difference}}{\text{horizontal distance on ground (feet)} \times \text{adjusted photobase}} \quad (5)$$

$$\text{or Tan angle of dip} = \frac{H' \cdot \Delta p}{d \cdot (ab \pm \Delta p)} \quad (6)$$

Since

$$\frac{\text{flying height (feet)}}{\text{horizontal distance on ground (feet)}}$$

is also equal to

$$\frac{\text{focal length (inches)}}{\text{horizontal distance on photograph (inches)}}$$

the following formula may also be used to calculate angles of dip when flying height, H' , is not known or cannot be determined:

$$\text{Tan angle of dip} = \frac{\text{focal length} \times \text{parallax difference}}{\text{horizontal distance on photograph} \times \text{adjusted photobase}} \quad (7)$$

The tangent of dip, in photogrammetric terms, has been described in more detail by Desjardins (1943b, p. 1536-1538) and Elliott (1952, p. 8). When angles of dip are determined from enlarged photographs and formula (7) is used, the effect of photographic enlargement on focal length must be considered; effective focal length is increased in direct proportion to the amount of photographic enlargement (see p. 4).

Hemphill (1958a, p. 43) has devised a chart that shows the number of feet represented by each millimeter of parallax change as H' and $(ab + \Delta p)$ of formula (2) vary. The factor determined from the chart is then multiplied by Δp to arrive at h , in feet, pro-

vided formula (2) is used. A simple circular photogrammetric computer has also been designed that permits easy computation of the number of feet represented by each millimeter or hundredth millimeter of parallax as flying height and photobase vary. In addition, the computer allows multiplication of this factor by the parallax change to give altitude differences in feet. The number of feet represented by each hundredth millimeter of parallax measured on paper prints may also be determined from the ratio

$$\frac{\text{Flying height (feet)}}{\text{Photobase (millimeters)} \times 100}$$

This relation is further discussed on page 73.

Need for correct orientation of photographs.—Misorientation of a stereopair of photographs can be considered from the standpoint of rotation around the center of one or both of the photographs. This rotation results in misalignment of the stereopair and flight line. Parallax differences are not then measured in the true x direction, or flight-line direction, but at a slight angle to it; an error in the adjusted photobase also results. The measurement of parallax difference is not normally significantly affected but the adjusted photobase on a stereopair misoriented by a few degrees, even though the human eyes can tolerate a certain amount of error and yet see a well-defined stereoscopic image, may be in error by as much as 5 to 10 percent. This will cause a similar error in differences in altitudes determined by the parallax method when paper prints are used.

USE OF DOUBLE-PROJECTION INSTRUMENTS

When double-projection instruments are used to determine altitude difference between two points, only one distance need be measured. This is a vertical distance within the stereoscopic model that results from the translation of linear parallax recorded on the glass-plate diapositives to angular parallax in the viewing arrangement (fig. 24). The vertical position of intersecting light rays to the lower point to be measured is determined by placing the floating dot on the apparent ground in the stereoscopic model and recording the instrument reading. The vertical position of the upper point is recorded in a similar manner. The difference in readings is a measure of the parallactic displacement and is related to the difference in altitude of the two points. With double-projection instruments measurements are normally made in increments of tenths of millimeters, although some instruments are so designed that selection of proper gear trains permits readings to be converted directly to heights in meters or feet.

In stereoscopic models formed in double-projection instruments the vertical scale remains constant with

respect to the horizontal scale and a simple multiplication factor—called the *K* factor—for relating increments of vertical measurement to absolute feet can be determined by converting the standard fractional scale (representative fraction) of the model to feet per unit of vertical measurement, that is, per 0.1 millimeter. This is most rapidly accomplished using the formula

$$K = \frac{\text{model scale denominator}}{3,048 \text{ (number of tenths of millimeters in 1 foot)}}$$

Thus a stereoscopic model with a scale of 1:4,000 would have a *K* factor of 4,000/3,048 or 1.31 feet per 0.1 millimeter of vertical measurement. Increments of vertical measurement are merely multiplied by the appropriate *K* factor to obtain differences in altitude in feet. A constant factor for converting increments of vertical measurement to feet is appropriate because the horizontal and vertical scales are equal and constant throughout the stereoscopic model, but when paper prints are used, the horizontal scale is not constant throughout the model and hence different multiplication factors must be determined for different levels in the model.

Because the horizontal and vertical scales in stereoscopic models from double-projection instruments are equal and constant throughout the model, inclined distances, such as stratigraphic thicknesses of dipping beds, may also be measured. A special device for measuring distances in inclined directions was developed by R. H. Morris and C. L. Pillmore of the Geological Survey; it consists of a multiplex tracing table modified so that the platen, platen socket, and light source can be tilted as a unit (fig. 22). An additional worm-screw drive, separate from the conventional worm-screw drive, allows the platen to move in an inclined direction perpendicular to the surface of the platen. The resulting measured distance within the model is converted to feet in the usual manner, and a measure of the inclined distance is obtained.

TILT

Tilt in present-day vertical photography is generally small—under good flying and photographic conditions 50 percent of the photographs taken for domestic mapping are reported to be tilted less than 1° and 90 percent tilted less than 2° (see Tewinkel, 1952, p. 319). But tilt may be significant in the photogrammetric calculation of many geologic measurements, and care must therefore be exercised in determining altitudes from parallax measurements. The significance of tilt on vertical measurements used in geologic interpretation depends in large part on the geologic problem. Where vertical measurements must be referred to a

horizontal datum, as in structure contouring, tilt may cause significant errors, but where relative vertical measurements between pairs of points are desired, as in constructing isopach lines, tilt may have relatively little effect especially where points of any one pair are separated by only a small horizontal distance (see p. 73). If only simple stereometers are available for parallax determinations it may be necessary to entirely discard some photograph prints unless (a) vertical control is available and the geologist carries out the tedious task of constructing a correction graph (Desjardins, 1950, p. 2304–2305; McNeil, 1952, p. 610–615; and Visser, 1954, p. 849–853), or (b) points of measurement are selected so that the effect of tilt will be minimized (Hemphill, 1958a, p. 46–47, 49). It is also possible to partially correct for tilt locally on planar orientations, such as the strike and dip of beds, by stereographic projection and appropriate rotations in stereographic constructions.

If photogrammetric instruments are available that allow photographs to be tilted, it is generally possible to eliminate any large amount of tilt (greater than 1°) by careful inspection of physiographic features of the stereoscopic model, thereby permitting reliable parallax measurements to be made even though vertical control is not available for leveling the model. For example, lakes or other standing bodies of water may appear tilted, or certain streams or stream meanders may appear to flow uphill (fig. 109). Tilt is also often detected by observing that headwater tributaries in subdued divide areas where gradients are very low appear to flow uphill. Adjustment of the instrument so that the lakes appear flat and streams have a normal gradient will minimize tilt, and parallax measurements can then be made.

For certain sensitive measurements, such as measurement of low stream gradients or measurements used to determine the strike of low-dipping beds, it is essential that vertical control for leveling models be available and that a precision plotting instrument, such as the Kelsh plotter, be used. Because a small amount of tilt may seriously affect the measure of stream gradient the economic advantage of photogrammetric techniques may be lost where the measure of gradients is the primary photogrammetric objective, inasmuch as a considerable amount of vertical control must be obtained by ground survey to level the stereoscopic models. However, for many geologic measurements, particularly where relative intervals are to be measured, ground control, although desirable, is not essential for making satisfactory parallax determinations, either from paper prints or glass-plate diapositives.

DETERMINATION OF ALTITUDE DIFFERENCES FROM A SINGLE PHOTOGRAPH

Under certain conditions altitude differences between two points may be determined by making appropriate measurements of radial displacement on a single photograph and substituting them in the formula

$$h = \frac{mH}{r}$$

where h = difference in altitude desired;

m = relief displacement of upper image point with respect to the lower image point;

H = height of airplane above lower image point;

and r = radial distance from principal point of photograph to lower image point.

The distance m and r must be measured in the same units. The height, h , will then be in terms of the units chosen for H .

This procedure is only applicable to vertical objects where the upper point is known to be directly above the lower point. Under these restricted conditions, the length of the image of an object, such as a tree, or a cliff face at right angles to a radial line from the principal point, is a measure of the relief displacement. The radial distance to the lower point can be easily measured, and the flying height can be obtained from the formula $H = f/S$ (see p. 53-54) when base maps are available, or from the specifications of the photographic mission. Thus, for example, if the radial displacement of a cliff is 0.03 inch, the flying height of the airplane 10,000 feet, and the lower point is 3 inches from the photograph center, the height of the cliff will be

$$h = \frac{0.03 \times 10,000}{3.0}$$

$$h = 100 \text{ feet.}$$

Because relief displacement is generally small, a small error in measuring such a distance on a single photograph will result in a relatively large error in the height of the object, which further limits the usefulness of the formula for determining vertical intervals.

GEOLOGIC USES OF PARALLAX MEASUREMENTS

Parallax measurements always result in the determination of spot altitudes or vertical intervals when paper prints are used; and generally result in spot altitudes or vertical intervals when glass-plate diapositives are used in double-projection instruments, except when a special tracing table is used that permits measurement of inclined distances (fig. 22). These spot altitudes and differences in altitudes combined with horizontal distances determined from the stereoscopic model, or under some circumstances from

a single photograph, may be used to compile structure-contour maps and to determine dips of beds, thicknesses of beds, offsets on faults, gradients of streams, and related data.

Because of relief displacement, however, it may be necessary to correctly locate the relative horizontal positions of points, whose altitudes have been measured, before computing strikes and dips, determining stratigraphic thicknesses, or any other geologic measurements where dips are involved. Because tilt is usually negligible in present-day photography, horizontal positions of points generally may be plotted satisfactorily with any instrument that removes relief displacement, such as the radial planimetric plotter, paper-print plotters, and double-projection plotters even though the stereoscopic model cannot be leveled. Horizontal distances may then be scaled off. However, in the absence of plotters for locating the relative map positions of radially displaced points when measurements are made with parallax bar and paper prints, an overlay or similar procedure may be used to determine corrected horizontal distances, unless orthophotographs (see page 69) are available from which correct horizontal distances may be scaled.

The overlay procedure requires first laying out on transparent material a line equal in length to the adjusted photobase. The overlay is then placed over the right photograph of the stereoscopic pair so that the line drawn is coincident with the flight direction and its right end terminates at the photograph center. Radial lines are then drawn on the overlay from the photograph center through all points whose relative horizontal positions are to be determined. The procedure is repeated with the overlay positioned over the left photograph, again with the original line coincident with the flight direction and its left end terminating at the photograph center. The intersection of a pair of lines through the same image points is the corrected horizontal position for that point.

DETERMINING STRIKES AND DIPS

Where bedding surfaces coincide with topographic surfaces it is generally sufficient to measure the altitude difference between only two points, one directly down-dip from the other in calculating the amount of dip. The horizontal distance between these two points, together with the difference in altitude, gives the required information for determining the angle of dip from the trigonometric relation

$$\frac{\text{Vertical distance}}{\text{Horizontal distance}} = \text{tangent of angle dip.}$$

If relief in an area is low the horizontal distance may be scaled directly from a single photograph with-

out significant error in computing the dip, but where relief is moderate or high a correction for the relief displacement of the upper point with respect to the lower point generally should be made. In the unique circumstance where the strike is radial from a photograph center or where the surface on which the dip to be measured is at or near a photograph center, there is little or no relief displacement in the dip direction, and no correction in scaling the horizontal distance need be made. Hemphill (1958a, p. 53) suggested that the corrected horizontal distance between the upper and lower points should be at least 0.2 inch for computing dip angles. Where dips are greater than 50° , a longer horizontal distance is needed to determine the dip angle reliably, as the tangent increment per degree of dip is significantly greater for steep angles of dip than for low angles of dip.

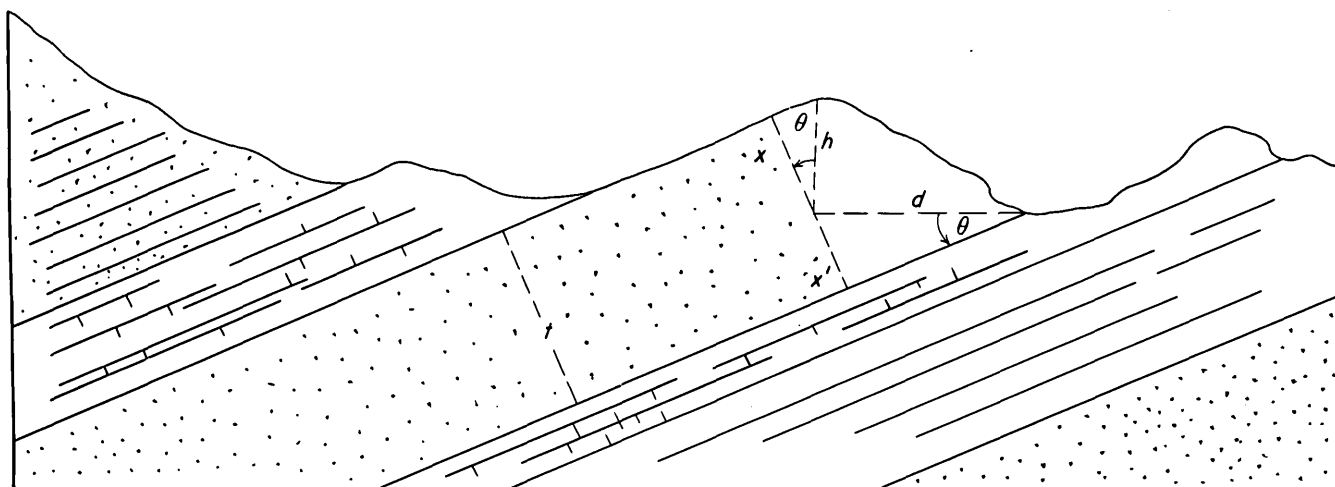
The strike line generally can be determined readily by inspection of the stereoscopic model and noting two points of equal altitude on a bed. Where dips are low, however, tilt in the photographs will affect the direction of strike; the lower the dip, the greater the effect, generally, on the amount of shift in the azimuth of the strike line. Graphs may be constructed to show the effect of tilt on low-dipping beds. (See Hemphill, 1958a, p. 48.)

Where a bed crops out in a valley wall it will generally be necessary to determine the altitudes of three points on the bed. In areas of moderate or high relief corrections for relief displacement must be made before distances between these points can be determined; otherwise distances may be scaled directly from the single photograph. Determination of the strike direction and amount of dip are then made graphically or graphically and trigonometrically.

DETERMINING STRATIGRAPHIC THICKNESS

In areas where beds are horizontal or nearly horizontal the stratigraphic thickness may be determined directly by converting to feet the parallax difference between the top and the bottom of the bed. No correction is necessary for relief displacement. However, if beds are inclined, the angle of dip must first be determined; then corrections must be made for relief displacement and for the effect of dip on the stratigraphic thickness. The thickness may be calculated by simple trigonometry or by graphic solution (fig. 26).

Desjardins (1950, p. 2308-2309; 1951, p. 829-830) suggested that floating lines be employed with paper prints for determining stratigraphic thicknesses where beds do not dip more than 15° . In the "floating line" procedure, lines are drawn on transparent strips of



Stratigraphic thickness is determined from the formula

$$t = x + x' = \frac{h}{\cos \theta} + \frac{d}{\sin \theta}$$

where t = stratigraphic thickness;

h = difference in altitude between some point on the lower contact of the bed and some point, along a line at right angles to the strike line, at the upper contact of the bed; altitude h is determined from the parallax formula;

d = corrected horizontal distance between points at lower and upper contacts of the bed;

and θ = angle of dip.

material that are superposed over each of the photographs. When one line over one photograph is positioned parallel to a line over the second photograph, a single floating line will appear when viewed stereoscopically unless the lines are parallel to the flight direction. The line will float above or within the model and appear to be horizontal; its vertical position in the model will depend on the separation of the two individual lines in the flight direction. A series of lines will form a grid or reference plane (Smith, H. T. U., 1943a, p. 171; Desjardins, 1943a, p. 219; Hackman, 1957, p. 593). When any one pair of lines is divergent rather than parallel the floating line in the stereoscopic model will appear to plunge. By changing the horizontal separation of any two lines in the flight direction the floating line can be made to rise or fall in the model, just as with the floating dot of the parallax bar. When the floating-line procedure is used in measuring stratigraphic thicknesses, a line is first floated preferably in the bedding plane at the upper formational contact, and parallax measurements are then made at the lower formational contact and on the floating line at a position in space vertically above this point (see fig. 27). If beds are

horizontal or nearly horizontal the parallax difference will be approximately a measure of the stratigraphic thickness. If the beds dip, the stratigraphic thickness will bear a cosine relation to the dip angle and parallax measurement (see fig. 27).

Where dips are steep it may be desirable to measure a horizontal distance along a line at right angles to the strike direction between two formation contacts and relate this distance and dip angle to stratigraphic thickness. Points must be chosen at approximately the same altitude in the stereoscopic model (fig. 28).

ISOPACH MAPPING

The use of aerial photographs in studies of certain areas in the Colorado Plateau of Western United States has included the photogrammetric compilation of isopach maps that show local thickenings of certain formations in which uranium minerals are likely to occur. These thickenings of formations are channel-fill deposits in stream channels that were cut in the underlying formation. Uranium minerals are locally concentrated in these deposits. In the Monument Valley area of southern Utah it has been demonstrated that isopach lines, indicating the trends and thicknesses of different channel-fill deposits, could be drawn

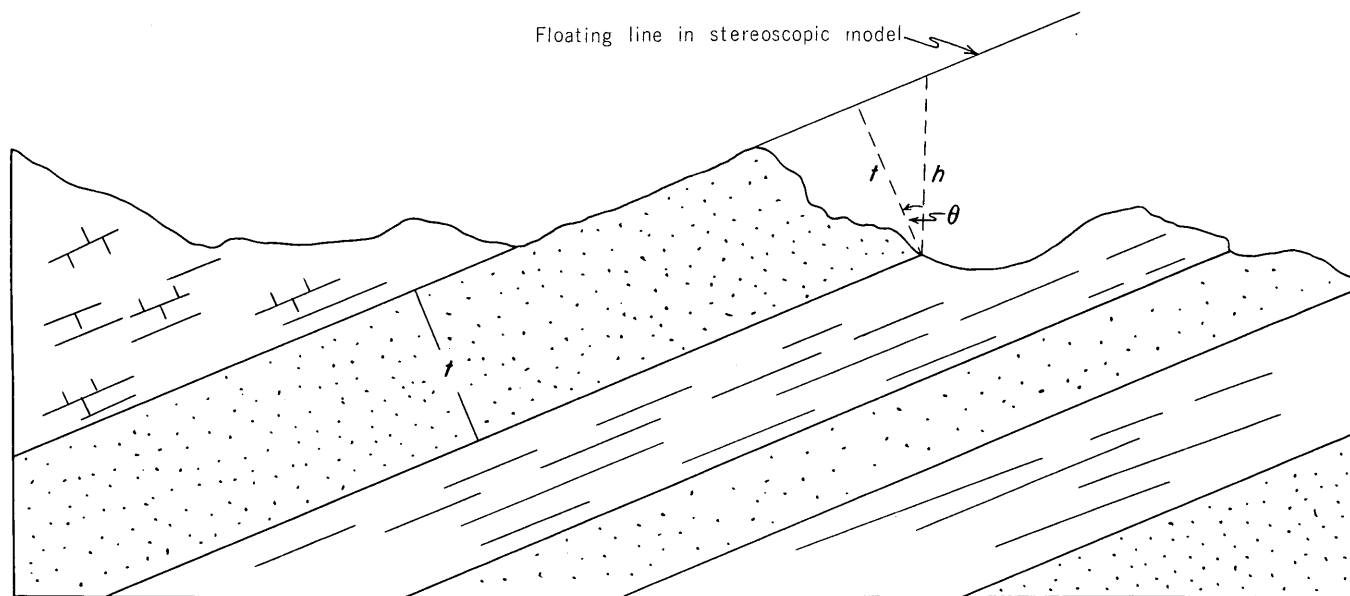


FIGURE 27.—Diagram of gently dipping beds showing relation of stratigraphic thickness to differential parallax determined by floating-line method.

Stratigraphic thickness is found from the formula

$$t = \frac{h}{\cos \theta}$$

where t = stratigraphic thickness;

h = difference in altitude between bottom of bed and point on floating line vertically above, as determined from the parallax formula;

and θ = angle equivalent to angle of dip.

on the basis of measurements made on vertical aerial photographs. In this area uranium minerals are present in channel-fill deposits at the base of the Shinarump member of the Chinle formation of Triassic age. However, because the top of the Shinarump member is eroded away in many areas, or because it is gradational with the overlying member of the Chinle formation, a stratigraphic unit below the Shinarump member was chosen as the unit for which isopach lines were drawn. A thinning of this underlying unit then was interpreted to indicate a thickening of, or channel deposits of, the overlying Shinarump member. The unit selected for isopach measurements, the Moenkopi formation, is expressed on aerial photographs as a dark-toned slope-forming unit that contrasts markedly with the light-toned cliff-forming units of both the underlying De Chelly sandstone member of the Cutler formation and the overlying Shinarump member of the Chinle formation (fig. 44).

A series of altitude measurements was then made along the contact of the Moenkopi and Shinarump formations from aerial photographs by means of the Kelsh plotter, and the locations of these measurements were plotted on a base sheet. Similarly, a series of altitude measurements was made along the contact of the De Chelly and Moenkopi formations and the locations were plotted on the base sheet. Measurements along the respective geologic contacts were

generally spaced at horizontal distances of about 500 feet. Because the stratigraphic units dip locally it was necessary to compute the strike and dip of the beds and to correct for the dip angle in determining the stratigraphic thicknesses of the Moenkopi interval. Thickness computations were plotted at the points of altitude measurements along the contact of the Moenkopi and the Shinarump, and isopach lines were drawn at 10-foot intervals on the basis of the distribution of thickness figures. The relatively large number of readings, both for strike and dip of beds as well as for altitude measurements, permitted elimination of certain computations that were inconsistent with regard to the overall mass of statistical data. The locations and depths of channels of Shinarump member as shown by isopach lines based on photogrammetric measurements and plotting were generally in close agreement with those determined by field methods. Details of the photogeologic study are described by Witkind, Hemphill, Pillmore, and Morris (1960).

FACIES CHANGE

Measurements from aerial photographs in conjunction with stratigraphic studies of Cretaceous rocks in northern Alaska have demonstrated the rate and direction of "shaling," or facies change, of certain formations. In the Utukok-Corwin area resistant rocks of the Kukpowruk formation, which is predominantly silty shale, siltstone, and sandstone, overlie less resistant

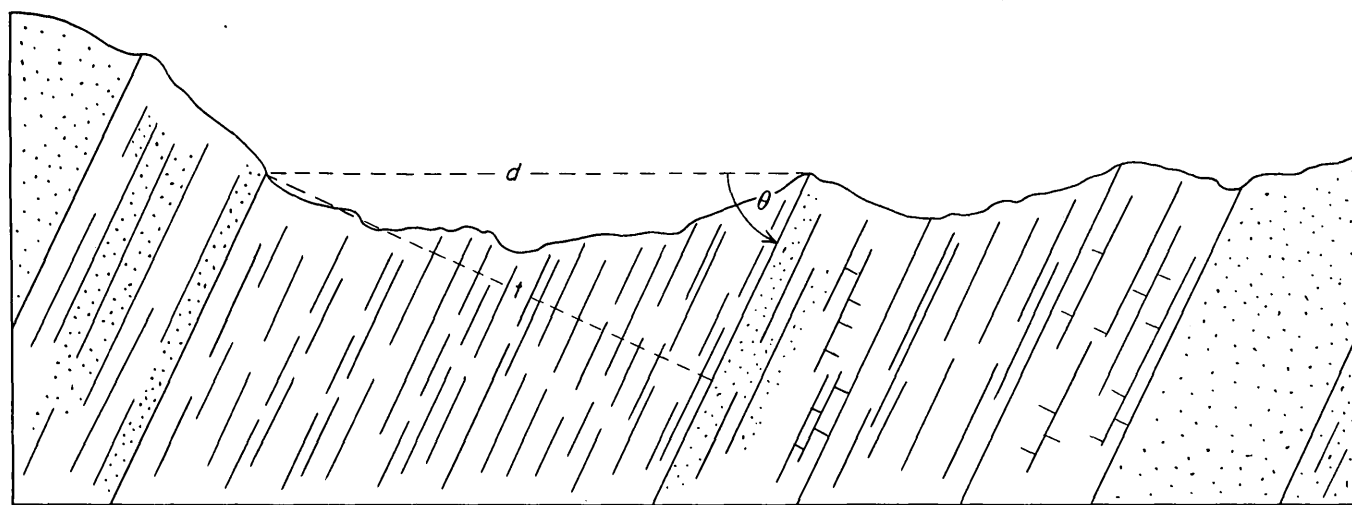


FIGURE 28.—Diagram of steeply dipping beds showing relation of stratigraphic thickness to dip angle and horizontal distance between top and bottom of bed.

Stratigraphic thickness is determined from the formula

$$t = \frac{d}{\sin \theta}$$

where t = stratigraphic thickness;

d = horizontal distance at right angles to strike line between points at same altitude on top and bottom of bed;

and θ = angle of dip.

rocks of the Torok formation, which is largely clay shale, claystone, and silty shale. The Torok formation commonly forms the lowlands, which are characterized by rather uniform and low-dipping topographic slopes. The Kukpowruk formation forms high, resistant ridges that can be traced many miles. The contact of the two formations is marked by a break in topography that has been mapped in the field in conjunction with the study of aerial photographs. Slopes below the contact are generally smooth and unbroken; slopes above the contact are marked by conspicuous topographic breaks caused by hard, resistant sandstone beds in the basal part of the Kukpowruk formation. Vertical exaggeration of the stereoscopic model accentuates these topographic breaks in slope. Photogeologic and field studies show that these resistant beds pinch out usually in an easterly or northerly direction (see fig. 97). It is significant that their topographic expression is lost. Ground observations along stream cuts indicate that the resistant beds grade laterally into shaly sections.

Quantitative studies from aerial photographs of the amount of section affected by facies change in the Utukok-Corwin area show that several thousand feet of sandy section of the Kukpowruk formation grade laterally to the east and north into shale of the Torok formation. Chapman and Sable (1960) stated that the methods used in these studies included tracing on vertical aerial photographs a resistant unit within the Kukpowruk formation around the flanks of a large open structure and then measuring the stratigraphic intervals between the resistant bed and the contact of the Kukpowruk and Torok formations to determine the new relative stratigraphic positions of the contact in different parts of the area. Photogrammetric measurements were made whenever possible in localities of good field control; a few stratigraphic thicknesses were determined solely by photogrammetric methods without field control. Locations for measurements were chosen along east-west and north-south lines. Relative stratigraphic positions of the contact of the Kukpowruk and Torok formations were then plotted graphically against lateral distances between points of measurement; this resulted in a line whose gradient showed the average rate of rise of the contact between points of measurement. An average eastward-rising gradient of 58 feet per mile and an average northward-rising gradient of 97 feet per mile were calculated.

It was concluded on the basis of plotting these average gradients as vector quantities that a resultant maximum gradient of 115 feet per mile exists and that more than 10,000 feet of sandy beds grade into shaly sections over the area studied. The maximum gradient direction was further interpreted to lie at right angles

to the direction of minimum facies change, which is believed to indicate the general trend of the old shoreline during the period of deposition of the Kukpowruk and Torok sediments. Thus the photogeologic measurement of stratigraphic intervals not only permitted determination of the directions and amounts of facies change, but further allowed inferences concerning the geologic history and environment, which may be significant in the search for petroleum in that area.

STRUCTURE CONTOURING

Structure contours are usually constructed on the basis of a series of spot altitudes, some of which may be photogrammetrically determined at the top of the horizon to be contoured, but many of which will be measured at formation contacts above or below that horizon. Photogeologic procedure is similar to field procedure and requires adjusting the altitudes of all points not on the horizon to be contoured by making appropriate considerations of strike and dip and stratigraphic thickness. Structure-contour lines are then adjusted to the resultant series of altitudes projected to the same formation contact.

NOTOM-15 QUADRANGLE

In photogeologic interpretation and mapping of the Notom-15 quadrangle, Utah, (Hackman and Tolbert, 1955) altitudes for structure contouring were measured using a Kelsh plotter. No previous geologic or topographic mapping had been done in the area; geologic data and altitude measurements were plotted to a control net established by photogrammetric methods. The Notom-15 quadrangle is well-exposed canyon country typical of the Colorado Plateau of Utah. Gently folded sedimentary rocks of Triassic and Jurassic age underlie the area. Canyons transecting the general structure trend made the application of photogeologic procedures ideal. A series of altitude measurements were made along the contact of the Wingate sandstone of Triassic age and the overlying Kayenta formation of Triassic(?) age. The wide exposure of this contact throughout the area permitted sufficient measurements to control structure contouring. Structure contours were then drawn on the top of the Wingate sandstone. Subsequent fieldwork corroborated the general structure as contoured by Kelsh plotter from aerial photographs and also corroborated the distributions of rock formation as interpreted and mapped from photographs. Positioning of other planimetric data, such as streams, was shown to be in excellent agreement with the subsequently compiled standard topographic map of the quadrangle. The positioning of data and altitude determinations by Kelsh plotter thus resulted in a highly reliable geologic map of the area.

DISCOVERY ANTICLINE

Procedures used in contouring the Discovery anticline in northern Alaska included stereometer measurement of altitudes combined with simple trigonometric computations and graphic constructions to compile a generalized structure-contour map (Marshall and Rosendale, 1953). These procedures contrast markedly with the Kelsh-plotter compilation of the Notom-15 quadrangle, but demonstrate that simple methods may be useful in obtaining structural information of a reconnaissance nature from aerial photographs.

Discovery anticline, a gently folded structural feature approximately 25 miles long and 7 miles wide, is underlain primarily by Cretaceous rocks. The area is generally covered with tundra grasses, but resistant beds within the stratigraphic section are expressed topographically as ridges, or breaks in slope, that can be traced for many miles; some beds are expressed by photographic tone due to differences in vegetation (see fig. 40). Dip slopes rarely coincide with topographic surfaces.

Procedures for obtaining and positioning data for structure contouring involved the arbitrary selection of cross-section lines normal to the general structural trend. Strikes and dips of beds were then determined by simple stereometer methods at numerous localities and projected to the nearest cross-section line. Where the strike line did not intersect the line of section at right angles the apparent dip was determined and plotted on the section line. This procedure was fol-

lowed for all strikes and dips, and resulted in cross-section lines along which the different dips were plotted. A marker bed was then selected and its profile along the line of section graphically reconstructed on the basis of the positions and amounts of dip previously plotted (fig. 29). It was assumed that bedding throughout the stratigraphic section was parallel. Structure contours were then positioned along each line of section by further graphic constructions (fig. 30). However, the datum for each line of section commonly was different, depending on which part of the stratigraphic section was expressed in any one local area, and it was necessary to obtain stereometer measurements of altitudes between cross-section lines so that structure contours, as positioned along each line of section, could be tied together (fig. 31). The resulting reconnaissance map, plotted on an uncontrolled photomosaic, indicated the general magnitude and closure of the anticline and the attitude and steepness of bedding. Figures 29-31 show graphic constructions in reconnaissance structure contouring from measurements made with stereometer-type instruments.

DETERMINING DISPLACEMENTS ON FAULTS

The vertical component of displacement on some faults may be readily determined from parallax measurements made on marker beds on opposite sides of the fault by simple conversion of parallax difference to feet or other appropriate unit of measurement. If the fault plane dips, relative altitudes on marker beds may be related to the down-dip component of displacement by trigonometric or graphic solution.

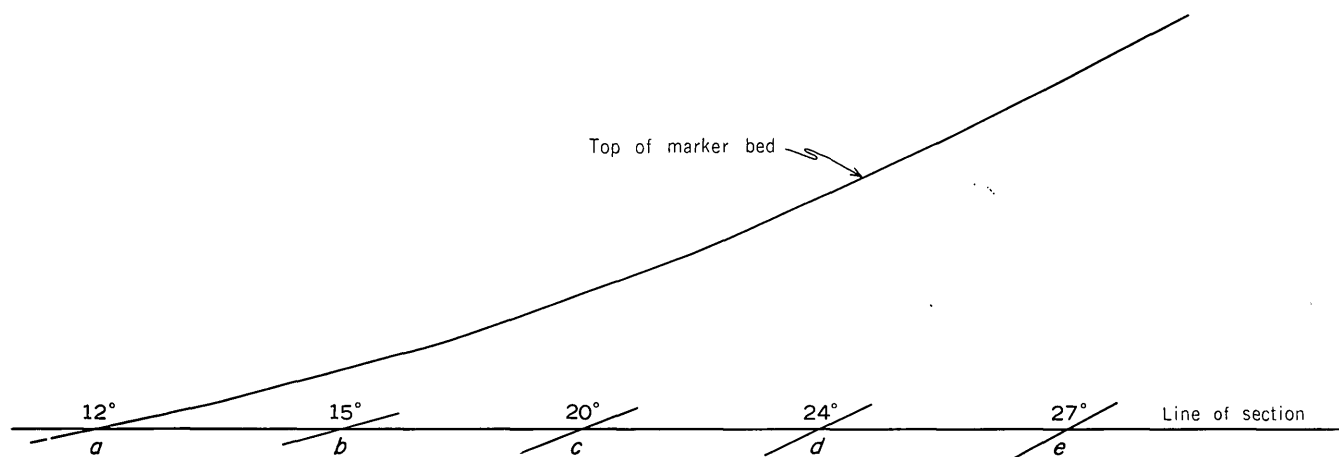


FIGURE 29.—Diagram showing graphic reconstruction of marker bed along line of section.

Dips determined from aerial photographs are first plotted along line of section. The marker bed is then reconstructed by extending bed upward from point *a* at 12° dip for half the distance between *a* and *b*. From this point the bed is extended at 15° dip to a point half the

distance between *b* and *c*. From this point the bed is again extended at 20° dip to a point half the distance between *c* and *d*, and so on. A smooth curve is then drawn to represent the marker bed.

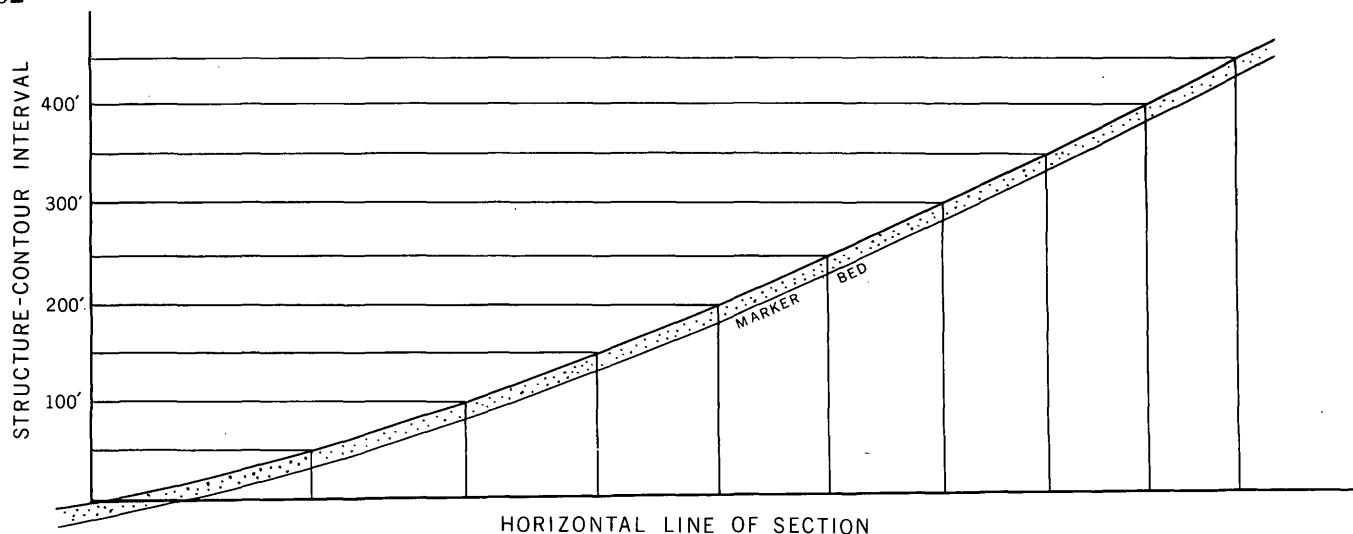


FIGURE 30.—Diagram showing graphic construction in positioning structure-contour lines on top of marker bed and the projecting of these lines to their relative horizontal positions along the line of section.

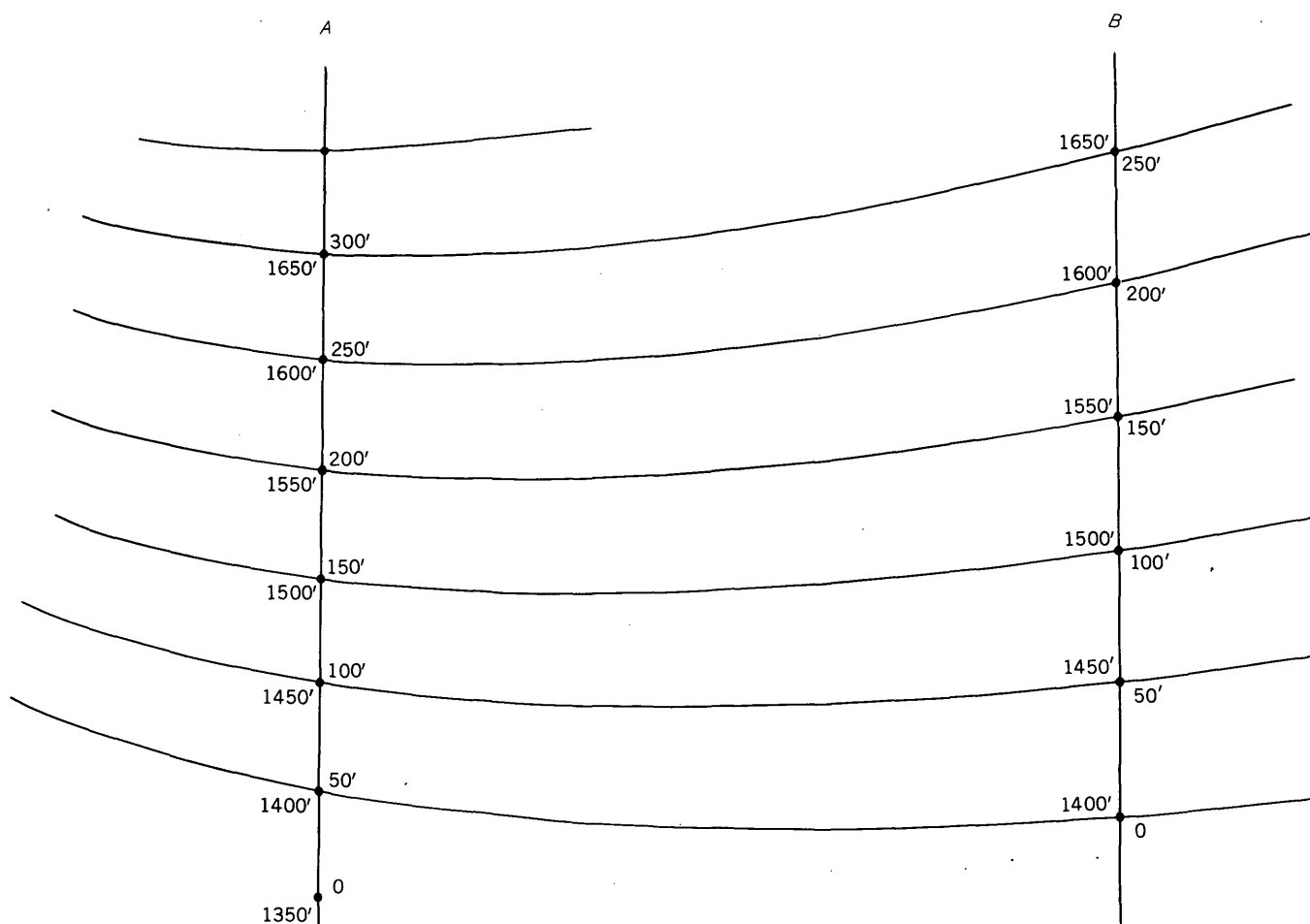


FIGURE 31.—Diagram showing relation of structure-contour positions along two lines of section at different altitudes.

Relative positions of 50-foot structure contours along each line of section are shown to the right of each line. Absolute altitudes of structure-contour positions are shown to the left of each line of section. Because the zero points on the reconstructed marker bed along lines A and

B lie at 1,350 and 1,400 feet, respectively, it is necessary to connect the 50-foot contour position on line A with the zero contour position on line B, in compiling the structure-contour map.

DETERMINING STREAM GRADIENTS

Stream gradients may be calculated from parallax measurements under certain circumstances. Because many stream gradients are very low—a few feet or tens of feet per mile—an instrument should be used that will permit correction for tilt in the photographs. It will also be desirable to have vertical control for the removal of tilt, as a small amount of tilt not removed from the stereoscopic model could seriously affect the computation of stream gradient. If a stream has a meandering course, then the horizontal distance along the stream between points of measured parallax must be determined by a chartometer or similar instrument for measuring distances along a curved path.

**DIRECT DETERMINATION OF SLOPE
DIPPING PLATEN**

In addition to the indirect determination of slope by the use of parallax measurements in conjunction with trigonometry or graphic solution, direct measurements of some slopes may be made, both from glass-plate dispositives in double-projection instruments and from paper prints. The simplest procedure is with double-projection instruments and involves the use of a modified platen that can be tilted to coincide with the dip of a topographic surface or bedding plane (fig. 32). Because all features of the terrain are optically re-created in the stereoscopic model of double-projection instruments in essentially true relation, the dip of the platen when made to coincide with the ground surface, or to intersect three or more points on a bedding plane, will be a true measure of the dip of that surface. The dip can be measured with a clinometer at-

tached to the platen or by an accessory device such as a "devil level" or Brunton compass. Dips below 40° can be readily obtained by this method, provided topographic expression or rock outcrops permit positioning of the platen. Dips greater than 40° are difficult to determine owing to the difficulty of positioning the dipping platen in the plane of a steeply dipping surface; steep dips should be computed using the parallax methods described above.

STEREO SLOPE COMPARATOR

A unique method for determining angles of slope from paper prints is employed with the stereo slope comparator (fig. 33), which was developed by the U.S. Geological Survey (Hackman, 1956b, p. 893-898). The instrument consists of two gear housings each containing a horizontal shaft on which small targets are mounted that can be fused stereoscopically into a single target. Swing of the horizontal shafts permits positioning the targets in any direction of strike. The gear housings are mounted on sliding tubes that permit the targets to be separated horizontally so that the fused target appears to rise or fall in space, just as the dot in stereometer-type instruments. However, the dip is determined by physical tilting of the target in space. The instrument is unique in that it measures the exaggerated dip of the imaginary slope created by stereoscopic viewing. With vertical photographs of normal 60 percent overlap, most individuals see the terrain exaggerated in height from 2.5 to 3.5 times. The exaggerated dip, recorded on a protractor attachment on the stereo slope comparator, must be reduced to a true dip. This is accomplished by reference to

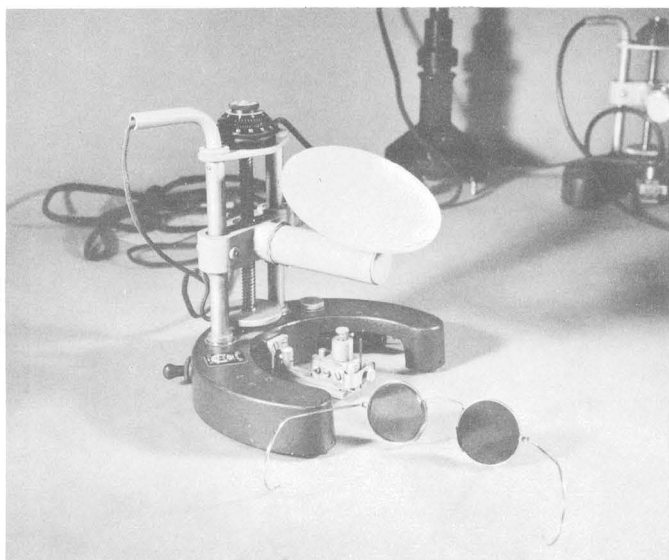


FIGURE 32.—Dipping platen.

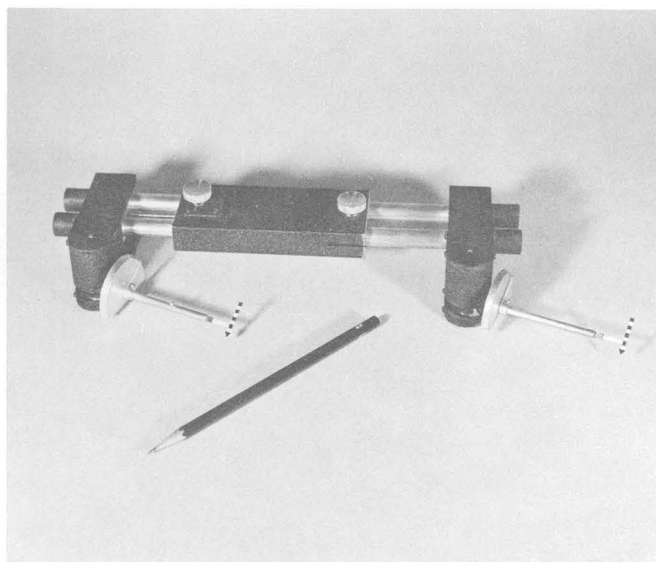


FIGURE 33.—Stereo slope comparator.

INSTRUMENTS FOR DIRECT DETERMINATION OF SLOPE

a slope-conversion graph made up of intersecting lines that represent true angle of slope, exaggerated angle of slope, and exaggeration factor (fig. 34). Construction of the graph is based on the relation

Tangent true angle of dip

$$= \frac{\text{tangent exaggerated angle of dip}}{\text{exaggeration factor}}$$

In determining dips from a pair of paper prints it is necessary to know the exaggeration factor of the interpreter for that stereoscopic model. This factor varies slightly with different individuals and is determined by reference to a supplementary slope chart on which a dipping surface of specific dip has been constructed by methods described by Hackman (1956a, p. 387-391). By measuring the exaggerated dip of this constructed surface, known to represent a given true angle of dip, an exaggeration factor is obtained; it is then possible to make measurements on a specific pair of photographs and to convert any exaggerated dip to a true dip. Because of the difficulty of placing the tilted target in a steeply dipping plane, the instrument is most reliably used where true dips are 20° or less.

DIP ESTIMATION

From paper prints an experienced interpreter can estimate dips, particularly in the range of 1° to 5°, with considerable reliability, as a result of vertical exaggeration in the stereoscopic model. Because of vertical exaggeration, angles of slope in terms of their tangent functions are exaggerated in the stereoscopic models as much as 2.5 to 3.5 times, with the result that low-dipping surfaces, which are in places difficult to observe in the field, are readily interpreted (figs. 45, 88, 90, 91, and 97). For example, a true dip of 1° may appear to be a dip of 3° or 4° in the stereoscopic model, and a dip of 5° may appear to be 15° to 20°. For true dips below 20° an error of a few degrees in estimating the exaggerated dip has only a small effect on the true dip (see fig. 35), and an interpreter is able to make reliable visual determinations of these dips from most stereoscopic models. But steeply dipping surfaces are also exaggerated and made more difficult to evaluate. Any small error in determining the angle of exaggerated dip of steep slopes results in a relatively larger error in the true dip calculation for that slope. Brundall and Harder (1953, p. 150) stated that "the accuracy of individual estimation is generally inversely proportional to the steepness of dip." In estimating dips a correction obviously must be made for the oversteepened slopes as they appear in the stereoscopic model (see figs. 34 and 35).

Factors affecting vertical exaggeration in stereoscopic models have been discussed by several writers (Treece, 1955; Goodale, 1953; Thurrell, 1953; Miller, 1953; Aschenbrenner, 1952; and Stone, 1951), but complete agreement has not been reached concerning the effects of specific factors such as viewing distance and image separation. However, once an interpreter has correlated amounts of dip, determined photogrammetrically or by field procedure, with a given set of conditions such as type of stereoscope, focal length of photography, photobase, and image separation, reliable estimates of true dip can be made over wide areas without reference to known dips.

OTHER METHODS OF DETERMINING ANGLES OF SLOPES

Another method of determining slopes in stereoscopic models is based on the floating-line principle. Brundall and Harder (1953, p. 150-151) briefly mentioned a device consisting of two lines scribed on plastic plates. The lines, seen stereoscopically as a single line floating within the model, can be made to converge so that the floating line appears to plunge in space. The plunging floating line is placed in the component of dip direction at right angles to the flight line. The angular rotation of the scribed lines required to obtain a given amount of steepness of plunge of the floating line is then related to true dip by means of a graph. As this method would result in true dip only for beds striking parallel to the flight line, the correction graph must also consider the azimuth of the dip component observed with respect to the strike of the beds.

Wallace (1950) has used angular relations in the plane of the aerial photograph as the basis for a method of determining strikes and dips from aerial photographs. The method is best applied where erosion has exposed bedding trace lines as contrasted to broad topographic surfaces that coincide with bedding. No parallax measurements are required. It is necessary to measure the angular relation of two bedding trace lines with respect to a known or assumed azimuth line on each photograph of a stereoscopic pair and to determine the plunge of the line of sight from the camera position to the outcrop, or bedding-trace line. These data are then plotted on a stereographic net to determine the strike and dip of the bed (Wallace, 1950, p. 275).

OTHER METHODS OF DETERMINING QUANTITATIVE DATA

Measurement of geologic data, other than altitudes and direct determinations of slope angles, are only infrequently made from aerial photographs. However, the possible applications of light-transmission measurements, from both black-and-white and color pho-

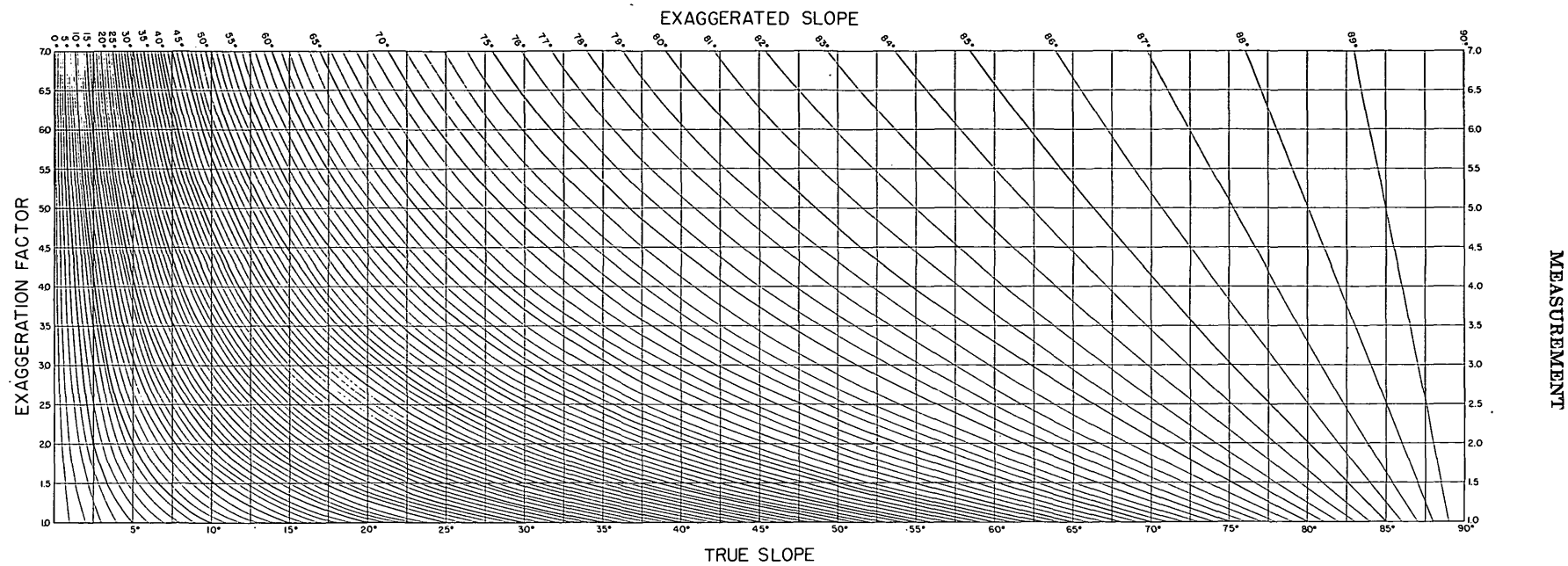


FIGURE 34.—Slope-conversion chart showing relation of exaggeration factor, exaggerated slope, and true slope.

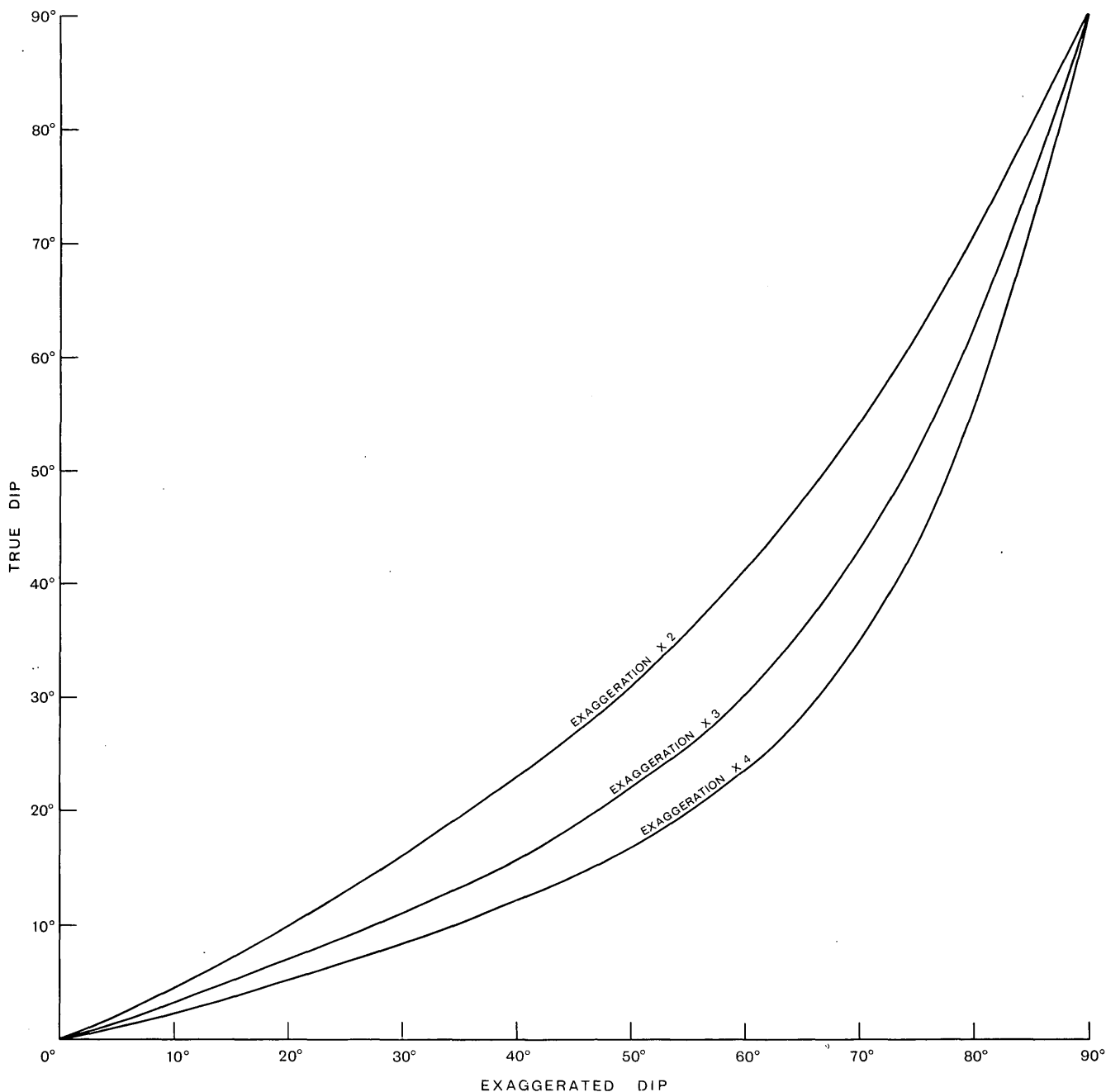


FIGURE 35.—Diagram, based on tangent functions, showing relation of true dips to exaggerated dips seen in stereoscopic models.

tography, light-reflectance measurements, measurements related to heat-retention characteristics of terrain photographed, infrared absorption, size, frequency, and orientation measurements of physiographic features, and perhaps others, offer challenging opportunities for future study (see Ray and Fischer, 1960).

PLOTTING

Map compilation—planimetric positioning of data—is basic to most geologic studies and generally requires

methods of plotting data orthographically. Thus, data plotted or interpreted on vertical aerial photographs, most of which are perspective in view, must be replotted on an orthographic base. The orthographic base may be planimetric or topographic. Where no base map exists perspective aerial photographs provide a medium for constructing a control layout on which geologic and other data may be plotted orthographically.

CONSTRUCTION OF CONTROL LAYOUT

A control layout is an orthographic plot of a series of points selected on aerial photographs that cover a given area. These points are used to control the positioning of data plotted from the perspective photograph. Plotting, or transfer, of data from the photograph may be done with simple overhead projectors or sketchmasters under some circumstances, or with stereoplotting instruments described above. The accuracy of the final plot will depend primarily upon the control net and the instrument used in plotting (see p. 74-75).

Basically a control layout or control net is established by triangulation from the aerial photographs in much the same manner as field triangulation is carried out. This aerial triangulation requires mechanical construction of templates which are assembled together into the triangulation network. There are two general methods of constructing templates. One method involves radial triangulation using the principal point of the single photograph as a principal triangulation station to construct radial templates; the other method involves radial triangulation using some orthographically positioned pass point from the stereoscopic model as a principal triangulation station to construct stereotemplates.

Where single photographs are used for triangulation it is generally assumed that the photographs are truly vertical and have no tilt; relief displacement is radial from the photograph centers. However, a tilt of 1° or 2° does not significantly affect horizontal positioning over small areas. Templates from single photographs may be constructed by the hand-templet method, the radial-arm ("spider"-templet) method or the slotted-templet method. Photographs are first prepared by marking the centers, conjugate centers, and selected pass points, usually six in number, along the margins of a photograph; pass points are selected which are common to adjoining flight strips and common to succeeding and preceding photographs within the flight strip. From each photograph, azimuth lines are then constructed from the photograph center through all other selected points to form a templet for that photograph. Azimuth lines may be drawn in pencil on an overlay sheet (hand-templet method); they may be constructed of metal arms ("spider"-templet method), or they may be cut as slots in a piece of cardboard (slotted-templet method). After templates have been constructed for all photographs they are assembled into a triangulation network in which the intersections of azimuth lines locate the orthographic positions of the points selected. The result is a base sheet with a series of points located

in their correct relative horizontal positions. Where horizontal control points are available, the distance between plotted positions of any two of them determines the scale of the control layout. Details of constructing and assembling these templates are described by Kelsh (1952, p. 419-429).

Construction of stereotemplates requires the use of a stereoplotting device to plot selected points common to adjoining flight strips and within the flight strip. The templet is actually a double templet of the area of the stereoscopic model rather than the single photograph. Azimuth lines are constructed for each part of the templet using one of the pass points as a principal triangulation station for one part of the templet, and using a different, generally diagonally opposite, pass point as the principal triangulation station for the second part of the templet. These two parts are joined together to form the completed templet for each stereoscopic model. Details of constructing and assembling the stereotemplates have been described by Scher (1955). Because of the longer base line of stereotemplates the resulting triangulation network is said to have a stronger scale solution than can be obtained from radial templates constructed from single photographs. Other photogrammetric advantages are mentioned by Scher (1955).

ORTHOGRAPHIC POSITIONING

PLOTTING ON ORTHOGRAPHIC BASE MAPS OR CONTROL LAYOUTS

The main objective in orthographic plotting of geologic data is to show the true planimetric relations of geologic features by removing relief and tilt displacement that may be present in perspective vertical aerial photographs. Relief displacement is commonly large, but tilt displacement is generally small and is usually disregarded when positioning geologic data on a planimetric base sheet. When positioning geologic data to a topographic base both relief and tilt displacement may be significant and require plotting from a leveled stereoscopic model. For horizontal positioning of data to a planimetric base in areas of low relief the relief displacement will be small; overhead projectors may be used to transfer data from the photograph to base map or control net. For example, with common photography of 1:20,000 scale taken with a 6-inch-focal-length lens, radial displacement near the edge of the photograph will only amount to about 0.1 inch where topographic relief does not exceed 300 feet. Basically relief displacement of a given amount of relief is a function of flying height and is independent of focal length and scale (see p. 74-75).

Where relief displacement is excessive it is possible

to change the photograph scale by racking the overhead projector up and down and, provided base map control is sufficiently dense, to scale small areas of the photograph to the base, thus compensating for much of the radial displacement of the perspective photograph. The reliability of the final plot will be in part a function of the density of control points on the base. The suitability of the final plot will depend on the geologic objective. On most radial triangulation networks it is common to find eight control points, exclusive of the photograph center, for each photograph; this number of points will not normally be sufficient to give a reliable plot of the geologic detail in areas of moderate or high relief unless a stereo-plotting instrument is used. The vertical sketch-master, in which the image of a single photograph is seen superposed on the base map or control sheet, generally is used in the same way that overhead projectors are used in plotting. The same general limitations of the overhead projector apply to the sketch-master; that is, radial displacement due to moderate or high relief cannot be effectively removed.

Orthographic plotting may also be accomplished with the radial planimetric plotter (fig. 14), or with the more complex paper-print plotters, such as the KEK or Mahan plotters. (See p. 42, 45). The radial planimetric plotter is the simplest to operate. It is easily scaled to control points on the base map or triangulation network and effectively corrects for the radial displacement of vertical aerial photographs. Fine detail, such as the configuration of reentrants in contact lines, may be lost in plotting, however. Tilt inherent in photographs cannot be eliminated, but horizontal positioning due to small amounts of tilt found in present-day photography do not significantly effect horizontal positioning of photographic detail for most geologic interpretations. The KEK and Mahan plotters may also be used to plot geologic data from paper prints. These instruments permit compensation for any inherent tilt that may be present in the photographs but are more difficult to operate than the planimetric plotter.

Whenever paper prints are used in plotting or transferring geologic data to base maps or control sheets it may be desirable to annotate, or mark, the geologic features to be transferred. This is particularly desirable when overhead projectors are used and is usually a necessity for all instruments if someone other than the interpreter is to do the plotting.

Double-projection instruments afford a high degree of reliability in plotting geologic data from aerial photographs. The ability to correct for tilt and relief displacement combined with an enlarged view

of the stereoscopic model when the Kelsh, multiplex, or ER-55 plotters are used permits a highly reliable compilation of geologic data. Even when vertical control is lacking, it is possible to remove most of any tilt inherent in the stereoscopic model by careful reference to physiographic manifestations of tilt such as oversteepened or reverse stream gradients, tilted meanders of a stream, or tilted bodies of standing water (see p. 55).

True orthographic positioning is not always attained, however, in geologic compilations from aerial photographs. Not only is there a question at times of the reliability of interpretation because of the subjective nature of much photogeologic study, but the various instruments themselves have differing degrees of accuracy inherent in their construction. Positioning of clearly identified geologic features by overhead projector, which does not permit adjustments for tilt or effective removal of relief displacement, would be far less reliable under most circumstances than positioning by double-projection instruments. However, the geologic product sought should determine in part the procedure to be used in plotting. Normally there is no reason to use an instrument that will plot detail more accurately than is needed to satisfy the geologic requirement. For example, in small-scale reconnaissance mapping, it is hardly necessary to use a precision plotting instrument for horizontal positioning. The problem of instrument requirement in relation to the geologic problem is further considered under a discussion of interpretation and plotting systems (see p. 69-75).

Only where a significant saving in time and money can be shown is it justifiable to use an instrument whose capability exceeds the minimum requirements of the geologic problem. Such a condition may exist for example where small-scale photographs of an area are available. Much of the United States is now covered by photographs at a scale of approximately 1:60,000. The use of such small-scale photographs in an instrument such as the Kelsh plotter may reduce by as much as 90 percent the number of stereoscopic models that would normally be oriented for interpretation, measuring, and plotting if 1:20,000-scale photographs were used. Even when 1:20,000-scale photographs are used with simple instruments the common practice is to separate the operations; that is, the stereoscope is used to interpret geologic detail and another instrument, such as the stereometer, is used to determine vertical measurement. Thus, by using a precision plotter, which combines interpretation, measuring, and plotting, a significant saving in time and money may be expected.

PLOTTING ON ORTHOPHOTOGRAPHS

An orthophotograph is a photograph that has the position and scale qualities of a map. In addition it has the abundant imagery of the conventional perspective photograph and hence a wealth of photographic detail (fig. 47). Theoretically the orthophotograph, with tilt and radial displacement eliminated in preparation (Bean and Thompson, 1957), has the desirable detail of a photograph and the geometric characteristics of an accurate planimetric map. The method of constructing the orthophotograph from double-projection stereoscopic models results in a small loss of photographic resolution, but horizontal positioning accuracy is comparable to that of the standard topographic map of the same scale.

The orthophotograph, when viewed with an alternate perspective aerial photograph, forms a stereoscopic model, although with only a small amount of stereoscopic relief as contrasted to viewing two perspective photographs. In viewing an orthophotograph with a perspective photograph it is generally best to use the same perspective photography as was used in the preparation of the orthophotograph. Combining the orthophotograph with a perspective photograph permits plotting of geologic detail from the perspective photograph to the orthophotograph and gives a reliable photomap. Geologic data on the orthophotograph then can be transferred by direct projection to a topographic or other base, if desired, or merely traced off to give a reliable planimetric map of areas where no base maps exist. As an aid to field geologic mapping, in which a daily plot of observed data is desirable, the orthophotograph may be especially helpful.

The range of potential applications of orthophotography has been summarized by Bean and Thompson (1957, p. 178) who stated that " * * * whenever there is an advantage in being able to determine accurately on an aerial photograph the positions of points, the lengths or directions of lines, the courses of curved lines, or the shapes or areas of given tracts, the orthophotograph offers a potential means of accomplishing the desired end." In addition, as the basis for constructing mosaics the orthophotograph has a significant application, especially in areas of moderate or high relief.

PLOTTING ON GRIDDED BASE MAPS

Gridded base maps may be especially valuable for field plotting of geologic data without the assistance of photogrammetric instruments. In constructing a gridded base map a grid made up of small squares, usually 1 centimeter on a side, is first superposed

photographically onto the perspective aerial photograph. The same grid is then orthographically transferred to the base map by a photogrammetric technician using stereoplotting instruments (Landen, David, oral communication, 1958). The grid lines are straight as superposed on the perspective photograph but are curved on the base map (figs. 115 and 116). By dividing the photograph into many small grid squares the effects of tilt and relief displacement become so small as to be negligible within any one square. Information sketched within grid squares on the perspective photograph is transferred visually to the base map by matching grid squares on the photograph with those on the map. The method may be especially useful in the field where it is desirable to keep a compilation of each day's work.

VERTICAL POSITIONING IN CROSS SECTIONS

In addition to the orthographic positioning of photogeologic data on base maps it is commonly desirable to plot geologic cross sections. The third dimension of the stereoscopic model is then added in part to the normal two-dimensional planimetric presentation of geologic information. Vertical positioning of geologic data, as shown in cross section, may be helpful to the geologist interpreting the aerial photographs of an area, as well as to the map reader who may be less familiar with the geology of the area.

Cross sections are easily and rapidly constructed with a profile plotter from stereoscopic models in double-projection plotters. Modification of the tracing table permits profiles to be drawn in any direction within the stereoscopic model (figs. 19 and 20). Sections may be drawn at a horizontal-vertical ratio of 1:1 or they may be exaggerated as much as 5 times. When a 1:1 ratio is used, dips of beds or components of dip, stream gradients, thickness of beds, and similar data may be obtained directly from the section. Exaggerated profiles may be desirable where relief of terrain is low, or, for example, when interpreting the significance of vertical position of thin stratigraphic units in correlation studies. Vertical positioning in sections may also show information suggesting the presence of faults.

INTERPRETATION, MEASURING, AND PLOTTING SYSTEMS

An interpretation, measuring, and plotting system (see fig. 36) may be defined as a combination of photographs and instruments that will permit attaining specific qualitative and quantitative geologic information from stereoscopic models. The optimum system is generally achieved by combining the minimum

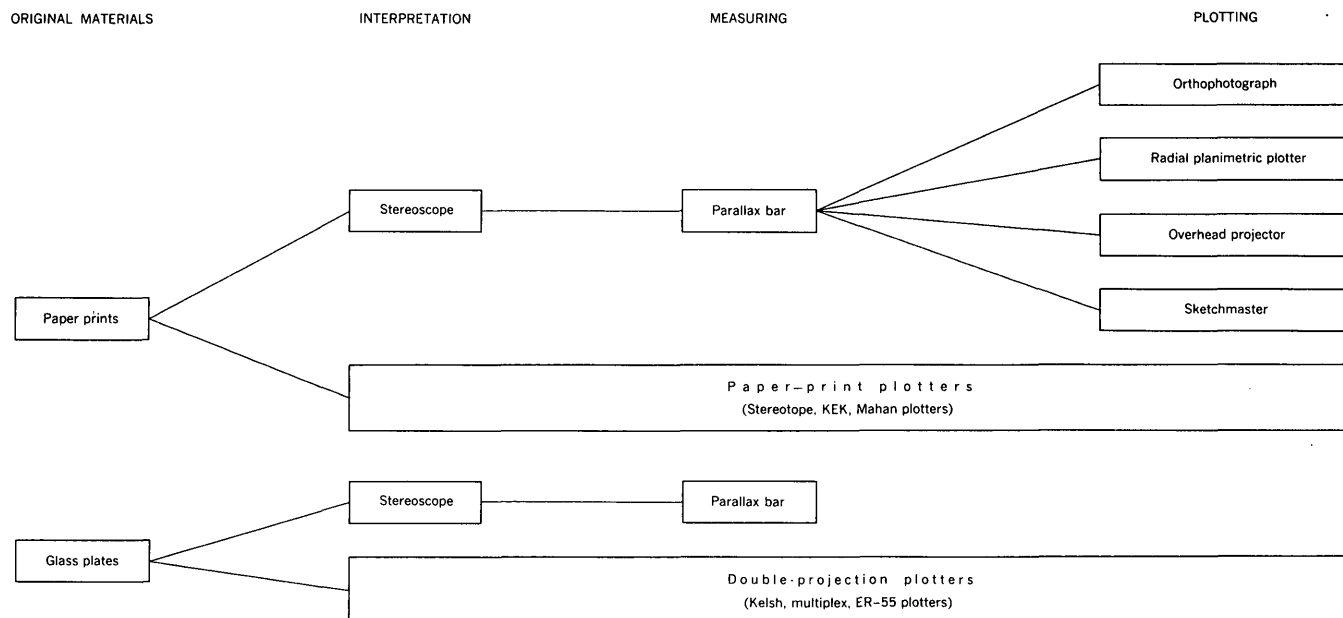


FIGURE 36.—Photogrammetric systems for geologists.

scale photographs and minimum instrument capability that will provide the desired geologic measurements within given accuracy requirements. That is, the scale of photographs should be the smallest that will permit differentiation of photographic detail needed for qualitative interpretation, as well as the smallest that will permit photogrammetric measurements within specified limits. Fundamentally, the geologic objective of a particular study is the controlling factor in the choice of the optimum system of interpretation, measuring, and plotting. The geologic objective may permit the use of existing instruments and photograph scales or it may necessitate new photography or instruments to attain given accuracy requirements.

The type of geologic map and its intended use—the geologic objective—can be considered on the basis of accuracy requirements or limits of error, both in obtaining vertical measurements and in plan positioning of geologic features, provided photographic detail is adequate for qualitative interpretation. For example, a detailed structure-contour map may require an accuracy of vertical measurement within ± 5 feet of altitude and a horizontal position of geologic features within $1/25$ inch of true map position. In contrast a small-scale structure-reconnaissance map for planning purposes may permit a vertical tolerance of ± 50 feet and have only general horizontal positioning requirements. Thus the choice of an interpretation, measuring, and plotting system may be reduced to certain mathematical requirements that can be satisfied by combining instrument capability with appro-

priate photography; or the geologic objective or tolerances of measurement may be modified to permit the use of existing photography and instruments.

However, geologic maps, unlike topographic maps, have no standard accuracy limits except those imposed by the individual geologist, with the one exception in the Geological Survey that solid lines, representing faults, contacts, or similar geologic features, should generally be within $1/25$ inch of their correct map positions for general geologic maps at a scale of 1:63,360 or larger. Horizontal positioning of data within $1/25$ inch of true map position may be accomplished with almost any plotting instrument or plotting system, especially if relief of the area is low and excessive tilt is not present in the photographs. Hence, the vertical-accuracy requirement specified by the geologist for a given geologic problem is ideally the determining factor in choosing an interpretation, measuring, and plotting system. This accuracy requirement, as well as the maximum range of measurements expectable for any system, may be equated against instrument capability and photograph scale as follows:

Geologic requirement of vertical-measurement accuracy	Instrument capability in terms of K and V factors (see fig. 37).
or Expected maximum range of vertical-measurement error	

Figure 37 is an elaboration of this equation and shows the general relations between the geologic requirements of vertical accuracy or expected maximum error in measuring spot altitudes or vertical intervals

GEOLOGIC REQUIREMENT OF VERTICAL-MEASUREMENT ACCURACY OR EXPECTED MAXIMUM RANGE OF VERTICAL-MEASUREMENT ERROR, IN TERMS OF INSTRUMENT CAPABILITY

PHOTOGRAMMETRIC INSTRUMENTS THAT MAY BE USED

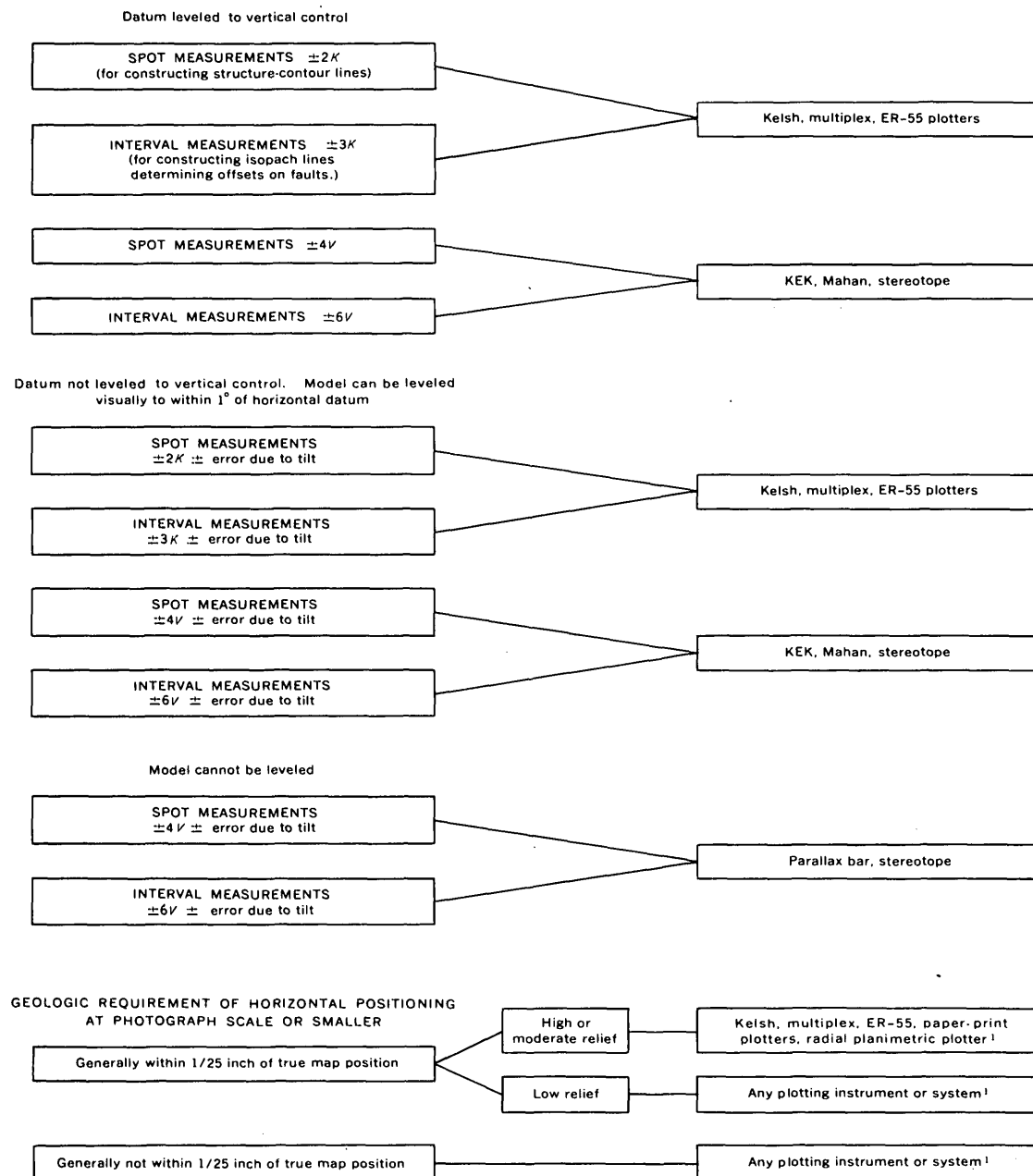


FIGURE 37.—Photogrammetric measuring and plotting systems for geologists showing relation of different instruments to vertical-measurement and horizontal-positioning errors.

where K factor = difference in altitude, in feet, on the ground per unit of vertical measurement in an anaglyphic-type model, that is, per 0.1 millimeter

$$= \frac{\text{model-scale denominator}^2}{3,048}$$

where V factor = difference in altitude, in feet, on the ground per unit of measurement from a parallax bar or a paper-print plotter, that is, per 0.01 millimeter

$$= \frac{\text{flying height (feet)}}{\text{photobase (millimeters)} \times 100}$$

¹ No excessive tilt assumed to be present for paper-print models that cannot be leveled.

² Model scale for Kelsh plotter is usually about 5 times original photography scale; for ER-55 usually about 3.5 or 5 times, depending on the projector model; and for multiplex usually about 2.5 times.

in terms of instrument capability on one hand and photogrammetric instruments that may be used for measuring and plotting on the other hand. The determination of spot altitudes or relative vertical intervals satisfies most geologic requirements of altitude measurements from stereoscopic models and permits construction of structure-contour lines, and isopach lines, and the determination of dips of slopes, displacements on faults, and similar data. Figure 37 can be used in choosing the best selection from existing photograph scales and instruments for measuring vertical distances, or it can be used to determine what combination of photograph scale and instruments would be optimum in making vertical measurements within certain specified tolerances. For economic reasons the geologist more often than not will be concerned with the best selection of existing photographs and instruments but this selection may not be the optimum interpretation, measuring, and plotting system. This may require modification of his geologic objective, at least in reporting the limits of measurement.

INSTRUMENT CAPABILITY

Instrument capability, selected as the principal basis for the systems shown in figure 37, is an empirically derived factor generally considered with respect to topographic mapping systems as the minimum contour interval—stated in terms of a fraction of the flying height—that can be plotted to fulfill certain accuracy requirements. For geologic measurements it is desirable to consider instrument capability as the minimum increment of vertical measurement that generally can be determined by the geologist from the stereoscopic model. This permits a simple evaluation of expected maximum errors in geologic measurements when double-projection stereoscopic models are used, or when stereoscopic models from paper prints are used. It also allows the geologist to determine what photograph scale and instrument combinations will give him a desired accuracy of measurement. Because the minimum increment of vertical measurement is empirically derived, the limits of error for vertical measurements described below may be subject to modification.

To determine the expected maximum error for a given combination of photograph scale and instrument three possible individual errors must be considered. These are (a) instrument capability in terms of the geologist's ability to measure horizontal linear parallaxes and increments of vertical measurement, (b) curvature of the datum within a stereoscopic model when double-projection instruments are used, or paper and lens distortions when paper prints are used, and (c) tilt. Consideration of the cumulative effect of

all three possible errors is necessary in determining the expected maximum error for a particular measuring and plotting system, except for leveled models where tilt has been eliminated. In measuring spot altitudes or relative intervals these errors may be compensating rather than cumulative and therefore many measurements will be well within the expected maximum error determined for a particular combination of photograph scale and instrument.

Experience has shown that for double-projection plotters, it is generally possible for the geologist to determine any one reading to one unit of vertical measurement. One unit of vertical measurement is equal to 0.1 millimeter. With care the increment of measurement may be read closer than one unit of vertical measurement. The amount of altitude difference, in feet, on the ground represented by one unit of vertical measurement in the model—called the K factor—depends solely on the scale of the projected stereoscopic model, and is determined by the ratio

$$\frac{\text{Model-scale denominator}}{3,048}$$

This factor is constant throughout the stereoscopic model. Hence spot altitude readings generally may be read within an amount equal to $\pm K$, that is, the geologist may read a point one unit (0.1 millimeter) too high or one unit (0.1 millimeter) too low. In addition, an error of $\pm K$ is added for curvature of the model datum. Thus the maximum error for spot altitudes can be expected to be on the order of $\pm 2K$ for models leveled to vertical control. Where errors due to reading and to curvature of the datum are compensating a minimum error approaching zero can be obtained. For interval measurements the altitudes of two image points in the stereoscopic model of course must be measured. Each point may be read within an amount equal to $\pm K$, or a total reading error $\pm 2K$. Curvature of the model datum may affect the reading of each point a similar amount and can be disregarded when relative intervals are measured on points close together in plan view; for points close together the expected maximum error generally will be similar to that for spot altitudes. But if points of measurement are not selected close together an added error of $\pm K$ due to datum curvature may be introduced. Thus the maximum error for relative interval measurements is on the order of $\pm 3K$ (figs. 37 and 38).

When vertical control is absent many double-projection stereoscopic models and some models from paper prints may be leveled visually to within 1° of a horizontal datum by observing certain physiographic

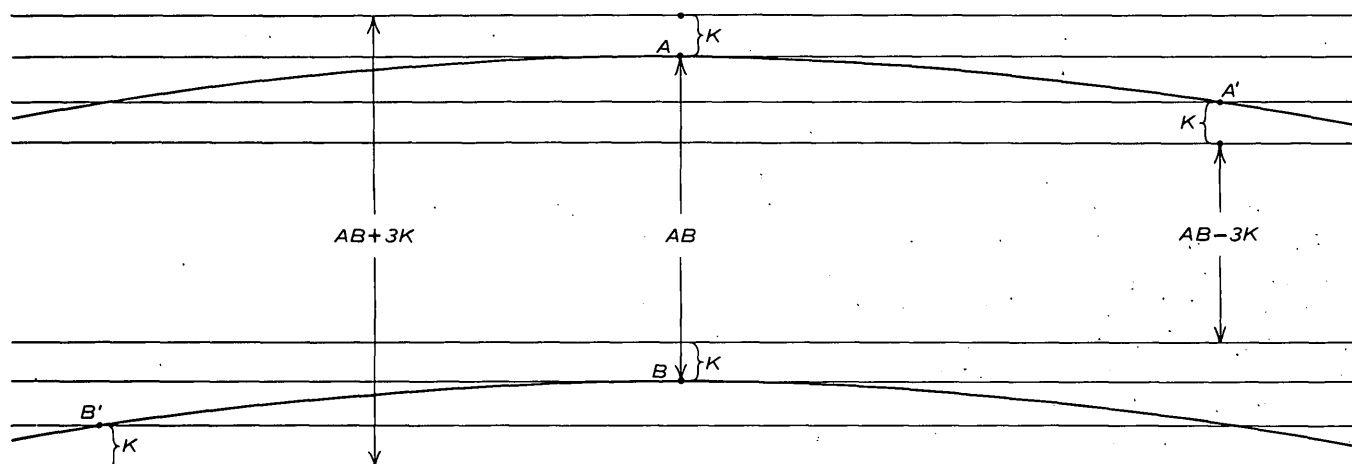


FIGURE 38.—Diagram showing datum-curvature relation to maximum expected error in measuring vertical intervals from leveled double-projection stereoscopic model.

Let AB equal the interval desired. If the upper point is measured at A' an error equal to $-K$, or one unit of measurement, may result from datum curvature; when point B' is measured an error of $+K$ may result. If points A and B' are chosen for measuring the interval and point A is measured one unit too high (equivalent to $+K$) and point

B' is measured one unit too low (also equivalent to $+K$) a maximum expected error, including datum-curvature error, of $+3K$ may result. Likewise if points A' and B are chosen for measuring the interval a maximum expected error, including datum-curvature error, of $-3K$ may result.

features in the model (see p. 55) and making appropriate instrument adjustments. For double-projection stereoscopic models that are leveled visually some error due to tilt thus may be present in addition to possible errors in reading and curvature of the model datum; the order of maximum error for spot altitudes becomes $\pm 2K \pm$ error due to tilt, and for relative interval measurements becomes $\pm 3K \pm$ error due to tilt. When relative stratigraphic thicknesses, displacements on faults, or similar geologic measurements are being made, errors due to tilt or from curvature of the model datum may be minimized by measuring points close together in the stereoscopic model. For points spaced far apart the error due to tilt can exceed the error in reading intervals.

Limits can also be placed on reading units of measurement with paper-print plotters or parallax bars, except that a V factor rather than a K factor is employed. A differentiation of factors is necessary as the V factor, unlike the K factor, is not constant throughout the model, but varies slightly due to differences in scale at different altitudes in models formed from paper prints. For practical purposes, V is the ratio:

$$\frac{\text{Flying height (feet)}}{\text{Photobase (millimeters)} \times 100}$$

The V factor represents the difference in altitude in feet on the ground per unit of measurement from a parallax bar or paper-print plotter, that is per 0.01 millimeter. Experience has shown that parallax meas-

urements from paper prints may be read within about ± 0.02 millimeter or $\pm 2V$. Considering possible errors due to paper or lens distortion and due to tilt, total expected errors for spot altitudes and relative intervals may be determined as shown on figure 37. (See also p. 74.) Errors resulting from paper and lens distortions are considered to be equivalent to about two units of measurement or about $2V$.

Thus two different factors are considered in relating geologic accuracy requirements or expected maximum vertical measurement errors to photograph scale and instrument capability. These factors are the K factor for use with stereoscopic models from glass plates in double-projection plotters, and the V factor for use with stereoscopic models formed from paper prints. For any given system of measurement it is likely that many measurements will fall well within the expected maximum errors as determined from figure 37, especially if high-resolution photographs are available that may permit reading units of vertical measurement less than K or V , and if points of measurement are carefully chosen. Also, errors of reading and datum curvature or tilt may be compensating rather than cumulative, as stated above. In a recent test of determining altitudes of gravity stations with multiplex leveled to vertical control, Kinoshita and Kent (1960) found that 96 per cent of the points measured fell approximately within the limits of $\pm K$ and that 71 percent of the points measured fell approximately within the limits of $\pm K/2$. Results of this special test do not represent the general order of vertical ac-

curacy that geologists may expect to obtain by photogrammetric methods, but they do suggest that many measurements made will be well within the limits shown in figure 37.

RELATION BETWEEN INSTRUMENT CAPABILITY, SCALE, AND VERTICAL MEASUREMENTS

Let it be desired to determine the accuracy of spot altitudes for compiling a structure-contour map of an area covered by recent, high-quality 1:20,000-scale photography flown at 10,000 feet. Adequate vertical control is available for leveling stereoscopic models and a Kelsh plotter is available for measurement and compilation. The expected maximum error shown in figure 37 for spot altitudes for leveled models is $\pm 2K$. Because the scale of the Kelsh model is approximately 5 times that of the original 1:20,000-scale photography (fig. 37), a projected stereoscopic model at a scale of 1:4,000 would result. Thus the K factor for this model would be $4,000/3,048$ or 1.31 feet (fig. 37). Spot altitude measurements could be expected to be correct within $\pm 2K$ or ± 2.62 feet for most points in the model.

Many geologists will have only paper prints and simple measuring devices to use so as a second example let it be desired to determine the expected maximum error in measuring a stratigraphic interval with a parallax bar and paper prints already available. Photographs at a scale of 1:20,000 and taken at 10,000 feet are available. Inspection of physiographic characteristics of the terrain indicates that very little tilt, estimated not to exceed 1° , is present. Rock units are clearly expressed, the formations are essentially flat lying, and points of measurement are within $\frac{1}{4}$ inch on photographs or a distance of about 400 feet on the ground. The photobase distance is 90 millimeters. Figure 37 shows that with parallax bar the expected range of error for relative intervals is $\pm 6V$ $\pm$ error due to tilt,

$$\text{where } V = \frac{10,000}{90 \times 100} = 1.1 \text{ (fig. 37).}$$

The maximum error due to tilt, however, could amount to 14 feet in this example and thus a total expected error of 20.6 feet could result. But the reading error plus paper and lens distortion error may well be less than $\pm 6V$ and the points of measurement may well lie in a direction other than the maximum tilt direction; thus, a measurement error of much less than 20.6 feet will probably result. Figure 37 is constructed to show only the order of maximum error. The percentage of error will depend on the total thickness of the stratigraphic interval; the percentage of error becomes smaller as the thickness of the interval increases.

The geologist will be concerned generally with the expected maximum error of measurement that photographs and instruments already at his disposal will give, and figure 37 is readily used to determine expected maximum errors of measurement for a given photograph scale and instrument combination. However, to determine what photograph scale and instrument combination would be needed to attain specified accuracy requirements is not so easy, as the photograph scale and instrument may be varied and yet give the same required tolerances of vertical measurements. For practical purposes it may be best to equate the vertical-accuracy requirement against instrument capabilities, and to determine from this the scale of photographs that would be needed. Thus, if a requirement for measuring vertical intervals of ± 5 feet is specified it can be seen, for leveled double-projection stereoscopic models, for example, that $\pm 3K$, the maximum expected error for relative intervals, must equal 5 feet or K must equal 1.66 approximately. It follows (see fig. 37) that the projected model-scale denominator must equal $1.66 \times 3,048$ or about 1:5,000.

The scale of photographs required to provide a projected stereoscopic model of 1:5,000 depends on the double-projection plotter used. For the Kelsh plotter, the original photography scale would be approximately 1:25,000; for the ER-55 plotter, approximately 1:17,000 or 1:25,000 depending on the projector model; and for the multiplex, approximately 1:12,000 (fig. 37). Similar computations can be made for other instrument capabilities and requirements of vertical measurements. Where two different combinations of instruments and photograph scales will provide the desired accuracy of vertical measurement, the optimum interpretation, measuring, and plotting system will be determined by the smallest scale of photography that will allow recognition and qualitative interpretation of geologic features pertinent to the given geologic objective.

HORIZONTAL POSITIONING

Horizontal positioning within $1/25$ inch of true map position generally can be accomplished at photograph scale or smaller with any of the plotting instruments that removes relief and tilt displacement. Such instruments include the double-projection plotters and some of the paper-print plotters. The small amount of tilt inherent in present-day vertical photography is generally of little significance in horizontal positioning of geologic features, however, and the radial planimetric plotter may also be used to plot geologic features within $1/25$ inch of true map position. Orthophotographs may also be used for reliable horizontal positioning of data (see p. 69). In addition, geologic features in areas of

low relief may be plotted within 1/25 inch of true map position by sketchmaster or overhead reflecting projector if tilt is negligible. Where relief is low, radial displacement (also called relief displacement) of image points is commonly less than 1/8 inch. For example, on vertical photographs taken from a flying height of 10,000 feet, displacement where the relief is 100 feet amounts to 1/25 inch at a point 4 inches from the center of the photograph. Nearer the center of the photograph the displacement is less. Thus, geologic data on such photographs can be plotted generally within 1/25 inch at photograph scale or smaller with simple overhead reflecting projectors, or can even be traced directly from the photographs and still be within the 1/25-inch tolerance for general geologic maps. The amount of radial displacement, m in inches, is determined from the formula

$$m = \frac{rh}{H}$$

where r =radial distance on the photograph, in inches, from principal point to base of image displaced;

h =height of object displaced, in feet above datum (height of terrain);

and H =flying height, in feet, above datum;

(h and H must be referred to the same datum and be measured in the same units. The amount of displacement, m , is then in the same units of measure as chosen for r). Thus, the limit of relief that can be adequately plotted within the 1/25-inch tolerance for general geologic maps is basically a function of flying height and not of focal length. Displacement due to relief varies inversely with flying height.



Stereoscopic pair

Approximately 1 mile

FIGURE 39.—POORLY RESISTANT PYROCLASTIC ROCKS OVERLAIN BY RESISTANT CAPPING FORMATION (COLORADO).

[Approximate scale 1:20,000. Photographs by Soil Conservation Service]

Coarse pyroclastic rocks, A, are highly dissected in contrast to the more resistant and protecting welded tuff cap-rock, B, in this area of flat-lying formations. Deep dissection of pyroclastic rocks, occurring here preferentially on one slope, permits delineation of contacts that can be traced into nearby areas where strong dissection has not taken place. The use of the floating-dot reference mark of

many photogrammetric instruments may be especially helpful in tracing a geologic contact from an area where the contact is well expressed to an area where the contact is obscured. Sandstone and shale below the pyroclastic rocks are in large part poorly exposed because of the slope wash that covers the deposits.

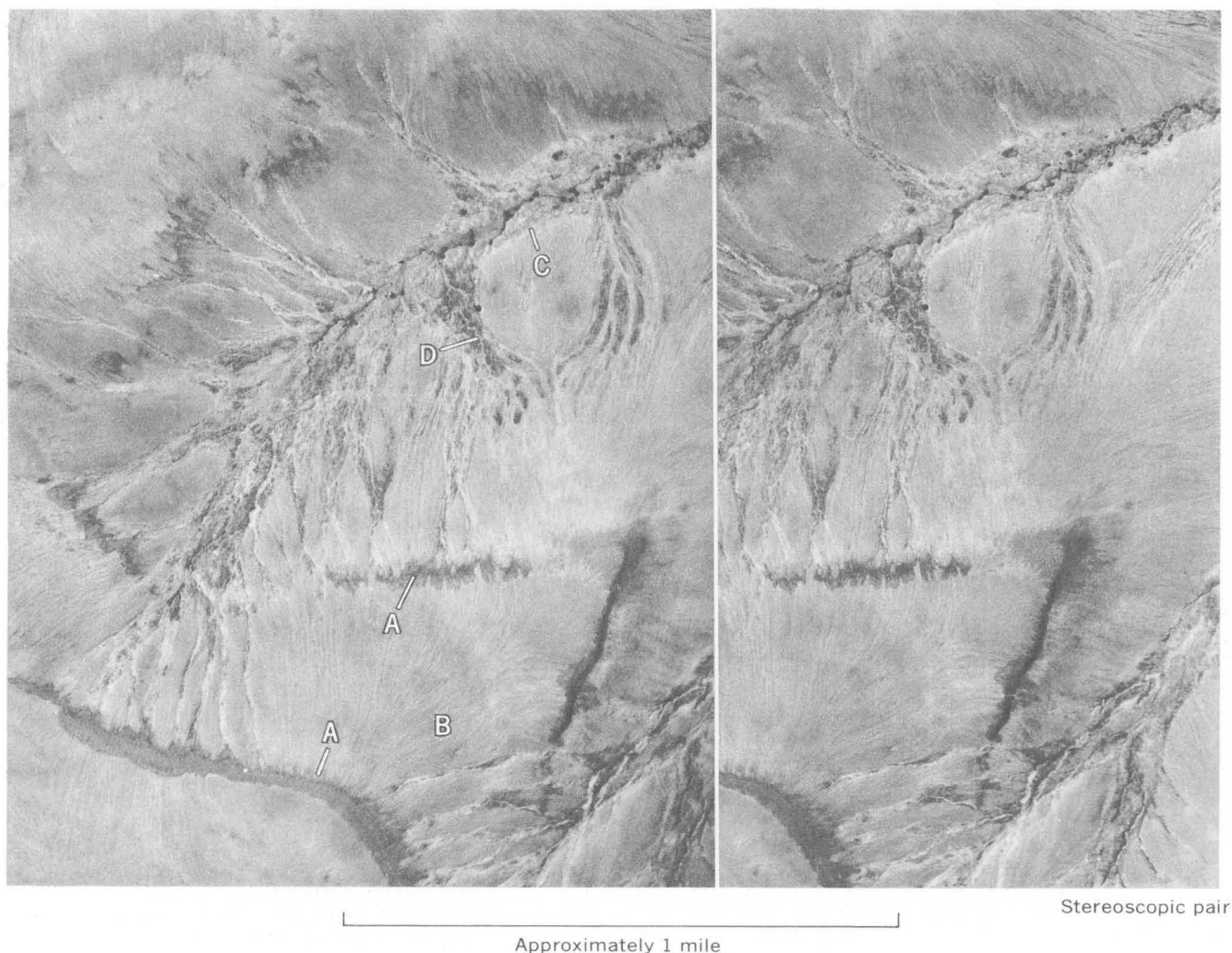


FIGURE 40.—AREA UNDERLAIN PREDOMINANTLY BY GENTLY FOLDED SANDSTONE, SHALE, CONGLOMERATE, AND GRAYWACKE (NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

In some areas where outcrops are sparse or lacking bedding may be traced on the basis of topography and vegetation. Resistant beds of sandstone and conglomerate cause small topographic rises, in some areas as little as 2 feet, which are easily discerned in the stereoscopic model because of vertical exaggeration present in viewing most stereoscopic pairs. The steepened slope caused by the resistant bed is commonly populated with a different mossy and grassy vegetation from that of surrounding areas, and bedding is revealed as wide, strongly curved bands of vegetation that are recognized on photographs by their lighter or darker photographic tone than surrounding areas. Such

bands of vegetation, as at A, are commonly seen clearly on aerial photographs or from a distance on the ground, but are not always readily distinguished when standing directly on them on the ground.

Permafrost is shown by the presence of beaded drainage, indicated by isolated pools of water connected by short, incised watercourses along main stream. Striped slopes, B, are typical but not unique to permafrost areas (contrast fig. 53). Note high-center polygons, C, that exhibit raised centers surrounded by depressed dark-toned edges. Angular drainage channels, D, are related to melting out of ice wedges and are common in permafrost areas.

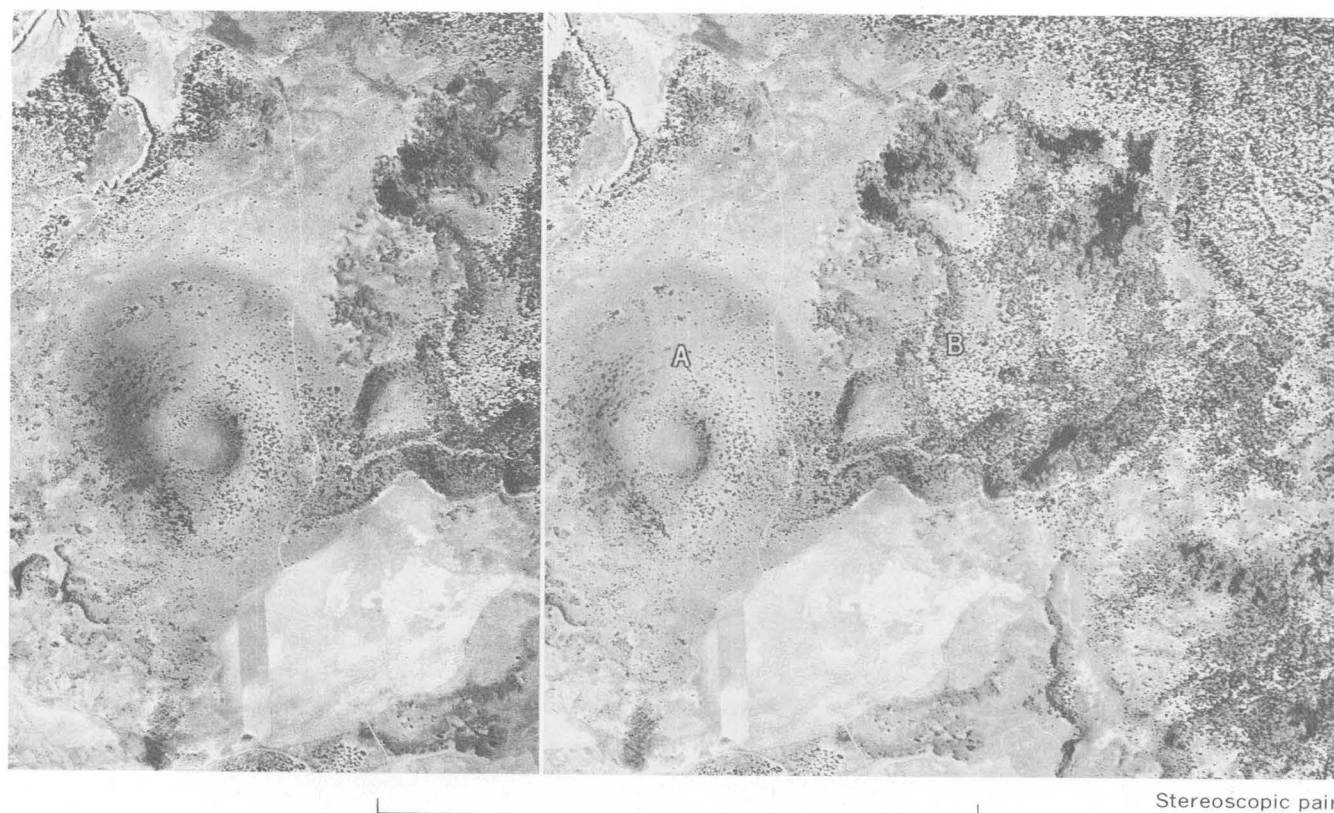


FIGURE 41.—EXTRUSIVE VOLCANIC ROCKS AND ASSOCIATED CINDER CONE (UTAH).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Cinder cone, *A*, is readily identified on the basis of shape of the constructional landform. Associated flows, *B*, are dark toned, irregular in ground plan, and marked by very uneven topographic surfaces. Many lava flows lack sur-

face drainage rills, which suggests permeable material. Note especially the lack of surface drainage channels on flanks of cinder cone.

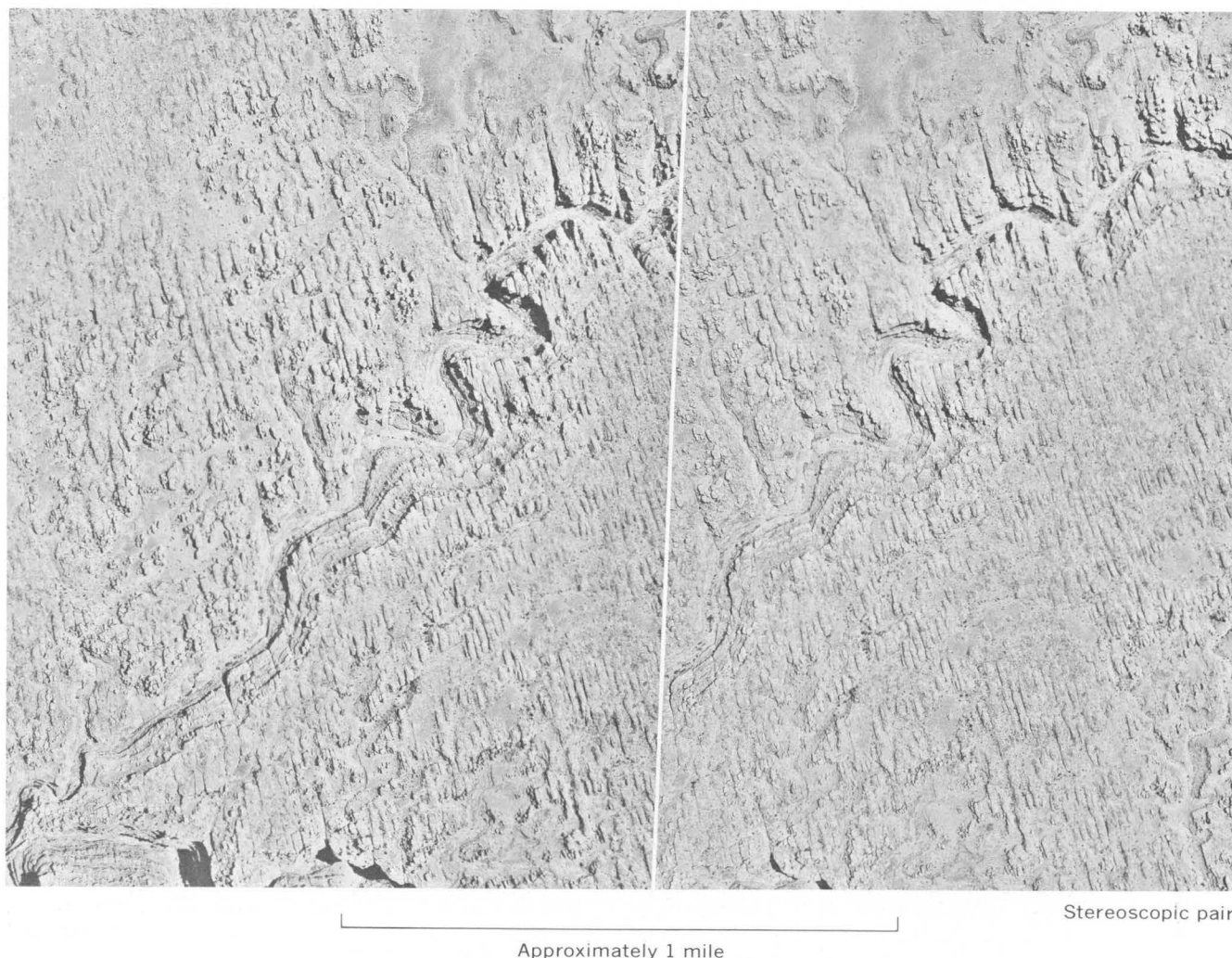
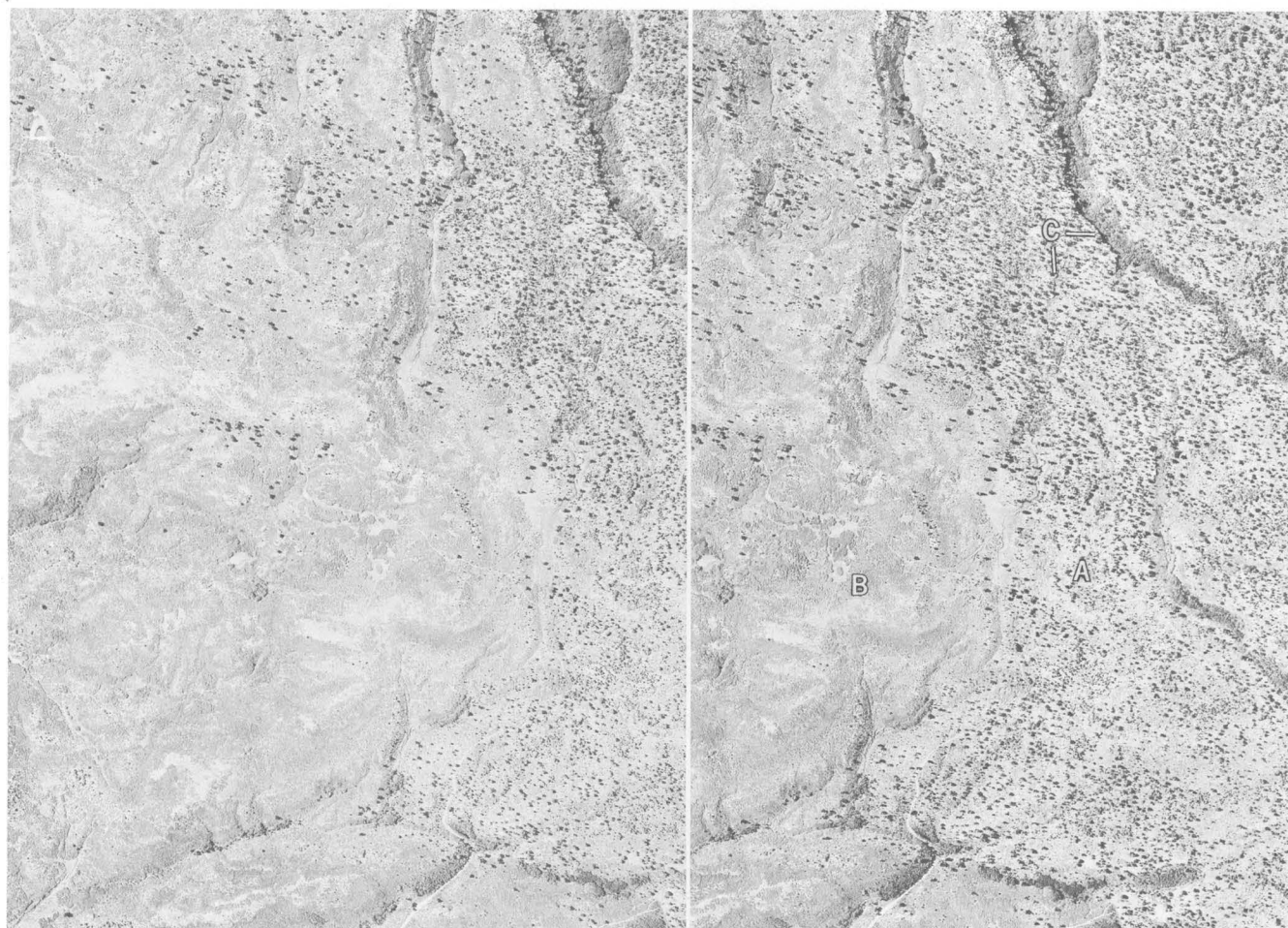


FIGURE 42.—FLAT-LYING SANDSTONE (SOUTHERN UTAH).

[Approximate scale 1:20,000. Photographs by U.S. Geological Survey]

Prominent wide-spaced joints are shown by many short lineations. Where beds are essentially flat lying, joints commonly form in a right-angle pattern and give the terrain a blocky appearance locally, although one direction of jointing may dominate and give a conspicuous linearity

to the topographic grain. The light photographic tone and coarse-textured drainage is typical of coarse sedimentary rocks. Major drainage is dendritic; this pattern is commonly characteristic of flat-lying rocks. Minor drainage is controlled by joints.



Approximately 1 mile

Stereoscopic pair

FIGURE 43.—SANDSTONE AND CONGLOMERATE BEDS INTRUDED BY DIORITE PORPHYRY LACCOLITH (UTAH).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Conspicuous contrast in vegetation results from different lithologic types. Sandstone and conglomerate beds, *A*, are covered largely with scattered tall jack, yellow, and ponderosa pine trees. Diorite porphyry, *B*, is covered with scrub oak as much as 10 feet high. This dense growth of

scrub oak forms a photographic texture that contrasts with areas covered with pines. Note serrated edges of bluffs, *C*, which are expressions of joints in sandstone and conglomerate beds.

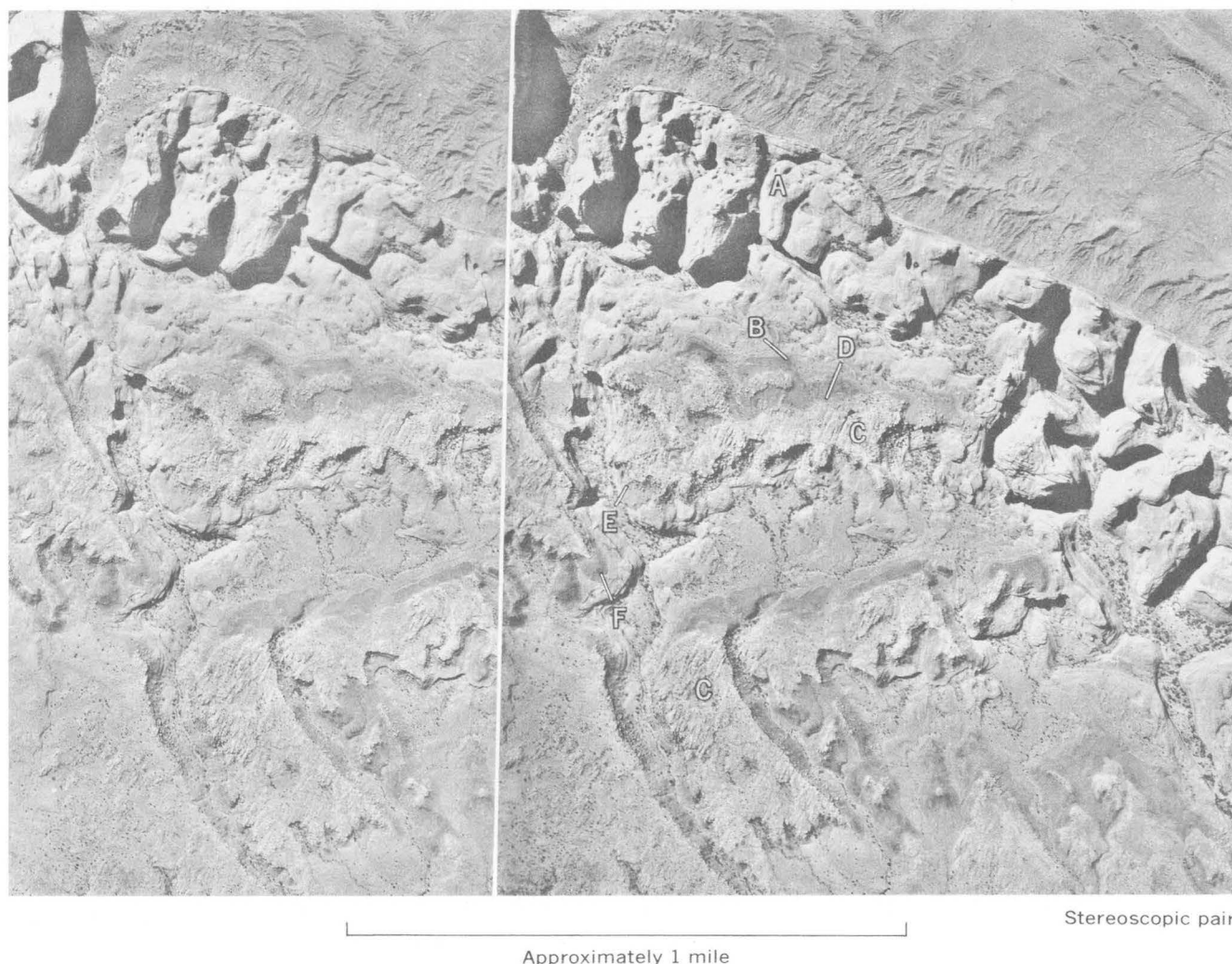


FIGURE 44.—GENTLY DIPPING BEDS OF SANDSTONE, SILTSTONE, AND CONGLOMERATE THAT LOCALLY CONTAIN CHANNEL-FILL DEPOSITS (ARIZONA).

[Approximate scale 1:20,000. Photographs by U.S. Geological Survey]

Light photographic tone of rocks, *A*, is typical of massive crossbedded sandstone in this area. Dark-toned rocks, *B*, are reddish thin-bedded shaly siltstone, shale, and fine-grained sandstone. Light-toned conspicuously jointed rocks, *C*, are uranium-bearing sandstone, conglomerate, and mudstone. Locally the dark-toned rocks have been eroded by channel scour, and the channels have been filled with sandstone and conglomerate that now lie unconformably on the older rocks. Erosion of dark-toned rocks along line *D*, which represents the line of unconformity and orientation of a channel in this area, is conspicuous by the photo-

graphic tone change. At *E* the dark-toned rocks have been completely eroded away and light-toned jointed sandstone and conglomerate rest on the light-toned massive crossbedded sandstone. At *F* the dark-toned rocks again become conspicuous where overlying rocks thin. Differences in stratigraphic thicknesses of the dark-toned rocks, which reflect a thickening of overlying rocks that were deposited in old river channels, can be measured photogrammetrically. Isopach lines may be drawn to indicate the orientation of the channel and the general depth of the channel.



Stereoscopic pair

Approximately 1 mile

FIGURE 45.—GNEISS, SCHIST, AND GRANITE FLANKED BY DIPPING SEDIMENTARY ROCKS TRUNCATED BY PEDIMENT GRAVEL (COLORADO).

[Approximate scale 1:21,000. Photographs by U.S. Air Force]

Topographically high, vegetated area, *A*, is underlain by gneiss, schist, and granite. Light-toned sedimentary rocks, *B*, lying unconformably on the igneous and metamorphic rocks, are primarily arkose and sandstone. Trace of unconformity between sedimentary rocks and igneous and metamorphic rocks is indicated by break in slope, *C*, which is locally accentuated by contrast of trees on steep slope

uphill from the trace of the unconformity with grassy vegetation on the gentler slope below. Note effect on dip of vertical exaggeration in the stereoscopic model. The arkose and sandstone unit dips about 25° . The grass-covered pediment gravel, *D*, which truncates the underlying sedimentary rocks, dips 2° to 3° .



Approximately 1 mile

Stereoscopic pair

FIGURE 46.—LANDSLIDE AREA (COLORADO).

[Approximate scale 1:37,000. Photographs by U.S. Geological Survey]

Landslides are indicated primarily by landform. Note the characteristic hummocky topography of slide material prominent at A. Minor ridges of the slide area are commonly parallel to the contour of the slope; clumps of vegetation locally are oriented parallel to the contour of the slope also. Poorly resistant sedimentary rocks underlie the

landslide debris; resistant volcanic flows (not shown) cap the sedimentary rocks. In many areas where poorly resistant rocks underlie a resistant caprock, conditions for landsliding are favorable. Highly fractured rocks in canyon are schist and gneiss.

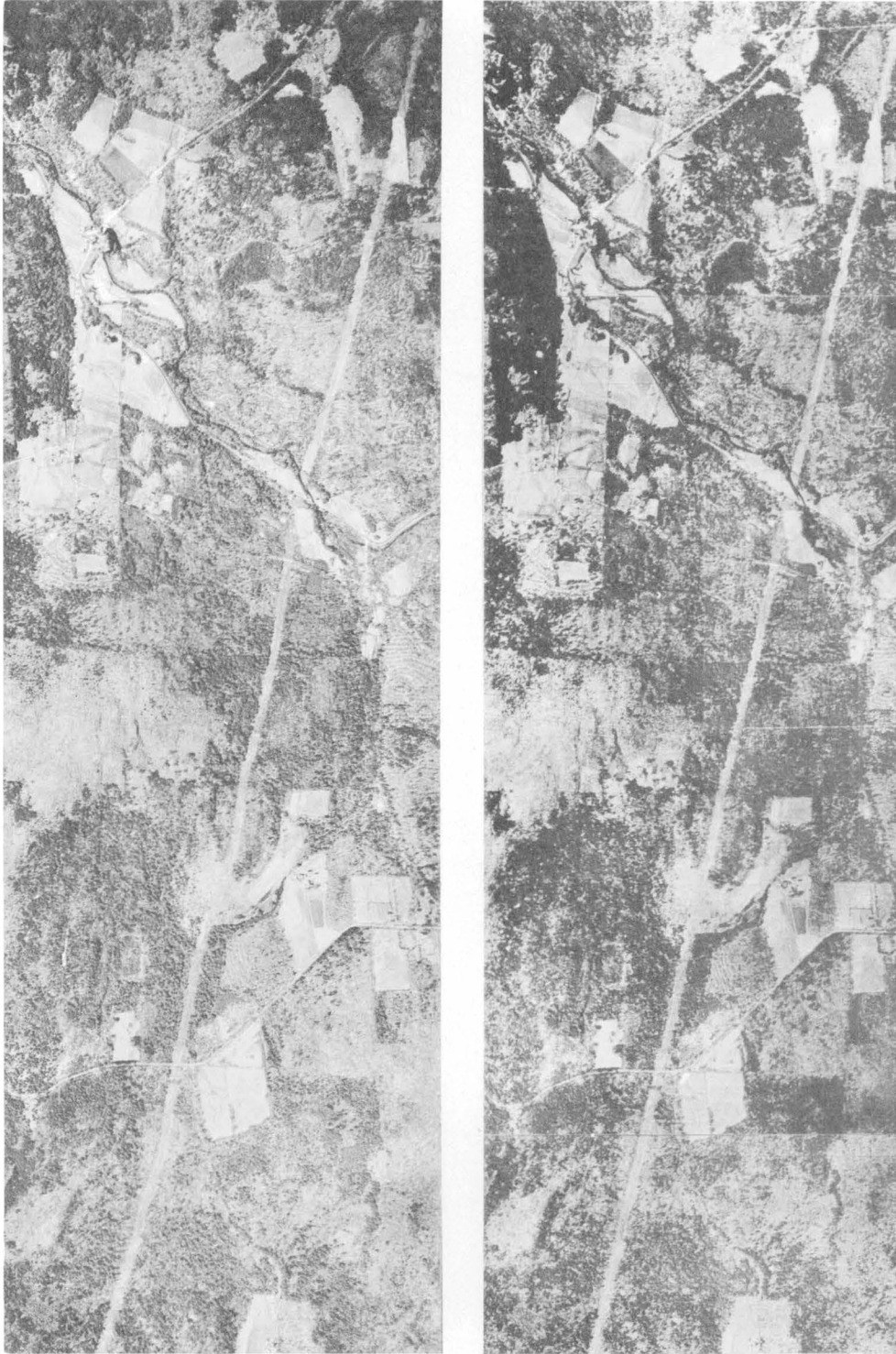
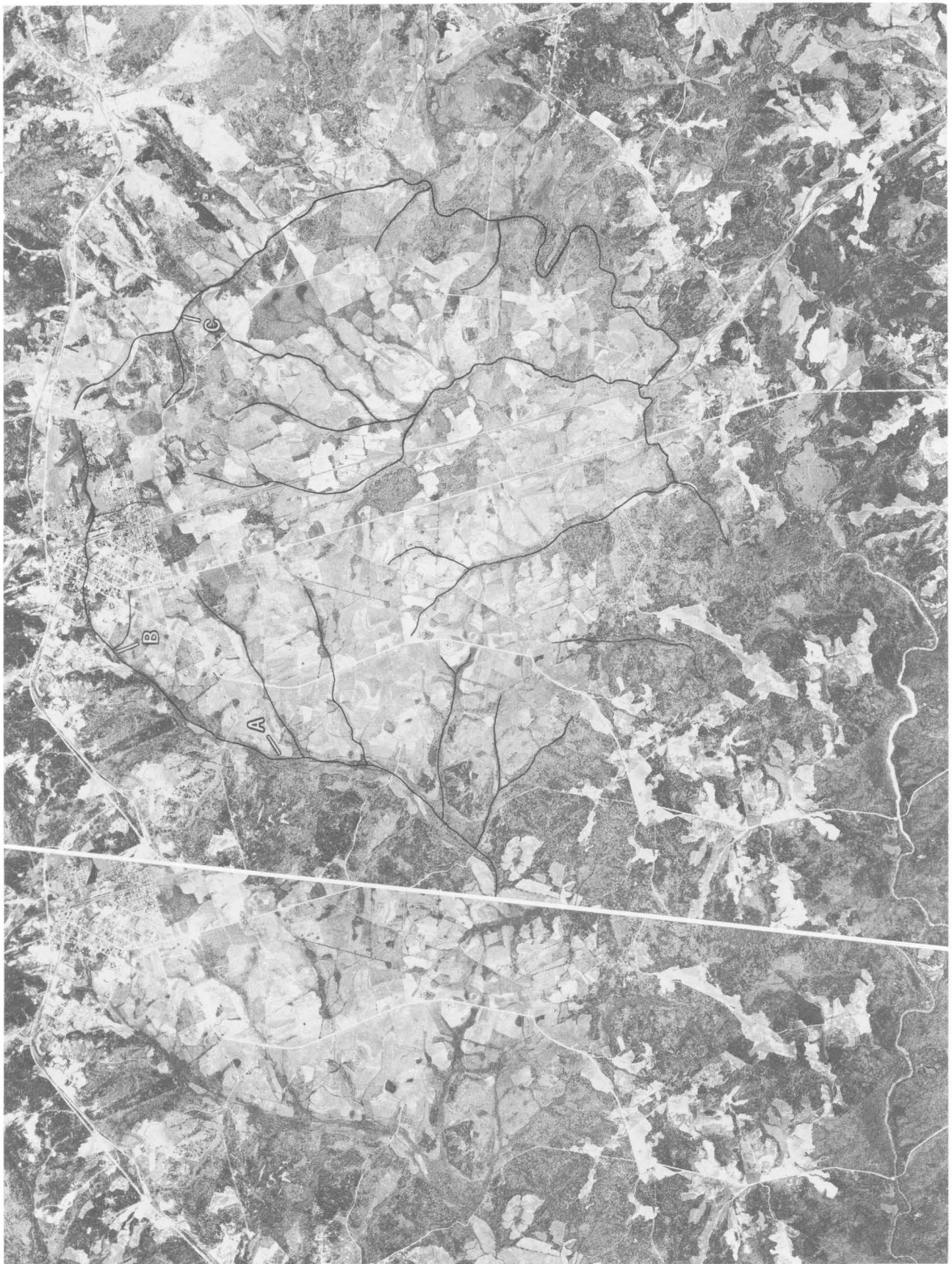


FIGURE 47.—ORTHOPHOTOGRAPH AND PERSPECTIVE PHOTOGRAPH OF SAME AREA.

(Left) Part of perspective aerial photograph showing distortions in powerline caused by relief displacement of image points. (Right) Orthophotograph of the same area showing that relief displacement has been eliminated in preparing orthophotograph. Note that the powerline is straight.



Stereoscopic pair

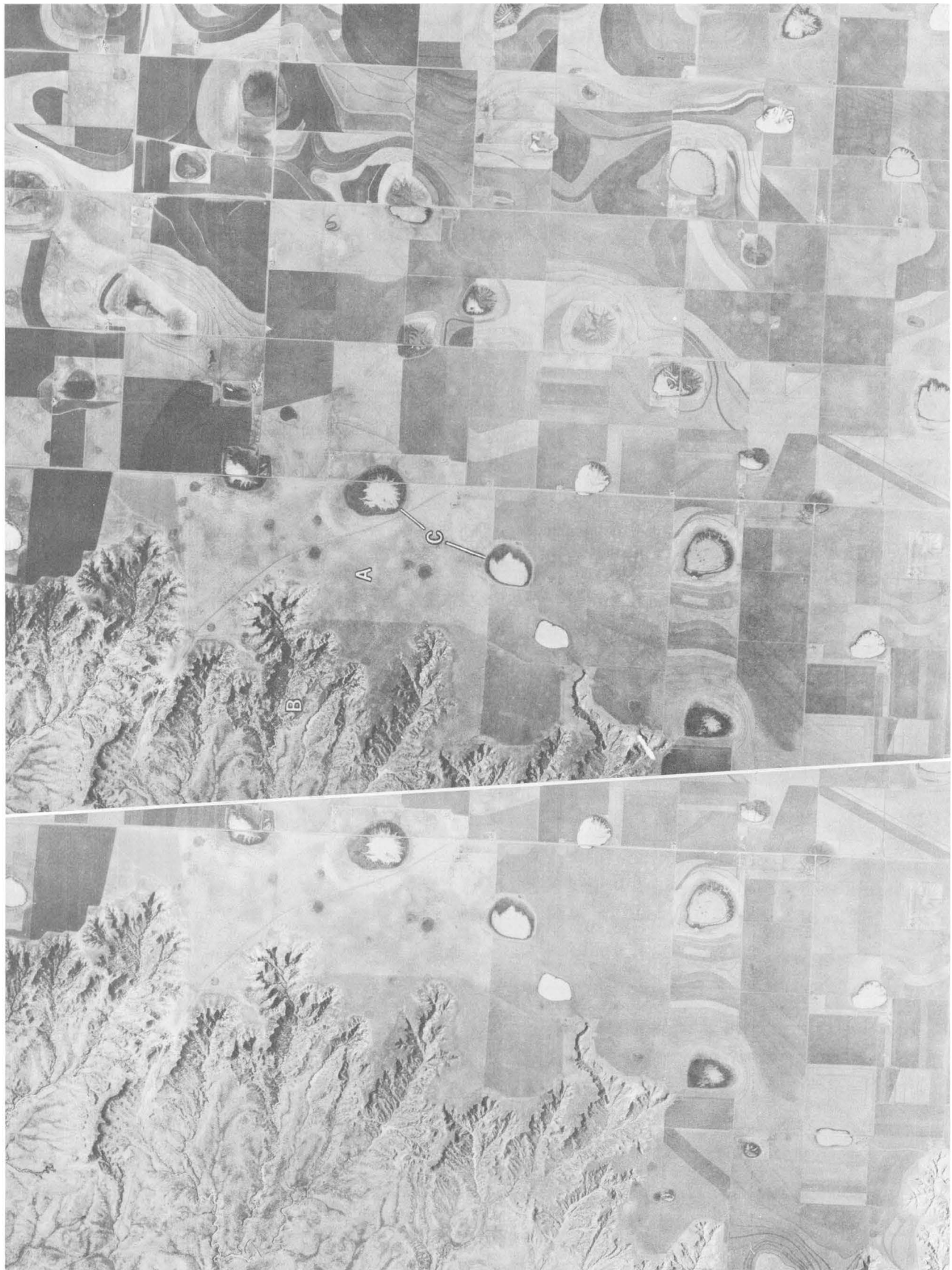
Approximately 1 mile

FIGURE 48.—AREA SHOWING RELATION OF PHOTOGRAPHIC TONE, LAND-USE PATTERN, AND DRAINAGE TO RESIDUAL SOIL, ROCK TYPE, AND GEOLOGIC STRUCTURE (SOUTH CAROLINA).

[Approximate scale 1 : 60,000. Photographs by Army Map Service]

Aerial photographs commonly show an association of features that is meaningful to the interpreter. Here photographic tones, land-use pattern, and drainage pattern are associated with specific soils, rock types, and geologic structure. Note that the small scale of the photographs is a significant factor in showing the striking land-use pattern and drainage pattern (see also fig. 4). The circular land-use pattern of the farmed area generally

bounded by vegetated areas, as at *A*, represents soils developed on underlying mafic rocks. Rocks in the immediately surrounding vegetated areas are largely silicic intrusive types. The drainage characteristics of the area also suggest a pluglike or domal geologic structure. Streams at *B* and *C* form a conspicuous annular pattern around the area of mafic rocks and probably mark the contact of the mafic rock body.



Stereoscopic pair

Approximately 1 mile

FIGURE 49.—SHALE AND THIN SANDSTONE INTERBEDS CAPPED BY POORLY CONSOLIDATED GRAVEL AND SAND, LOCALLY CEMENTED WITH CALCAREOUS MATERIAL (TEXAS).

[Approximate scale 1 : 63,360. Photographs by Army Map Service]

Lack of surface drainage at *A* indicates high degree of permeability in capping material. Note in contrast the striking fine-textured drainage on the relatively impermeable shale area, *B*. Broad depressions, *C*, in capping gravel and sand are very shallow and show little relief even with vertical exaggeration found in the stereoscopic model. These depressions resulted in large part from wind action; some solution of local calcareous cementing

material also may have taken place. Dark areas within depressions represent a darker vegetation growth; light-toned areas represent in part washed-in fine materials that were dry and hence light colored at the time the photographs were taken. Locally some light-toned evaporite deposits may be present.



Stereoscopic pair

Approximately 1 mile

FIGURE 50.—RECENTLY FAULTED STRAND LINES OF FORMER LAKE (NEVADA).

[Approximate scale 1:20,000. Photographs by Soil Conservation Service]

Strand lines of beach sand, *A*, are shown strikingly by dark photographic tone and slightly higher altitudes than surrounding surficial material. Note that strand lines are truncated by a recent fault, *B*, shown by narrow band of dark vegetation and by low scarp. Drainage density is relatively high

on the thin alluvial cover, *C*, but decreases noticeably on opposite side, *D*, of fault where better drained, thicker deposits of alluvial material are present. Strand line is faulted up about 25 feet at *E* by recent fault movement. An irregular fault trace is also seen at *F*.



Stereoscopic pair

Approximately 1 mile

FIGURE 51.—STEEPLY DIPPING SEDIMENTARY ROCKS INTRUDED BY QUARTZ DIORITE (CALIFORNIA).

[Approximate scale 1:20,000. Photographs by U.S. Geological Survey]

Generally massive dark-toned conglomerate sequence, *A*, exhibits coarse-textured drainage and erosional characteristics, whereas fine-grained weakly foliated quartz diorite, *B*, has a fine-textured drainage and erosional topography. Widely spaced joints, conspicuous in many intrusive masses, are not present in the quartz diorite. Dendritic drainage in the conglomerate se-

quence is not typical of most dipping sedimentary rocks; the dendritic drainage pattern suggests a massive character and uniformity of the conglomerate sequence and general lack of bedding which might control the drainage. Local light-toned interbeds, *C*, indicate strike and dip of the sedimentary rock sequence.



Stereoscopic pair

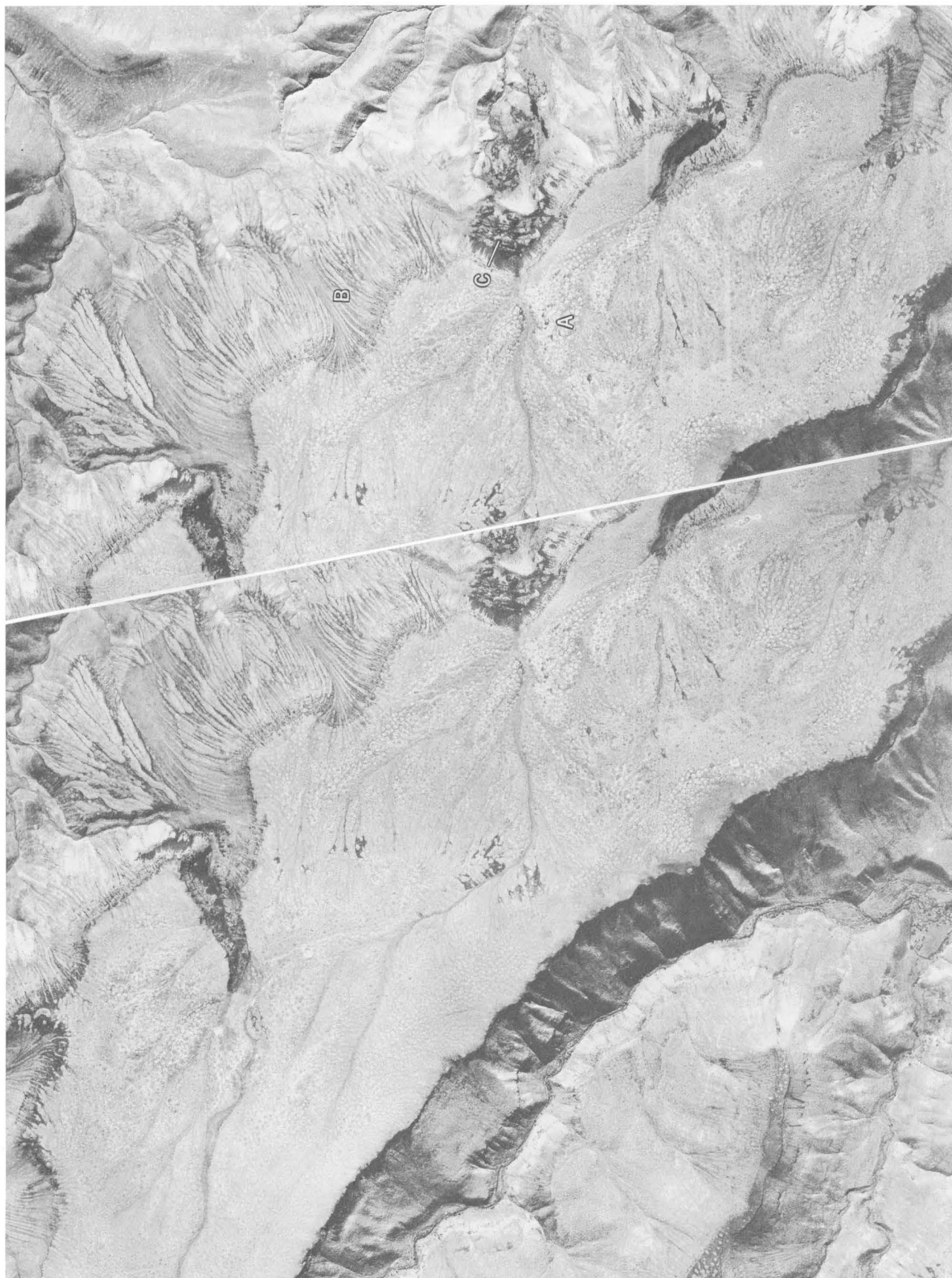
Approximately 1 mile

FIGURE 52.—AREA SHOWING DRAINAGE CHARACTERISTICS IN SURFICIAL MATERIALS (WYOMING).

[Approximate scale 1:28,000. Photographs by U.S. Geological Survey]

Strong contrast in drainage densities of areas *A* and *B* reflect differences in underlying materials. Fine-grained surficial sedimentary deposits, *A*, that form a thin cover on impermeable shale here exhibit fine-textured drainage. The many drainage rills flowing across the fine-grained surficial material

disappear into sand dune area, *B*, which is composed of granular material of high permeability. Although partly stabilized and covered by vegetation the sand dunes locally show barchan shapes, which aid in their identification.



Stereoscopic pair

Approximately 1 mile

FIGURE 53.—AREA OF BASALT FLOWS (IDAHO).

[Approximate scale 1 : 20,000. Photographs by Commodity Stabilization Service]

Conspicuous "snakeskin" pattern is commonly found on the undissected basalt flows, *A*; it is not observed on other rock types in this area. The pattern consists of white or light-toned spots scattered in a dark field. Note that a rounded "shape" is a distinctive part of the pattern. The light-toned rounded areas are mounds of clay and silt 20 feet or more across and 2 or 3 feet high. Grass grows on these areas and causes the light photographic

tone; the basalt is typically barren or covered with sagebrush and has a dark photographic tone. The striped pattern of closely spaced drainage rills, *B*, is also typical of basalt talus slopes in this area; however, similar-appearing stripes are found on a variety of rock types in other areas (see fig. 40). Where basalt cappings are underlain by poorly resistant rocks, conditions are favorable for landslides, as at *C*.

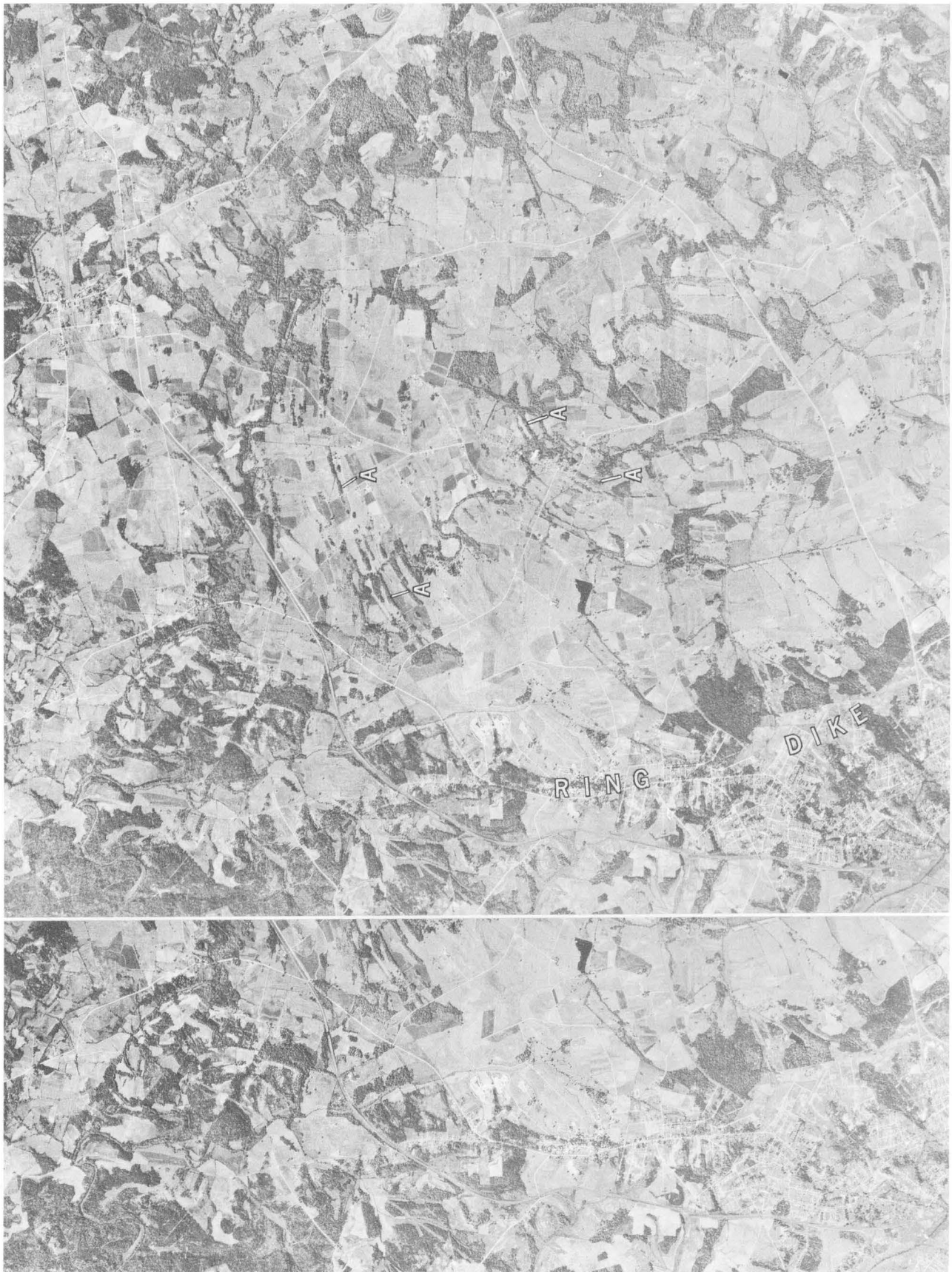
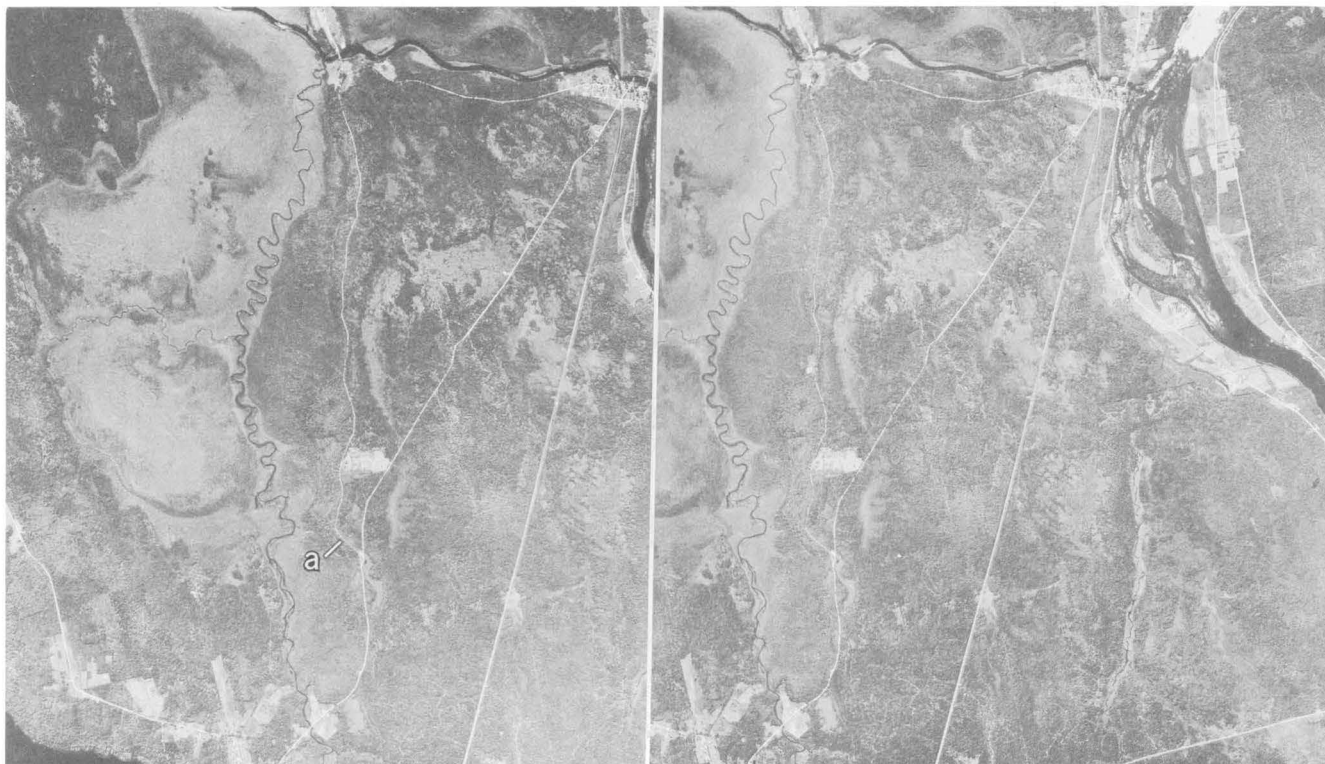


FIGURE 54.—RING-DIKE AREA (NORTH CAROLINA).

[Approximate scale 1 : 58,000. Photographs by Army Map Service]

Ring dike about 1 mile wide and an area of gabbro-diorite within the ring dike can be differentiated from surrounding areas primarily on the basis of the lesser tree coverage and greater land use within the ring-dike area. A ring structure is also suggested by the concentric pattern of trees, A, which may reflect structure within the igneous rocks. The contact of

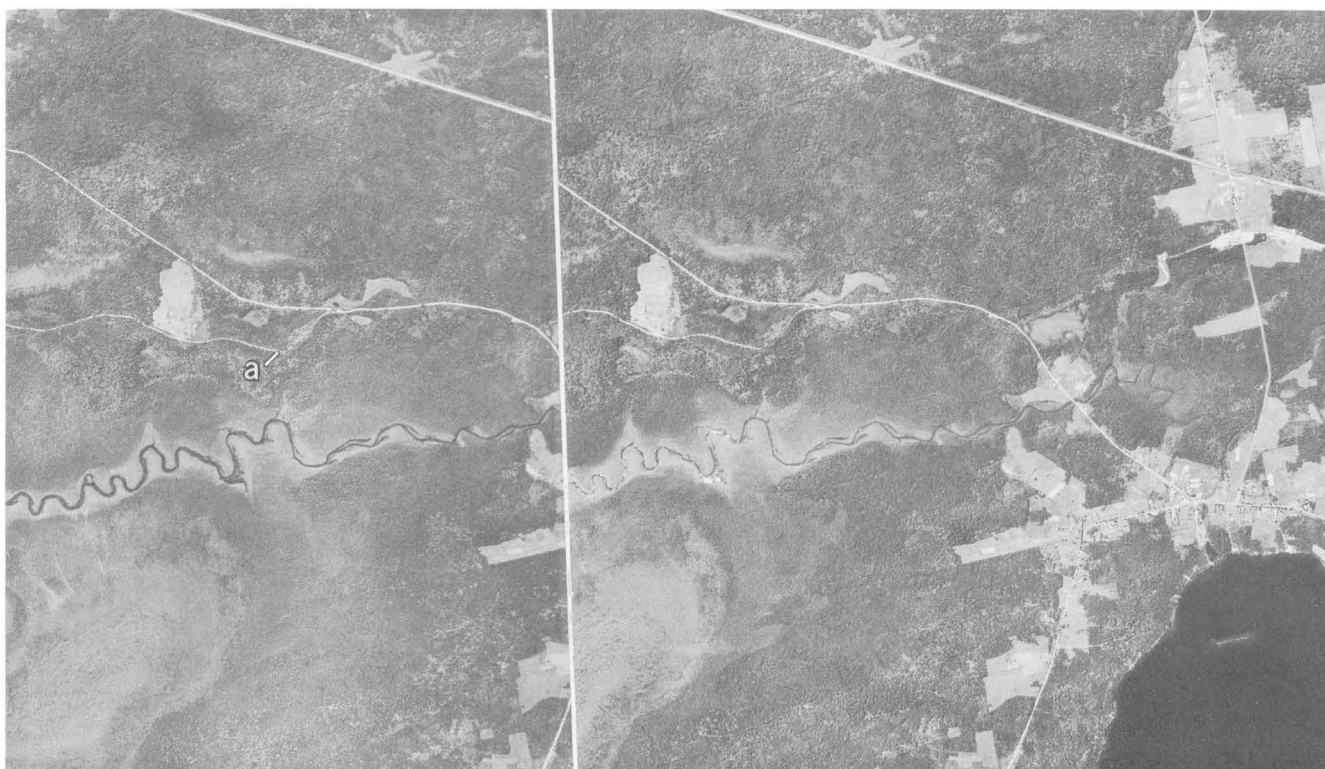
syenite of the ring dike and gabbro-diorite of surrounding areas cannot be identified in the stereoscopic model, and aerial photographs of this terrain serve primarily to differentiate anomalous features which then must be examined in the field. Note excavation in syenite of the ring dike.



A

Approximately 1 mile

Stereoscopic pair



B

Approximately 1 mile

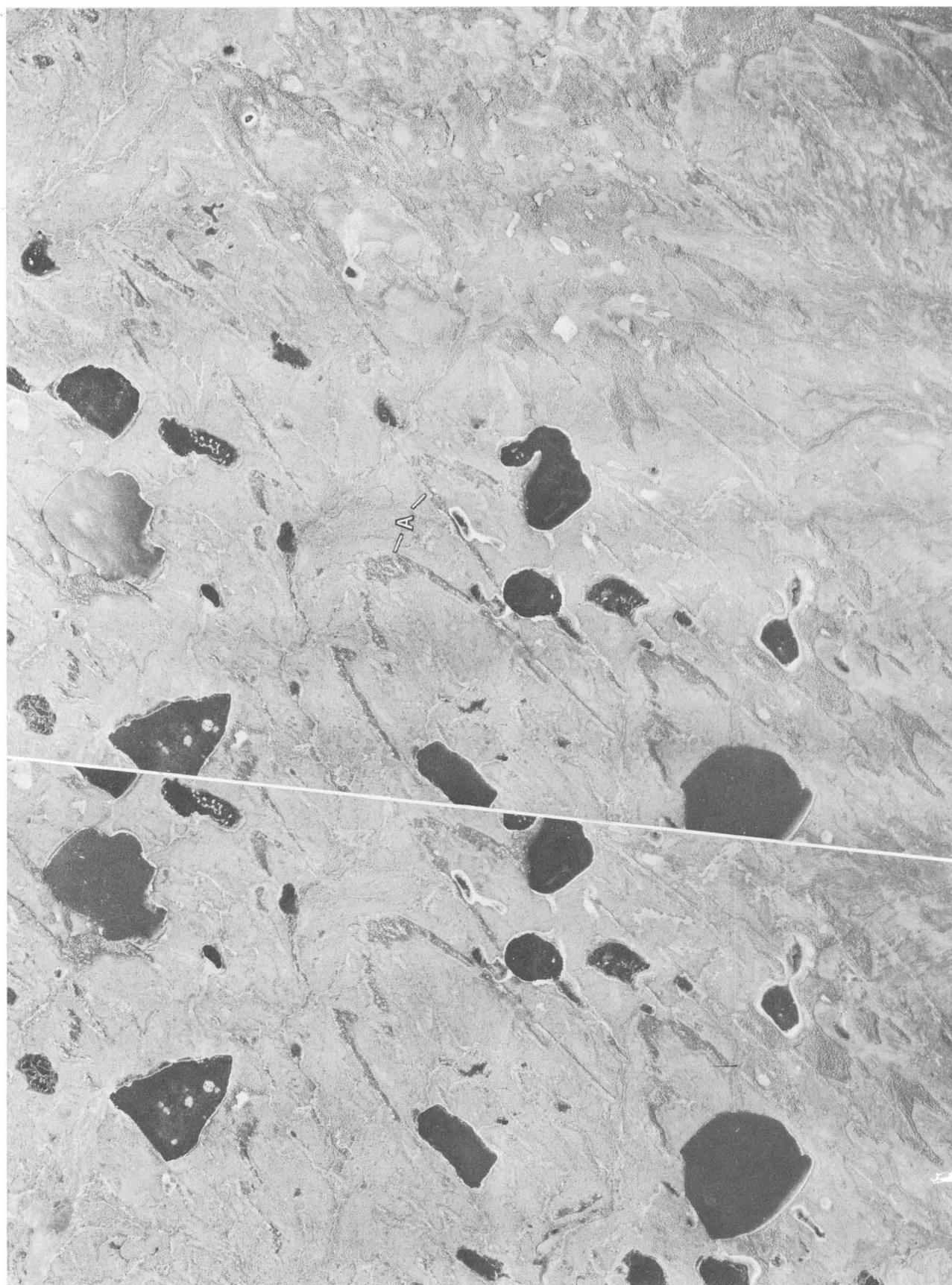
Stereoscopic pair

FIGURE 55.—AREA IN MAINE SHOWING ESKER LANDFORM ON PHOTOGRAPHS OF TWO DIFFERENT SCALES.

[A: Approximate scale 1:70,000. Photographs by Army Map Service]
[B: Approximate scale 1:44,000. Photographs by U.S. Geological Survey]

The serpentine shape in plan view and local topographic relief of the esker are readily distinguished in the stereoscopic view of figure A. The esker ridge is discontinuous, but the various segments are clearly part of the same ridge. The association of isolated ridge segments is readily made when small-scale photographs showing a large area are viewed. Landform is the primary recognition feature of esker ridges. In figure B the esker landform is not as readily identified as

in figure A, and on commonly available 1:20,000-scale photographs the serpentine shape would probably not be seen in any one stereoscopic model. Esker sands and gravels are commonly well drained and are a source of borrow material for the construction engineer. Note old secondary road, *a*, built along the top of the esker, probably because of good subgrade and drainage.



Stereoscopic pair

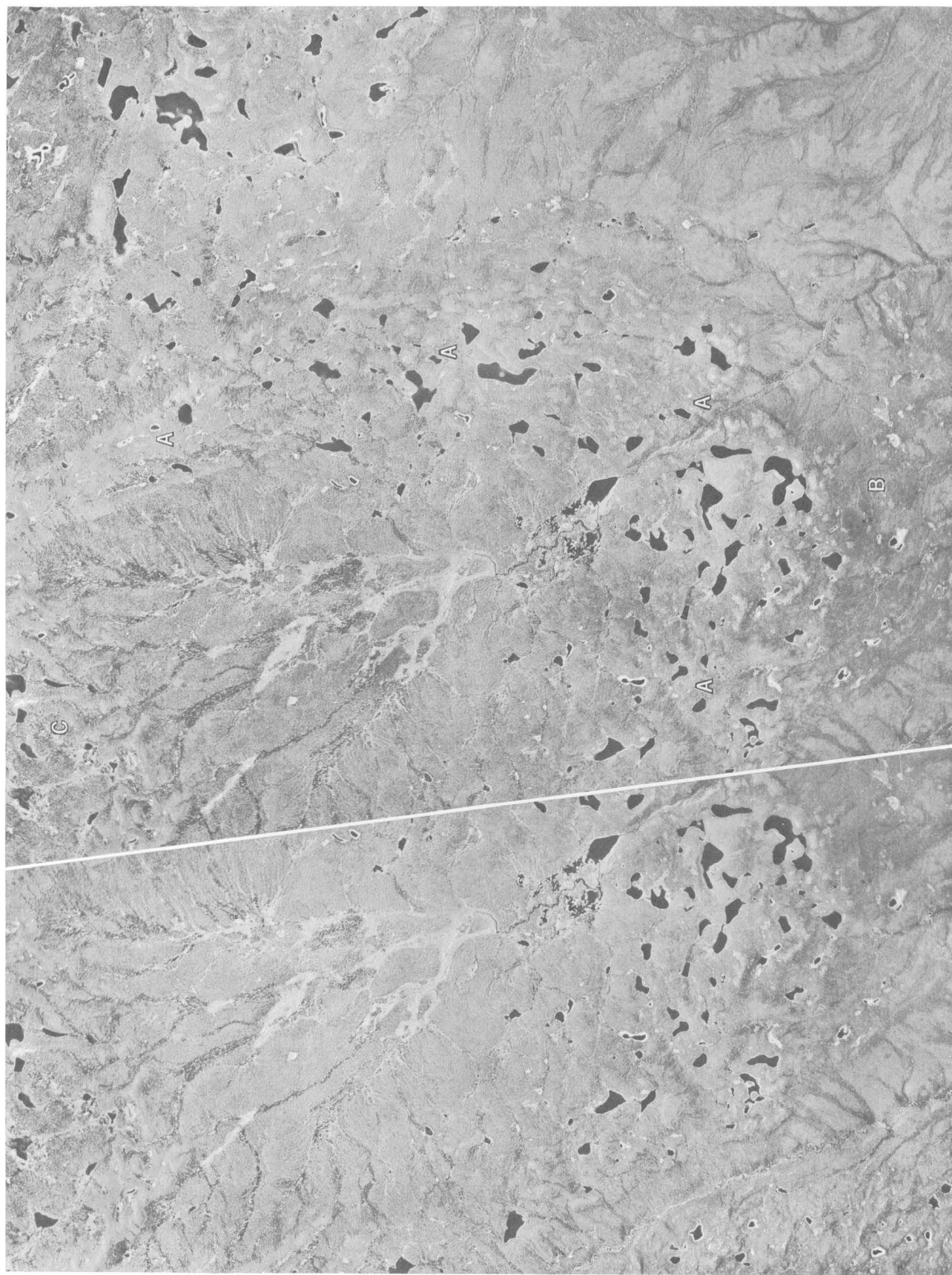
Approximately 1 mile

FIGURE 56.—STABILIZED SAND DUNES (CENTRAL ALASKA).

[Approximate scale 1 : 40,000. Photographs by U.S. Air Force]

Strong contrasts in photographic tone and photographic texture mark sand dunes and interdune areas. Dunes, as at A, are now stabilized and covered with trees. Coarse well-drained sands of the dunes support dark-toned black spruce. Light-toned interdune areas of frozen silt support grasses. Lakes were formed on the original glacial outwash plain, which

was the source of sand for dune formation. The shape of the dune landform is an important aid to recognition, and the association of trees is significant in the interpretation of the soils and ground conditions. Relief of the dunes is vertically exaggerated in the stereoscopic model.



Stereoscopic pair

Approximately 1 mile

FIGURE 57.—MORAINAL DEPOSITS OF TWO GLACIATIONS (CENTRAL ALASKA).

[Approximate scale 1 : 40,000. Photographs by U.S. Air Force]

Arcuate plan-view shape of terminal moraine, *A*, is marked by a lighter photographic tone than that of the surrounding area. This moraine is characterized by an abundance of small undrained lakes and ponds and by poorly integrated drainage. In older terminal moraine, *B*, lakes and ponds

are largely drained, but arcuate plan of this moraine is still preserved. Terminal moraine, *C*, represents an advance only slightly younger than *A*. Note similarity of topographic expression and development of ponds and lakes in moraines *A* and *C*.



Stereoscopic pair

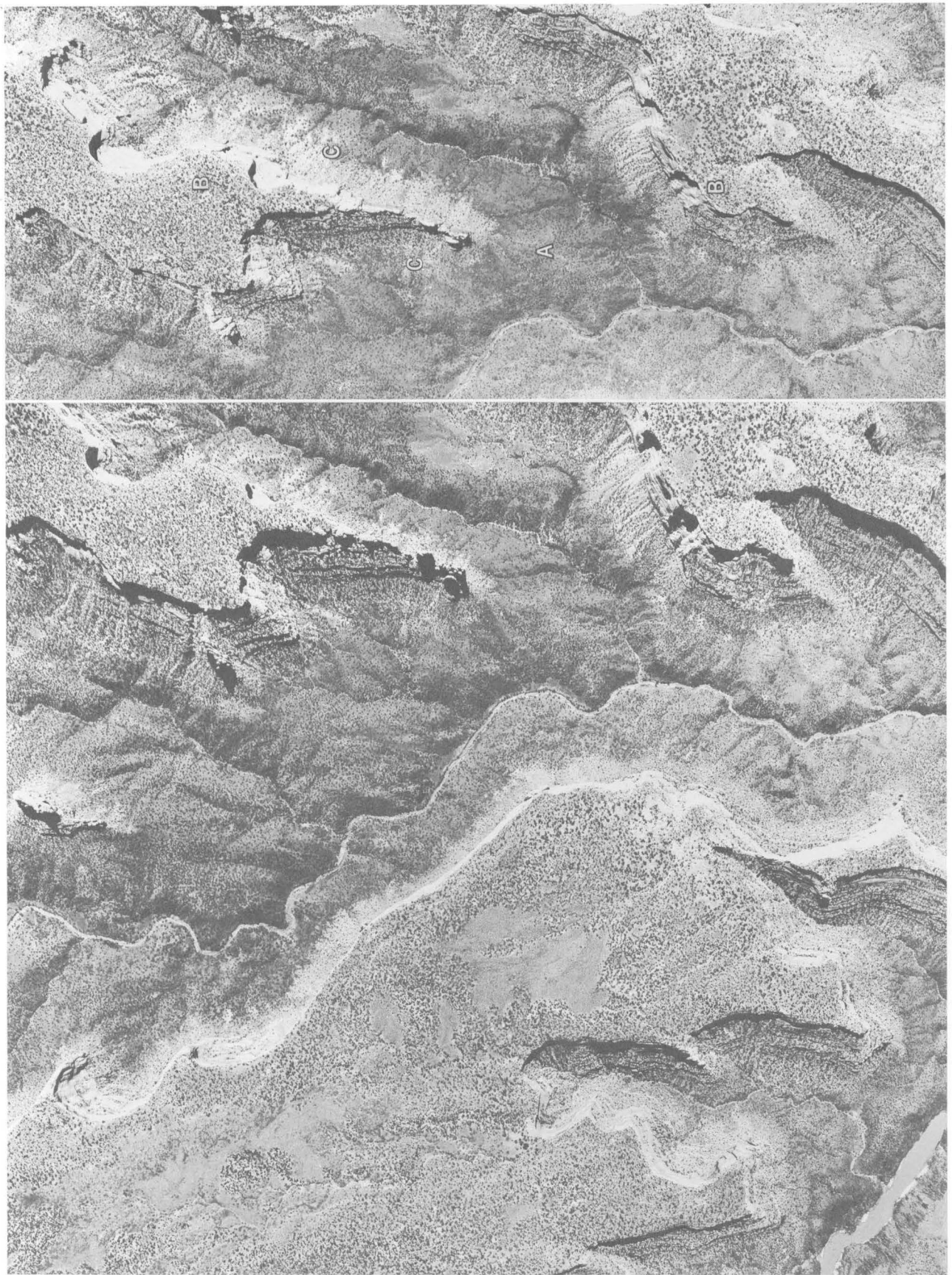
Approximately 1 mile

FIGURE 58.—MORAINAL DEPOSITS OF CONTINENTAL GLACIATION (SOUTH DAKOTA).

[Approximate scale 1 : 60,000. Photographs by Army Map Service]

Terminal moraine, *A*, contains generally few lakes and ponds in contrast with older ground moraine, *B*, in which water-filled kettle holes are numerous. Arcuate plan-view shape and higher relief than surrounding ground moraine are typical of the terminal moraine. Note drainage rills developed on parts of topographically high terminal moraine, but general lack of well-

developed surface drainage in ground-moraine areas. Ponding also indicates poor drainage in this area. Linear trends parallel to arcuate border of terminal moraine—which represent depositional and erosional characteristics—are similar to some linear trends indicative of faults in other areas.



Stereoscopic pair

Approximately 1 mile

FIGURE 59.—GENTLY DIPPING SEDIMENTARY ROCKS LYING UNCONFORMABLY ON GNEISS-GRANITE-SCHIST COMPLEX (UTAH).

[Approximate scale 1:20,000. Photographs by U.S. Geological Survey]

Strong photographic tone differences mark the gneiss-granite-schist area, *A*, and the sedimentary rocks, *B*. Relatively even dip-slope surfaces of sedimentary rocks contrast strongly with hummocky erosional topography of underlying crystalline rocks. The fine-textured dendritic drainage on the crystalline rocks stands out, although such fine-textured drainage is not necessarily diagnostic or typical of igneous and metamorphic areas. The gneiss-granite-schist area shows no bedding, but bedding is marked in the overly-

ing sedimentary rocks by topographic breaks in slope. Light photographic tone and vertical cliffs are characteristic of thick sandstone formation in this area. Large talus blocks, at base of slope, *C*, indicate massive and resistant character of overlying rocks. Shale and silty shale unit below sandstone has a lesser angle of slope, but this slope is masked in part by debris from overlying sandstone.



Stereoscopic pair

Approximately 1 mile

FIGURE 60.—GENTLY DIPPING SEDIMENTARY ROCKS CUT BY NUMEROUS NEAR-VERTICAL FAULTS (UTAH).

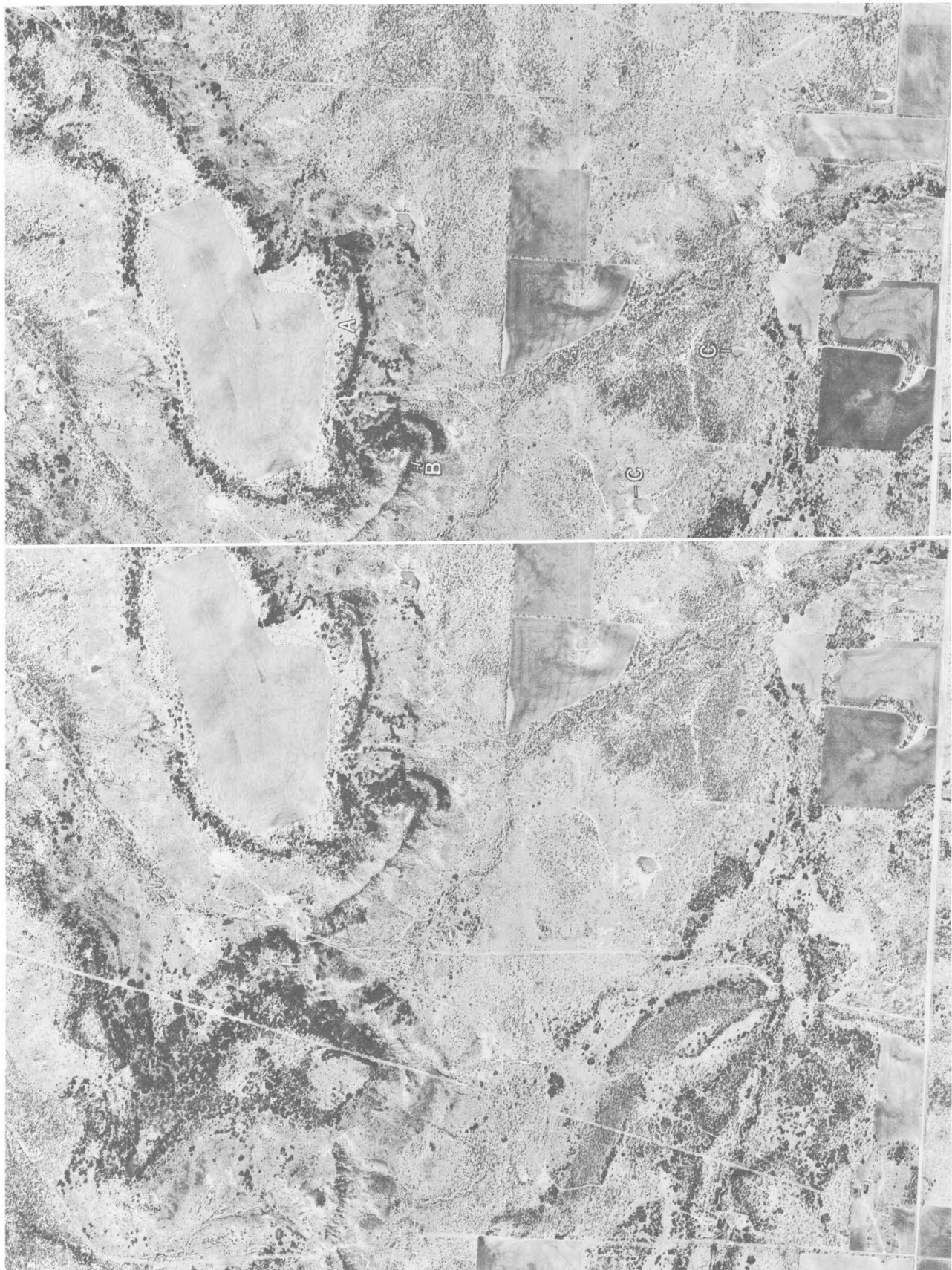
[Approximate scale 1:63,360. Photographs by Army Map Service]

Sedimentary rocks are indicated particularly by topographic expression. Jointed, resistant sandstone beds stand in bold cliffs, *A*. Soft rocks have lesser angles of slope. Strong photographic tone differences mark contacts of some rock units, as at *B*; locally vegetation changes are suggestive of different rock types, *C*.

Lava flow, *D*, cuts discordantly across formational contacts. Remnant

lava flow at *E* appears to have been continuous with flow at *D*. Small cinder cone, *F*, demonstrates use of shape as a recognition element of constructional landforms.

Faults are commonly marked by conspicuous topographic alignments (*G*, *H*). Throw on fault *G* is about 100 feet; on *H* the throw is about 150 feet. Note narrow alignments of vegetation marking faults, *K*.



Stereoscopic pair

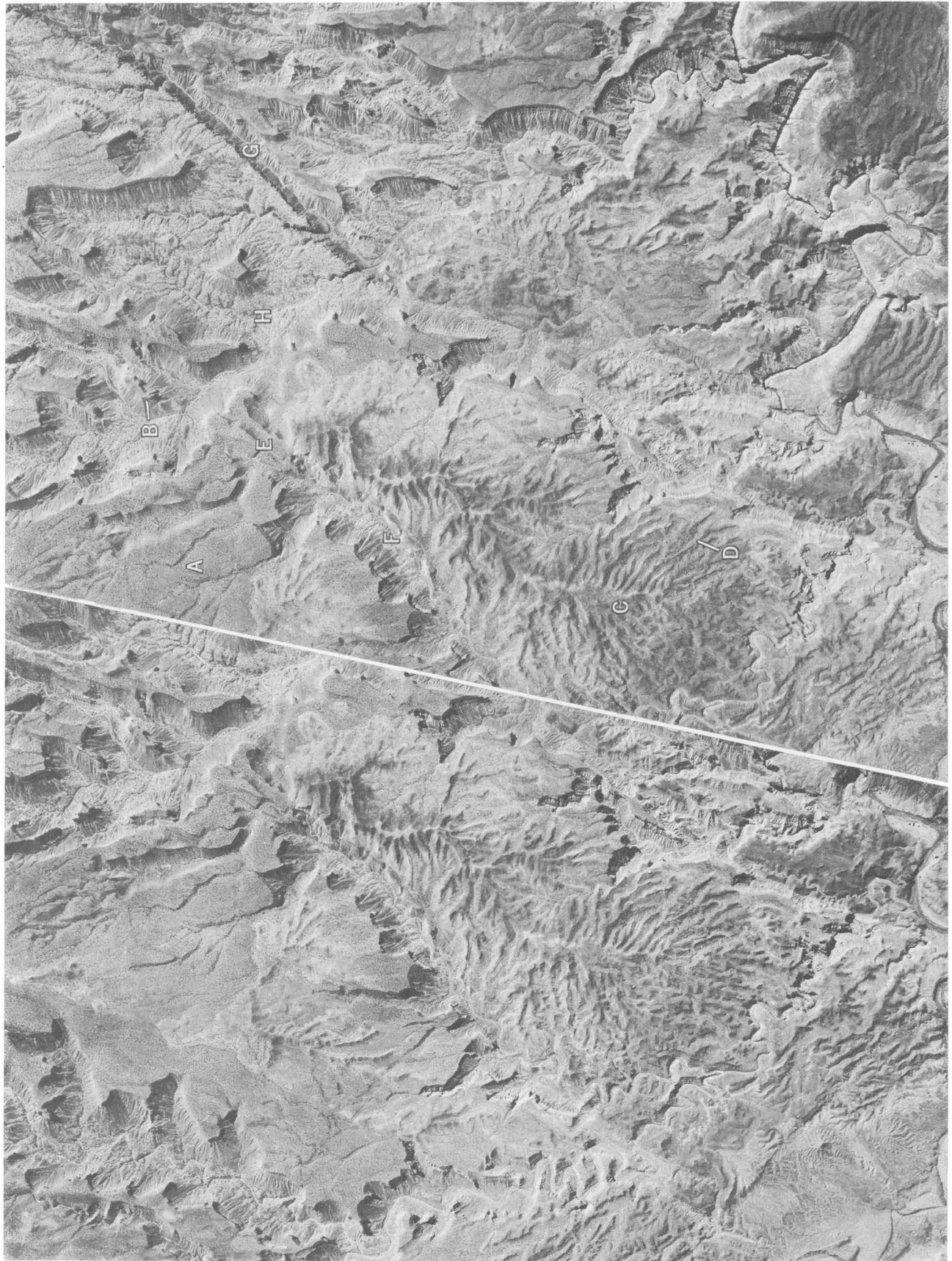
Approximately 1 mile

FIGURE 61.—FLAT-LYING BEDS OF SANDSTONE, LIMESTONE, AND SHALE (TEXAS).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Limestone caprock, *A*, shows a concentration of oak trees along rim but not across capping bench, which is covered by a veneer of cherty conglomerate. Sandstone break at *B* also has oak trees. Certain oaks have an affinity for limestone soils and some for sandy soils, but oak types are not distinguishable on conventional black-and-white photographs at a scale of

1:20,000. Shale valleys are covered with mesquite and locally have stock tanks, *C*, which suggest underlying impermeable materials. Note dendritic drainage and distribution of vegetation bands along the topographic contour, which in places form closed loops and suggest flat-lying or nearly flat-lying beds.



Stereoscopic pair

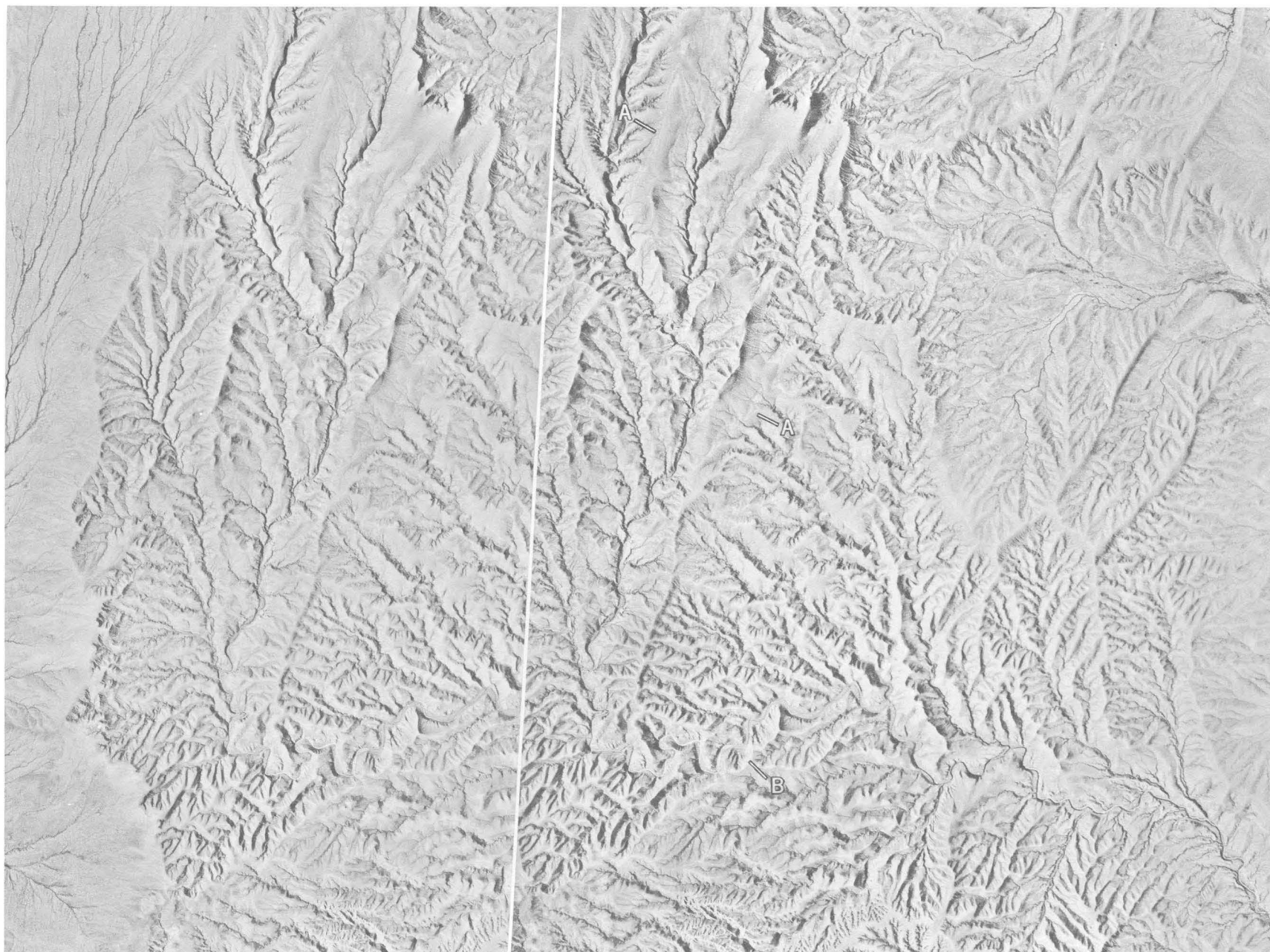
Approximately 1 mile

FIGURE 62.—AREA OF FAULTED, GENTLY DIPPING SEDIMENTARY ROCKS (UTAH).

[Approximate scale 1:37,000. Photographs by U.S. Geological Survey]

Strong contrasts in drainage densities and in erosional features of the terrain result from different sedimentary rock types. Coarse-textured drainage of little-dissected area, *A*, marks a persistent limestone bed that locally forms bluffs. These bluffs overlie fine-grained sandstone and shale, *B*, which have a lesser angle of slope than the limestone, although the difference in slope angle is masked by the vertical exaggeration of the stereoscopic model. Note that top of limestone and topographic surface coincide permitting ready

estimate of the amount of dip. Dark-toned shale and fine-grained sandstone and sandy shale at *C* show fine-textured drainage and erosional topography. Note closely spaced joints in fine-grained sandstone beds at *D*. Vertical offsets of resistant limestone bed at *E* are conspicuous. Drainage along trace of faults is prominent at *F* and *G*. A lower sandstone, *H*, contrasts locally with overlying dark sandstone and shale as a result of its light photographic tone and cover of scattered small trees.



Stereoscopic pair

Approximately 1 mile

FIGURE 63.—SHALE IN SEMIARID CLIMATIC AREA (UTAH).

[Approximate scale 1 : 20,000. Photographs by U.S. Geological Survey]

Fine-textured drainage is typical of shale and other fine-grained clastic rock types. Relief is commonly subdued and divide areas gently rounded. Note that rounding of some divide areas may not be conspicuous because of vertical exaggeration of the stereoscopic model. For example, the relief

at *B* is only about 70 feet. The fine-textured drainage and erosional topography suggest plastic soils. The numerous angular crenulations in minor tributaries probably reflect closely spaced joints. Thin light-toned bands, *A*, are expressions of bedding.



Stereoscopic pair

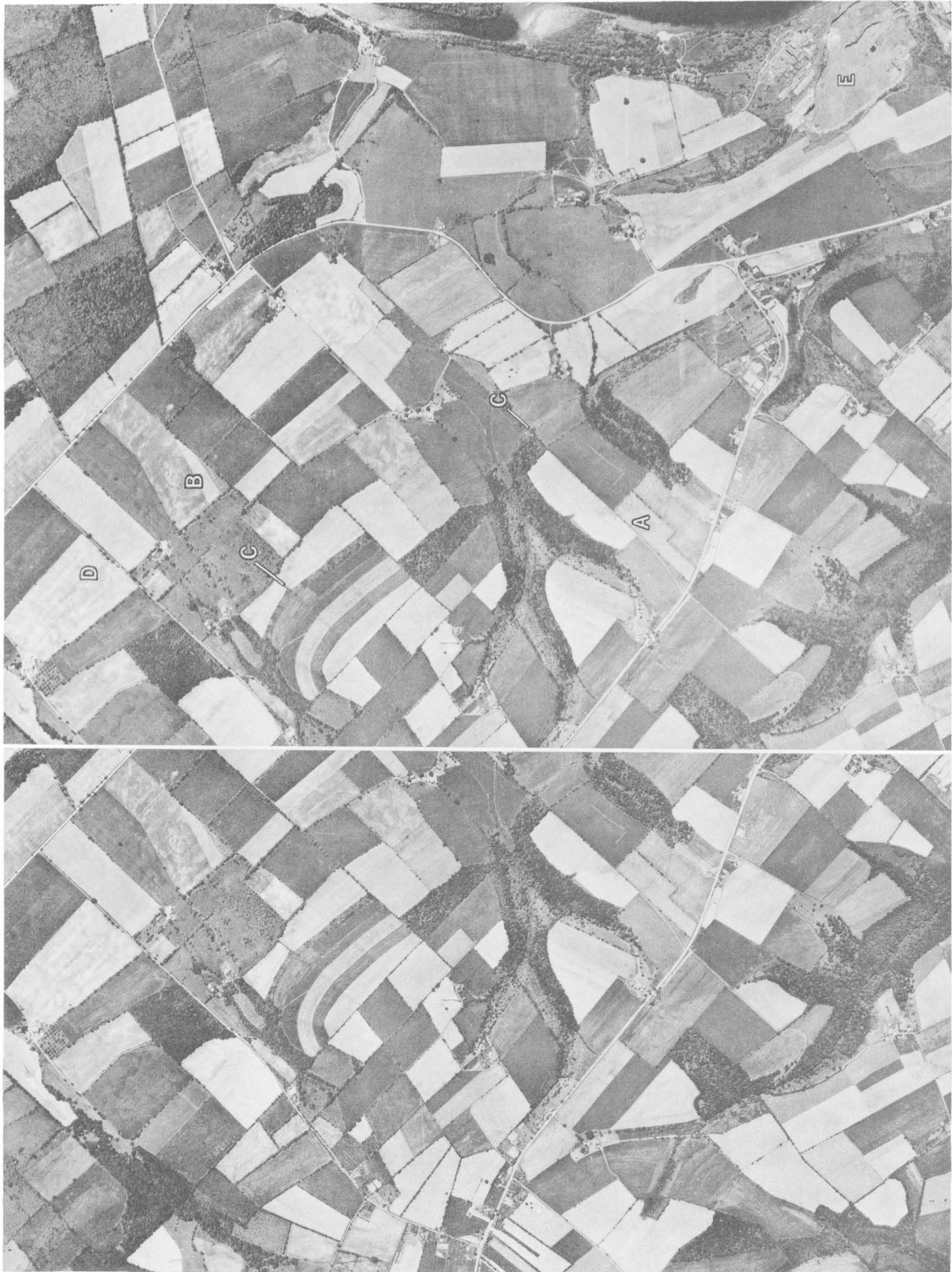
Approximately 1 mile

FIGURE 64.—SHALE AND LIMESTONE IN HUMID CLIMATIC AREA (VIRGINIA).

[Approximate scale 1:43,000. Photographs by U.S. Geological Survey]

Gently dipping shale, *A*, shows a fine-textured drainage. Main streams draining shale flow almost directly in the downdip direction. Limestone underlies anticlinal ridge, *B*. Sinkholes are present locally, *C*, but are not conspicuous within the area. In general the limestone areas are less dissected than shale areas because of better internal drainage in limestone.

Valley, *D*, is underlain by shale. Note discordance of strike of steeply dipping beds, *E*, with scarp, *F*, which suggests presence of a fault along this topographic break in slope. Thin resistant bed of sandstone, *G*, crops out conspicuously on flank of anticlinal ridge. Trellis drainage in area *D* is typical of folded sedimentary rocks.



Stereoscopic pair

Approximately 1 mile

FIGURE 65.—AREA OF GENTLY DIPPING LIMESTONE AND SHALE (PENNSYLVANIA).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Impermeable shale, *A*, has a greater resistance to erosion than the limestone, *B*, and stands topographically high in this area. The contact of shale and limestone is marked by a pronounced topographic break, as at *C*. The shale has been noticeably dissected by stream erosion in contrast to the limestone in which drainage is in large part internal. Note orchards in well-drained limestone areas. Vegetation along stream valleys in the shale

accentuates the drainage contrast of shale and limestone areas. Soil mottling, *D*, in limestone areas occurs where soil cover is thin and allows differences in moisture conditions, believed to result from drainage channels in the limestone bedrock, to stand out. Despite good drainage in the limestone area residual soils developed on limestone may react to engineering tests as a plastic soil and not as a granular soil. Limestone quarry is at *E*.



Stereoscopic pair

Approximately 1 mile

FIGURE 66.—AREA MANTLED BY GLACIAL DEPOSITS (SOUTH DAKOTA).

[Approximate scale 1 : 60,000. Photographs by Army Map Service]

Topographically high area, *A*, with typical knob-and-kettle topography is covered by morainal material; ponds are common but surface drainage channels are conspicuously absent. Rim of high ground has been noticeably dissected by deep channels. The distribution of these channels, accentuated by dark-toned vegetation, forms a radial pattern similar to that over some sub-

surface structures in other areas. Drainage disappears in permeable material, *B*, surrounding the high area. Contrast lack of surface drainage rills in moraine at *A*, where drainage is poor, as indicated by ponds, with lack of surface drainage rills in outwash at *B*, where internal drainage is good. Well-drained area, *C*, probably also represents glacial outwash.



Stereoscopic pair

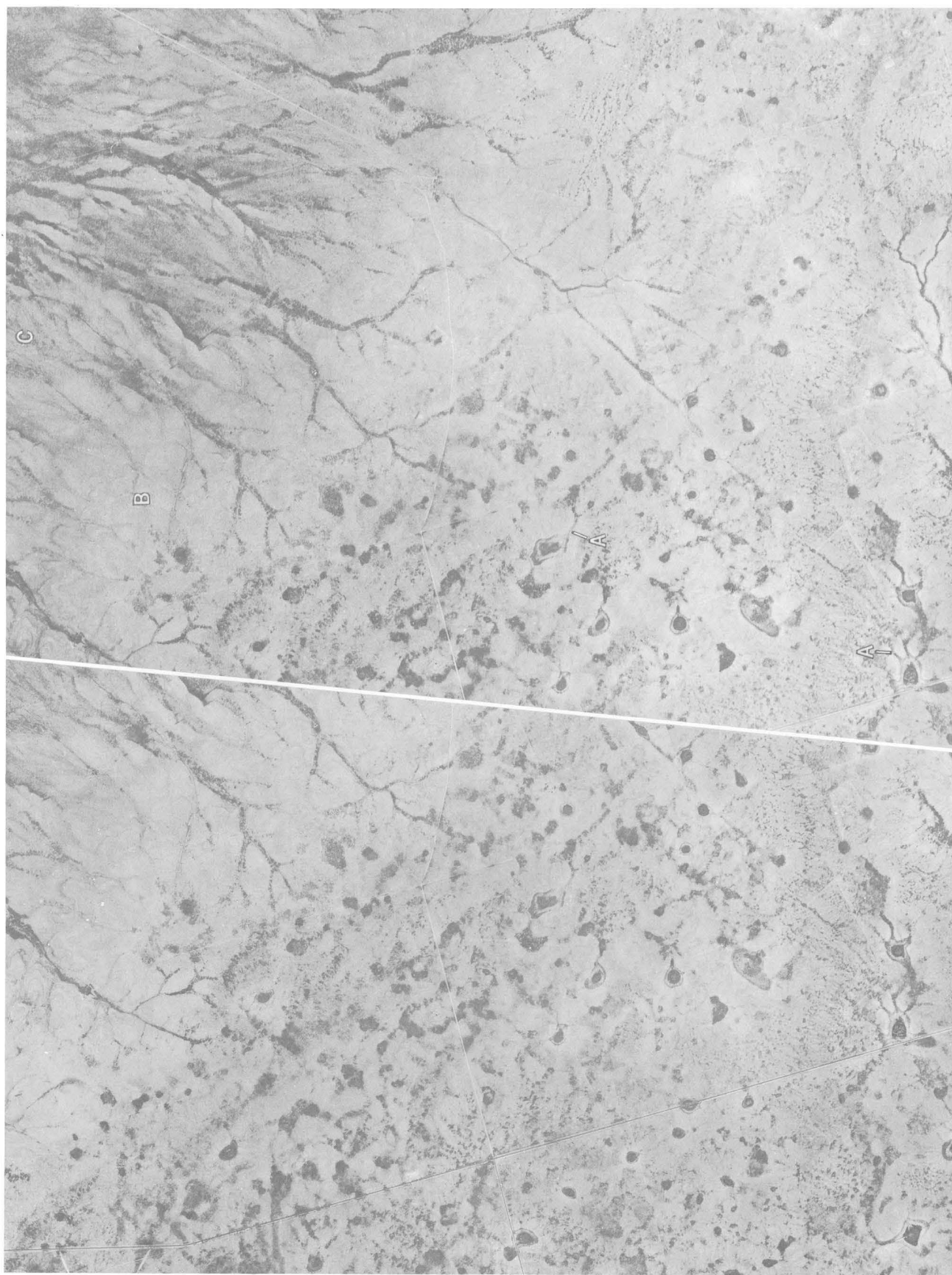
Approximately 1 mile

FIGURE 67.—GLACIATED AREA IN SOUTHEASTERN ALASKA.

[Approximate scale 1 : 40,000. Photographs by U.S. Navy]

Conspicuous linear trends, *A*, represent glacial grooving. These lineations, except for the fanning out in the direction of ice movement, may appear on photographs similar to lineations that represent foliation in metamorphic rocks. Drumlinoid features that give rise to this linear pattern are generally found in broad, flat, and topographically low areas, such as the floors of broad valleys. Commonly the drumlinoid features are elongated parallel or

subparallel to the valley or general topographic grain. Lineations representing foliation on the other hand may transect or parallel the topographic grain; unlike drumlinoid features they are not restricted to any one topographic level. Pock-marked area, *B*, is glacial outwash and probably some glacial lake deposits.



Stereoscopic pair

Approximately 1 mile

FIGURE 68.—APPROXIMATELY FLAT-LYING LIMESTONE AND INTERBEDDED SANDSTONE AND MARLSTONE BEDS COVERED LOCALLY BY ALLUVIUM AND WINDBLOWN DEPOSITS (TEXAS).

[Approximate scale 1 : 63,360. Photographs by Army Map Service]

Rounded dark-toned depressions are sink holes that mark area of limestone. Drainage is primarily internal and few surface drainage channels may be seen; a few short surface rills drain into the sink holes, as at *A*.

In contrast to the limestone area, surface drainage is conspicuously developed in the interbedded sandstone and marlstone, *B*, but becomes less well developed in permeable alluvium and windblown deposits, *C*.



Stereoscopic pair

Approximately 1 mile

FIGURE 69.—AREA OF BASALT FLOWS (IDAHO).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

The oldest basalt, *A*, shows subdued rounded topography and well-developed surface drainage. A younger basalt, *B*, is interbedded with light-toned sedimentary rocks. Some surface drainage has developed on the sedimentary rocks. The youngest basalt, *C*, shows a "lizard skin" appearance on

aerial photographs; locally a collapse structure may be present as at *D*. Almost no integrated surface drainage is present on the youngest basalt. Stream *E* flows in a fault valley. The fault is younger than, and separates, basalts *A* and *B*; basalt *A* has been upthrown.



Stereoscopic pair

Approximately 1 mile

FIGURE 70.—AREA OF GRANITE (SOUTH DAKOTA).

[Approximate scale 1:24,000. Photographs by U.S. Geological Survey]

Dendritic drainage, seen best in stereoscopic view, is typical of many terrains underlain by intrusive igneous rocks or other generally homogeneous rocks. The irregularly spaced joints in several different orientations are characteristic of granite and other intrusive rocks; extremely irregular topog-

raphy is also common in such terrain. Banding, suggestive of sedimentary or metamorphic rocks, is absent. The occurrence of trees predominantly of one variety and the lack of conspicuous preferred orientation of vegetation is suggestive of uniform composition of bedrock.



Stereoscopic pair

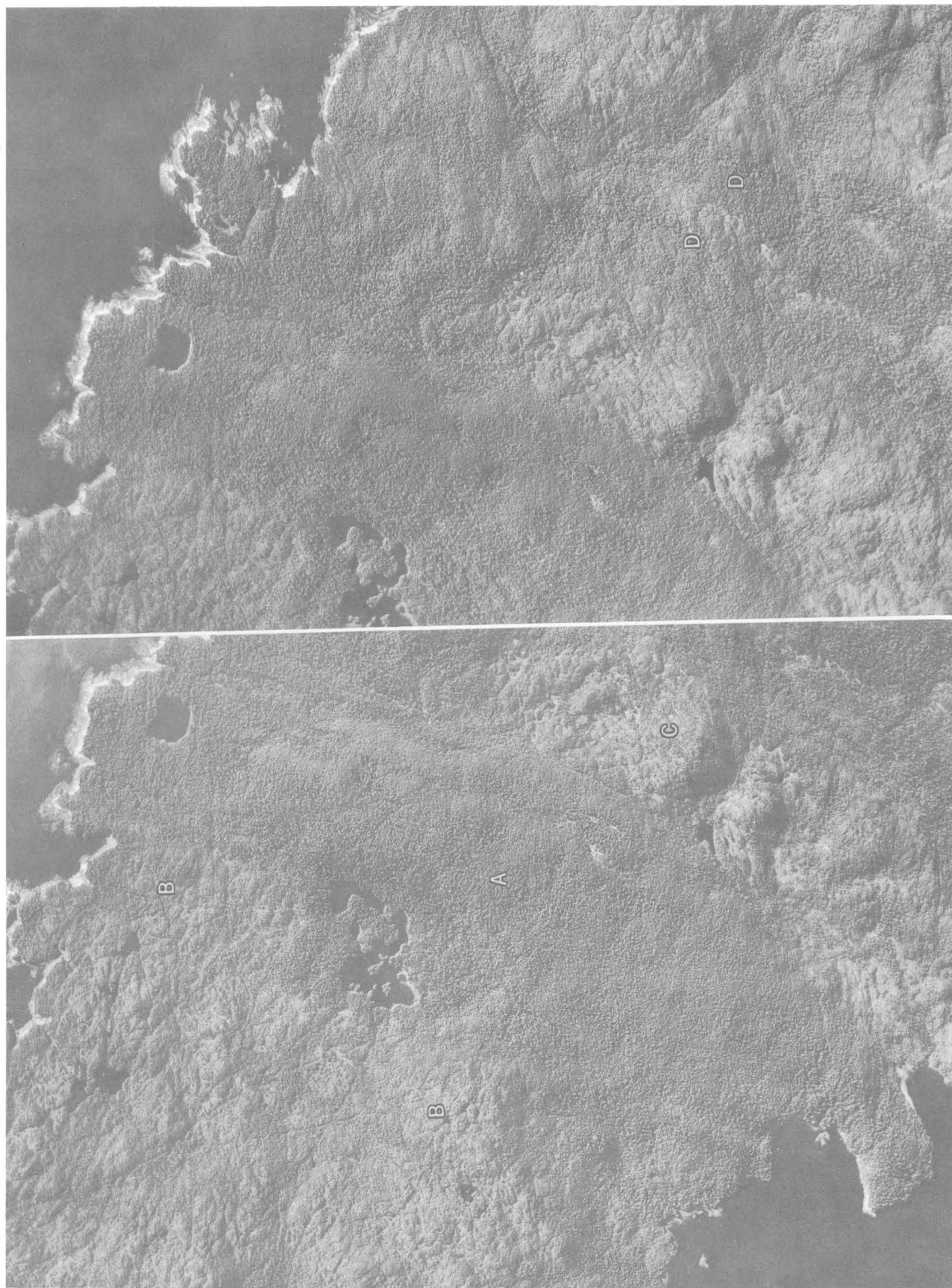
Approximately 1 mile

FIGURE 71.—AREA OF GRANITIC INTRUSIVE ROCKS (WYOMING).

[Approximate scale 1:28,000. Photographs by U.S. Geological Survey]

Profuse, irregularly spaced joints in several different orientations are typical, although not necessarily diagnostic, of intrusive igneous rocks. The massive character of the rocks and apparent lack of bedding in turn suggest igneous intrusive rocks, although locally the rocks shown appear similar to some highly fractured massive sandstone. Conspicuous rectilinear depres-

sions, as at *A*, marked by dark-toned vegetation, are shear zones that are more easily eroded than surrounding rock areas, and probably have a higher concentration of moisture that supports vegetation growth. In places, as at *B*, older shear zones have been offset by younger fractures. Note strong control of drainage by faults and joints.



Stereoscopic pair

Approximately 1 mile

FIGURE 72.—AREA SHOWING VEGETATION DIFFERENCES IN IGNEOUS-METAMORPHIC TERRAIN
(SOUTHEASTERN ALASKA).

[Approximate scale 1 : 40,000. Photographs by U.S. Navy]

Dense stand of coniferous trees, *A*, is typical of massive marble and related carbonate rocks in this area. Diorite, *B*, has only patchy tree growth but shows typical crisscross joint pattern of short lineations common in many intrusive rocks. Area *C* is schist. The surface expression of the schist is

similar to that of the diorite in patchy tree cover and irregular topography but the schist has a dominant lineation direction not present in the intrusive rocks. Vegetation bands, *D*, may cover thin beds of marble. Note that gently curved vegetation bands suggest steeply dipping rock units.



Stereoscopic pair

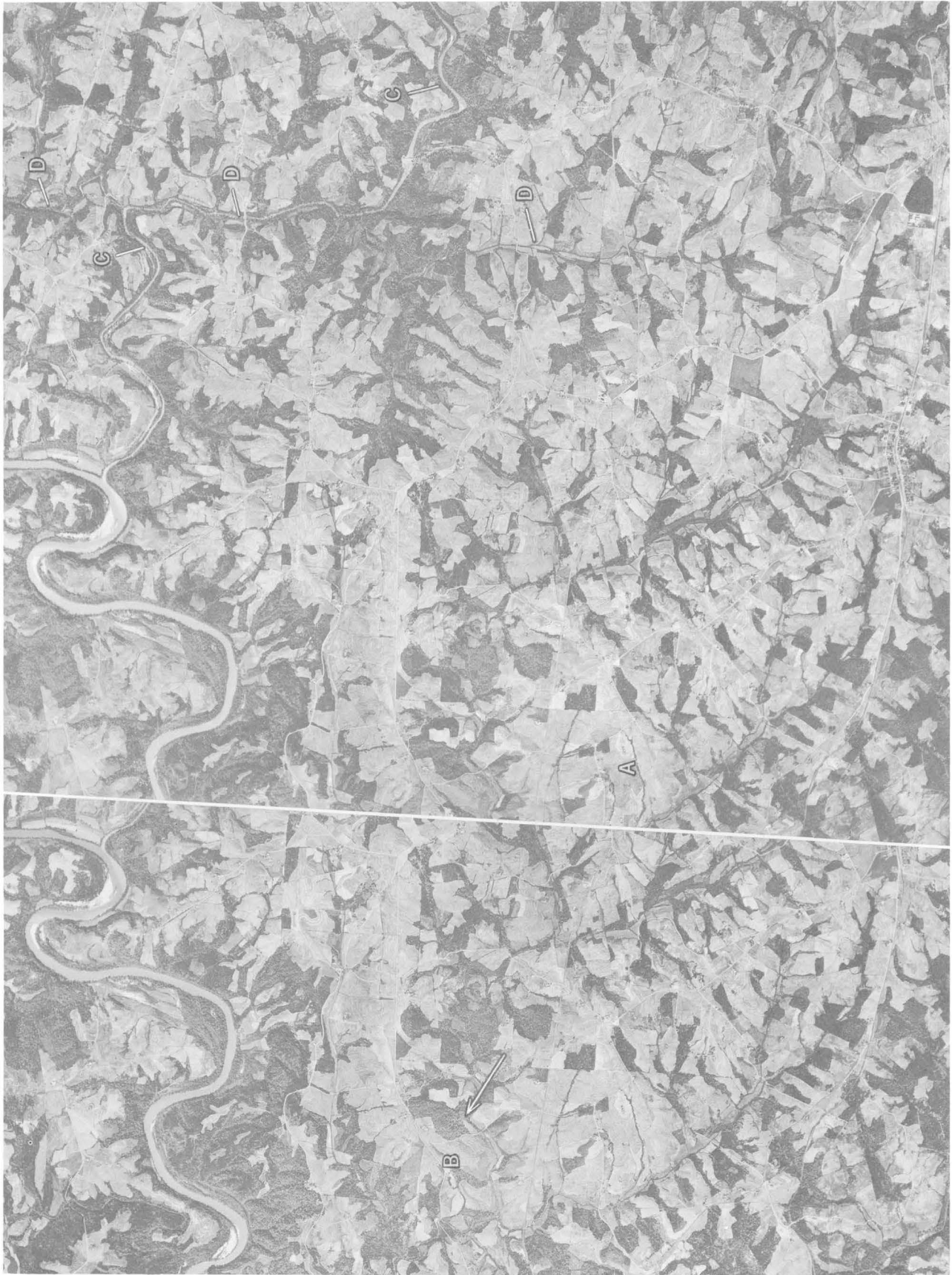
Approximately 1 mile

FIGURE 73.—AREA UNDERLAIN BY SILICIC VOLCANIC TUFFS AND FLOWS AND BEDDED ARGILLITE OR SLATE (NORTH CAROLINA).

[Approximate scale 1 : 58,000. Photographs by Army Map Service]

Major streams, 4, are developed along the regional cross-joint direction. Roads extending generally parallel to the major streams accentuate the cross-joint direction. Minor tributary streams flow predominantly parallel to the regional structural trend and at right angles to the cross joints. Hills are commonly elongate in the direction of the regional strike, which may represent foliation or flow cleavage rather than bedding. In such low-

relief areas the extensive land-use pattern tends to obscure structural trends; commonly the structural trends can be better observed from a mosaic composed of several photographs. Any one stereoscopic pair can only show a small part of the regional geologic structure. Structural interpretation may also be facilitated by study of separate drainage maps, as in figure 8.



Stereoscopic pair

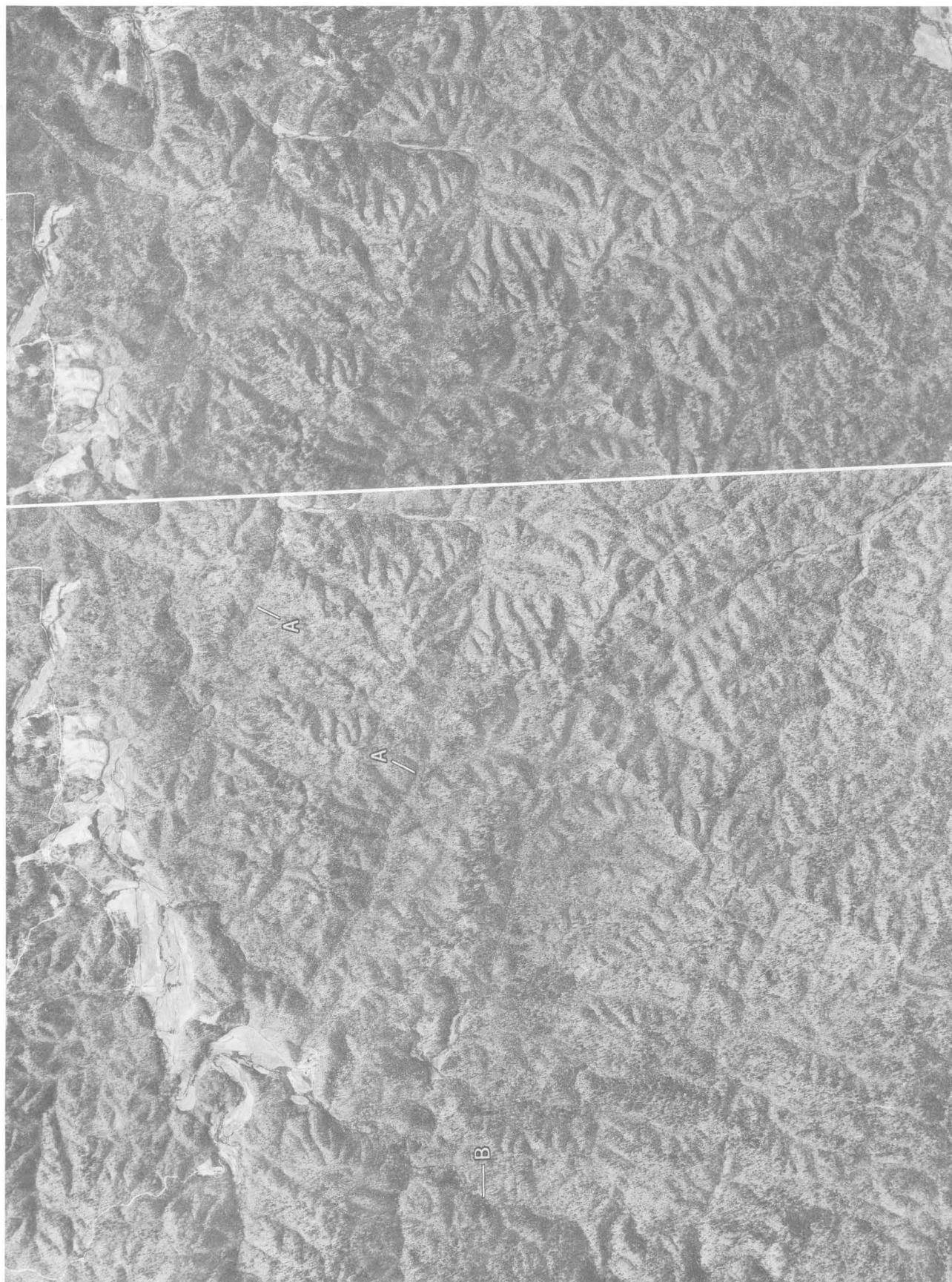
Approximately 1 mile

FIGURE 74.—AREA OF FOLDED, FAULTED, AND HIGHLY METAMORPHOSED ROCKS (NORTH CAROLINA).

[Approximate scale 1 : 57,000. Photographs by Army Map Service]

This pair of photographs illustrates a use of drainage characteristics in the interpretation of geologic structure. Where dips are gentle, tributary streams developed on the updip side of a strike valley commonly will be longer than tributary streams developed on the downdip side of the valley, as at *A*. The direction of dip of strata is thus indicated. Length relations of streams are commonly best studied on a separate drainage overlay (see fig. 7) where vegetation and other obscuring features in the stereoscopic model are not present. In the area shown, a plunging fold is also suggested by the

distribution of photographic tones and gentle curvature of streams around the nose, *B*, of the fold. Arrow indicates direction of plunge. Many streams in highly metamorphosed terrain have developed in response to, and therefore reflect, the strike and dip of foliation rather than bedding. Prominent cross joints are expressed by linear segments of major streams, as at *C*, and by alinement of vegetation along some tributary streams. Note conspicuous fault indicated by alinement of stream segments, *D*; this fault is inconspicuous on the ground.



Stereoscopic pair

Approximately 1 mile

FIGURE 75.—AREA UNDERLAIN BY PHYLLITE AND SLIGHTLY METAMORPHOSED SLATY ROCKS (ALABAMA).

[Approximate scale 1:29,000. Photographs by U.S. Geological Survey]

Poorly resistant phyllite and slightly metamorphosed slaty rocks here are characterized by fine-textured drainage, commonly found in fine-grained clastic rocks. The area also has a fine-textured erosional topography. Several conspicuous linear trends, *A*, are at right angles to the regional strike of bedding. These trends probably represent regional cross joints. In areas of metamorphic rocks the prominent regional cross joints commonly are widely

spaced and streams flow along them. The linear trend of the stream at *B* is parallel to the regional strike of bedding. There is no direct surface manifestation of bedding. Headwater tributaries form a generally dendritic drainage pattern that suggests uniformity of rock type, but principal streams show rectangular drainage probably influenced by bedding and cross joints.



Stereoscopic pair

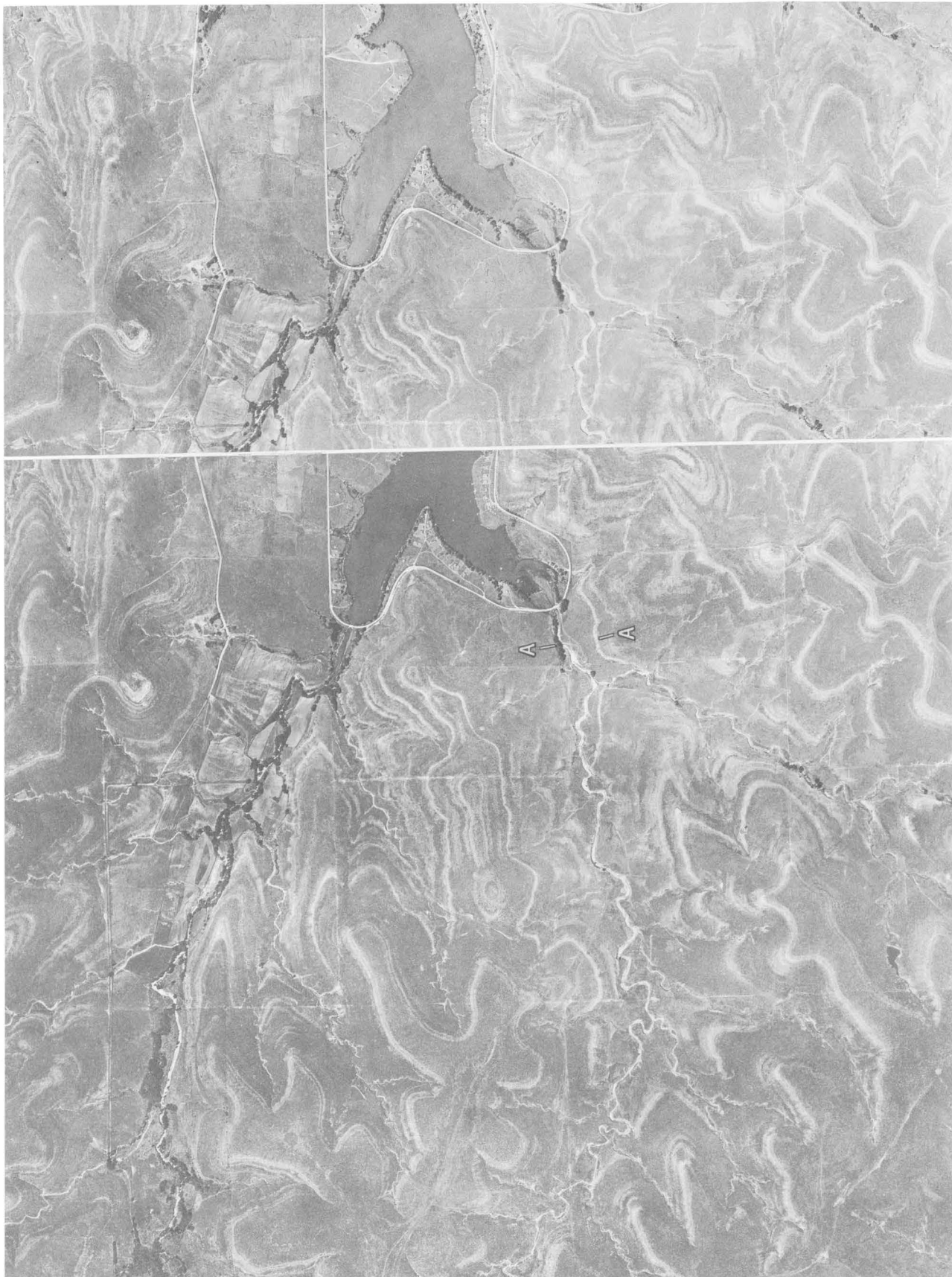
Approximately 1 mile

FIGURE 76.—HEAVILY VEGETATED TERRAIN UNDERLAIN BY METAMORPHIC AND EXTRUSIVE VOLCANIC ROCKS (SOUTHEASTERN ALASKA).

[Approximate scale 1 : 40,000. Photographs by U.S. Geological Survey]

Numerous subparallel lineations, *A*, represented primarily by rectilinear depressions that channel the drainage, are expressions of foliation in the metamorphic rocks. Conspicuous rectilinear depressions, *B*, transecting the foliation direction, represent faults. The remnant of a recent volcanic cone,

C, is recognized by its shape. Note lobate patterns of vegetation, *D*, suggesting areas of flow rocks. Absence of lineations in area *E* suggests that flows also are present there.



Stereoscopic pair

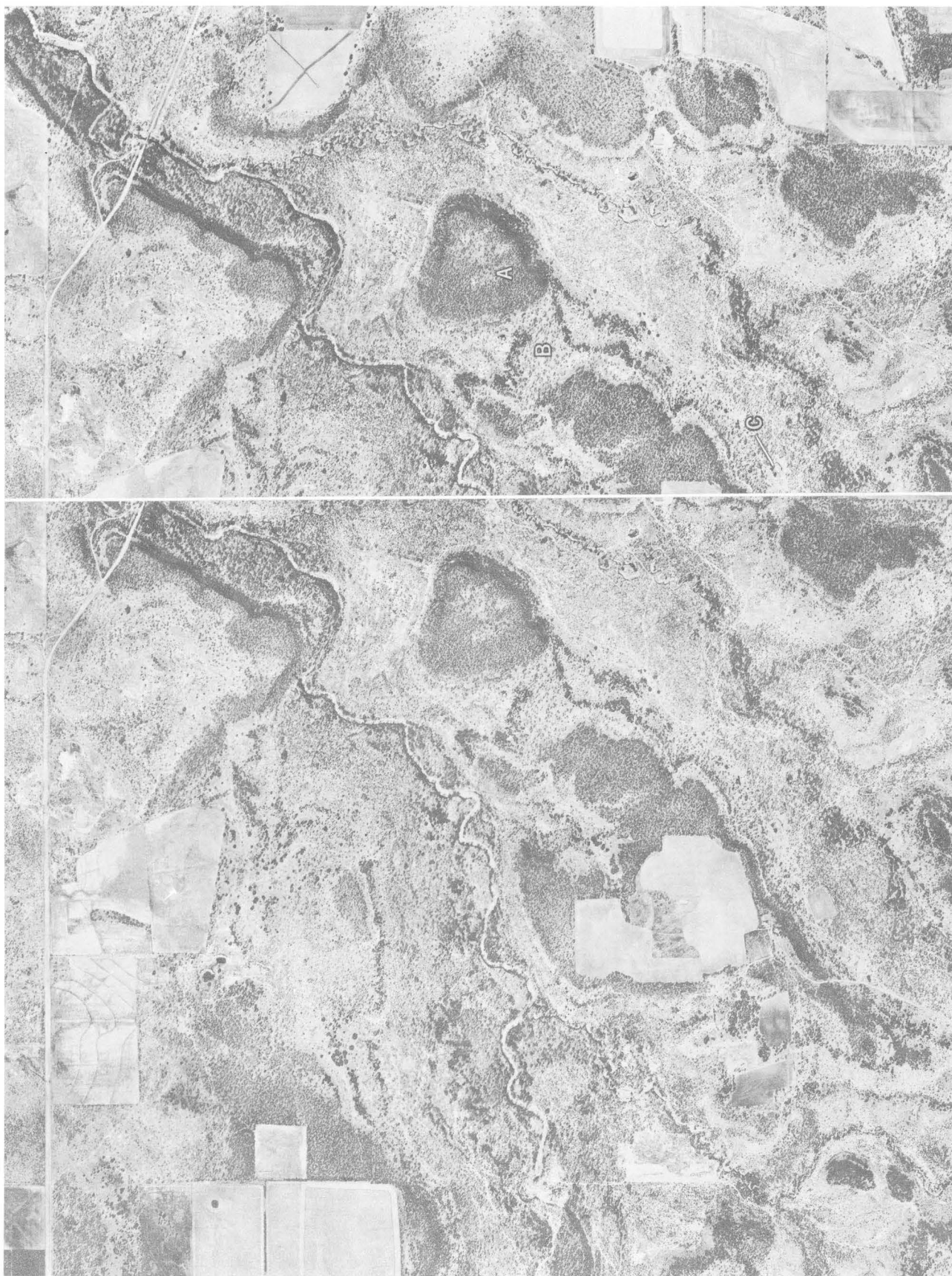
Approximately 1 mile

FIGURE 77.—FLAT-LYING BEDS OF LIMESTONE AND SHALE (KANSAS).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Strong contrasts in photographic tone result primarily from different lithologic characteristics of underlying formations; dark-toned beds are shale with some grassy vegetation; light-toned beds are limestone. The near-coincidence of bedding traces and topographic contours, closed loops of tonal patterns, as well as the dendritic drainage pattern are typical of flat-lying beds. Small thickness of limestone interbeds is not conducive to development of

sink holes. In some places individual limestone beds can be distinguished on the basis of weathering and erosional characteristics; massive cherty limestone benches may show rounded rims, whereas thin platy limestone benches may show a sharp break at the rim. Abundant trees and shrubs along part of bed A suggest a plentiful supply of water. Bed A is locally an aquifer.



Stereoscopic pair

Approximately 1 mile

FIGURE 78.—FLAT-LYING BEDS OF SANDSTONE, LIMESTONE, AND SHALE (TEXAS).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Flat-lying beds are indicated by benchlike landform, extension of tonal bands along topographic contour, and by dendritic drainage. Dark photographic tone on sandstone caprock, *A*, results from growth of oak trees. Benches of limestone, *B*, exhibit concentration of oak growth along rims but

not across flats. Valley areas are underlain by shale, which is covered predominantly by mesquite growth. Stock tanks, *C*, are common in impermeable material and where present suggest shale in this region.



Stereoscopic pair

Approximately 1 mile

FIGURE 79.—AREA OF SPARSE OUTCROPS UNDERLAIN LARGELY BY GENTLY FOLDED SANDSTONE,
CONGLOMERATE, AND SHALE (NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

Dip slopes are characterized by few streams in contrast to back slopes on which a system of numerous subparallel streams has developed. Drainage in the dip-slope direction is generally coarse textured except for profuse channels developed at heads of tributaries. Drainage on the back slopes is fine textured. The textural difference, or drainage density difference, rather

than any specific drainage pattern, stands out. The back slope, with its fine-textured drainage, is predominantly a shale section in contrast to the sandstone and conglomerate of the dip slope. Note horizontal offset of light-toned sandstone beds by near-vertical faults, illustrated at A, transverse to the strike.



Stereoscopic triplet

Approximately 1 mile

FIGURE 80.—GENTLY TO STEEPLY DIPPING SEDIMENTARY ROCKS OVERLYING SCHIST-GNEISS-GRANITE
COMPLEX (WYOMING).

[Approximate scale 1:59,000. Photographs by Army Map Service]

Striking discordance in dip of beds can be seen between beds at *A* and *B* and between near-vertical beds at *C* and flat-lying beds at *D*. Such a discordance in dip may represent tightly folded structures in some areas but here it represents faulting. Note also the conspicuous discordance in strike between beds at *A* and *C* and between beds at *B* and *C*. The locations of fault traces may be inferred from the positions of discordant beds, but

details of fault structure and positions of formation contacts cannot be seen clearly on the photographs of many parts of this complex area. Dark-toned rocks, *E*, lacking bedding or banding are schist-gneiss-granite complex. Light-toned jointed rocks, *F*, are predominantly limestone and dolomite. Where light-toned rocks are cut by a stream, as at *G*, the outcrop pattern forms a V in the direction of dip.



Stereoscopic pair

Approximately 1 mile

FIGURE 81.—GENTLY FOLDED SEDIMENTARY ROCKS (CENTRAL UTAH).

[Approximate scale 1 : 20,000. Photographs by Soil Conservation Service]

Contrasting photographic tones, representing different soil and rock types, strongly outline plunging anticline. Plunge of anticline is also indicated by stream curvature at *A* and *B*. Note that major stream has generally consistent direction of flow until it reaches anticlinal nose at *C*, at which point it is deflected in the direction of plunge of the structure. Outcrop pattern

of contact between light- and dark-toned rocks, *D*, along flank of the anticline forms pronounced V's, which point in the direction of dip. Local intrusions of basalt dikes, *E*, stand in topographic relief above softer surrounding rocks.



FIGURE 82.—RING DIKE IN NEW HAMPSHIRE.

[Approximate scale 1:34,000. Photographs by U.S. Geological Survey]

The ring dike, composed of several types of igneous rock, is the most conspicuous feature of the terrain. Different rock types in places are reflected in the topographic expression of terrain. An outer ring and partial inner ring, *A*, composed of monzonite stand in conspicuous topographic relief. Hornblende diorite, in places foliated, forms the low areas, *B*. Some geologic

contacts may be located on the basis of topography. However, specific placement of contacts cannot be made from the stereoscopic model; but in igneous terrain, where one rock type may grade into another, contacts are difficult to select in the field. The ring dike is cut by several faults, *C*, indicated by alinements of scarps, depressions, and vegetation.

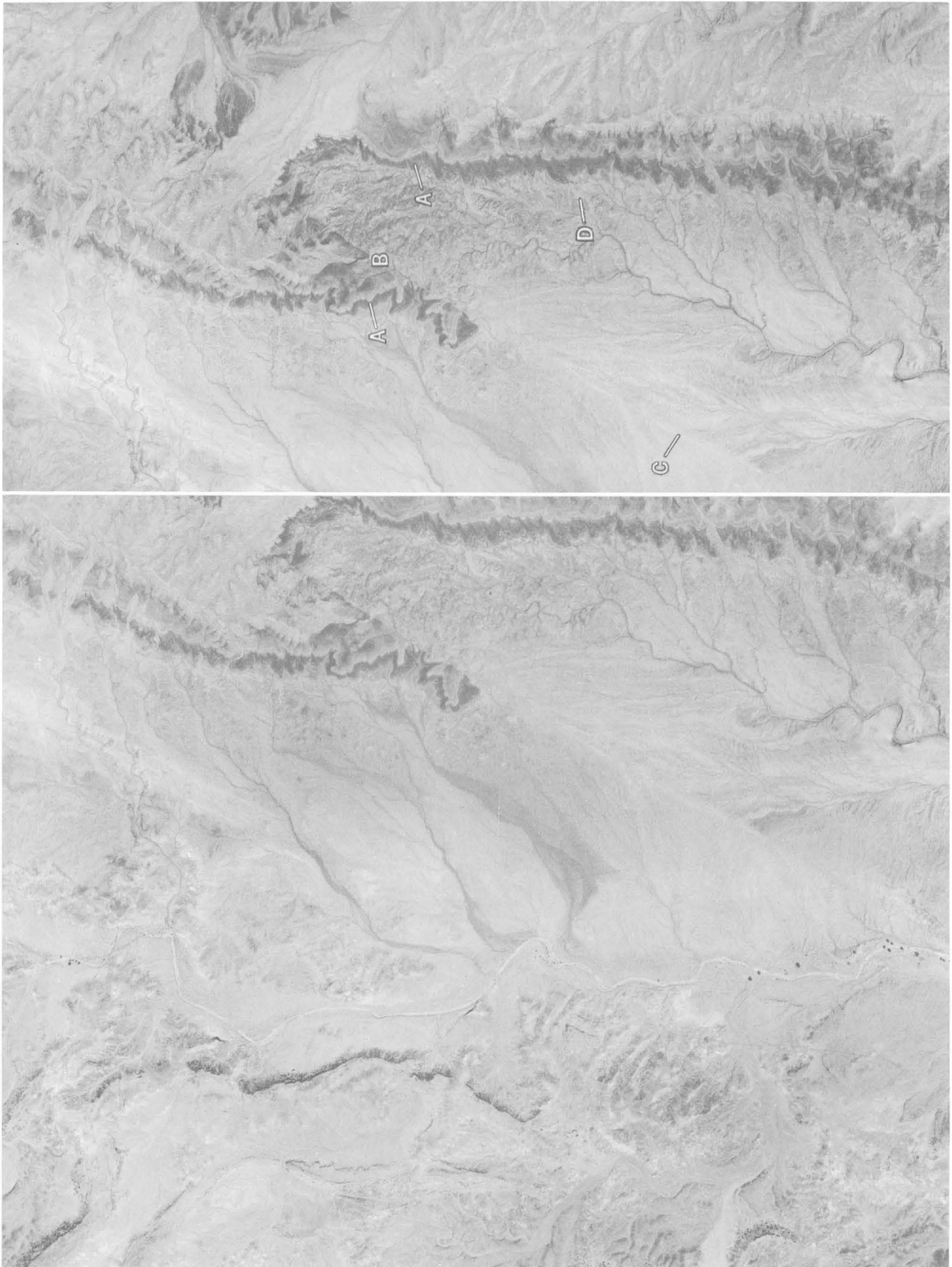


FIGURE 83.—GENTLY DIPPING SEDIMENTARY ROCKS OFFSET BY NEAR-VERTICAL FAULT (UTAH).

[Approximate scale 1 : 20,000. Photographs by U.S. Geological Survey]

Line separating areas of contrasting photographic tones is trace of fault. The straightness of the fault trace indicates that the fault has approximately a vertical dip. Note vertical offset of dark-toned shale bed, *A*, and difference in erosional character of topography on opposite sides of fault at *B*. Faint trace of fault in alluvium at *C* is locally marked by differences in

drainage on opposite sides of the fault. Light-toned sandstone interbeds, *D*, cap local areas and exhibit serrated margins as a result of closely spaced joints. Fine-textured drainage is typical of the poorly resistant shale and thin sandstone interbeds.

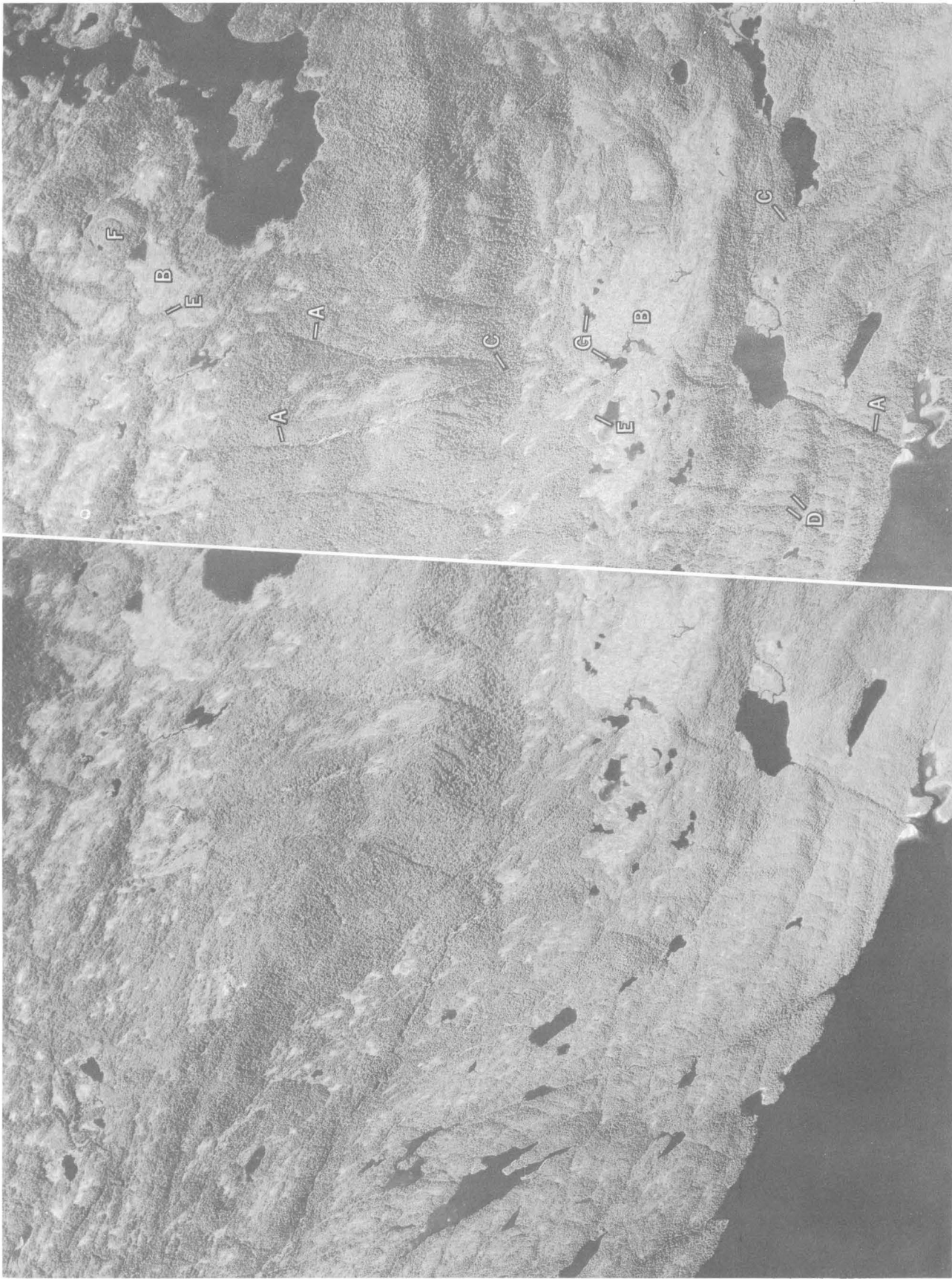


FIGURE 84.—FAULTED, GENTLY DIPPING SEDIMENTARY ROCKS (UTAH).

[Approximate scale 1:20,000. Photographs by U.S. Geological Survey]

Conspicuous high-angle faults offset beds in many places, as at *A*, where limestone caprock is down-faulted about 125 feet. Note the effect of vertical exaggeration in the stereoscopic model on the amount of offset. Fault is indicated by scarp, *B*, and its alinement with stream at *C*. Note right-angle bend in stream at *D* along trace of fault. Another fault is indi-

cated by alinement of stream *E* and break in vegetation *F*. Several other faults with only small displacements are shown by alinements at *G*. Resistant limestone caprock stands in vertical bluffs overlying less resistant shale and shaly siltstone that have a lesser angle of slope.



Stereoscopic pair

Approximately 1 mile

FIGURE 85.—VEGETATED TERRAIN UNDERLAIN BY IGNEOUS AND METAMORPHIC ROCKS LOCALLY COVERED BY BASALT FLOWS (SOUTHEASTERN ALASKA).

[Approximate scale 1:40,000. Photographs by U.S. Navy]

A significant contrast between the igneous and metamorphic complex and younger volcanic flows is shown in the distribution of faults and vegetation. Faults, indicated primarily by rectilinear depressions, *A*, are common in the igneous and metamorphic rocks, but are absent from the area of lava flows, *B*. Note that certain faults, as at *C*, may be traced up to the lava flows and that continuations of these faults may be picked up on the opposite side of the flow area. Some of the shorter lineations, as at *D*, probably represent wide-spaced joints. Lobate patterns of dark-toned vegetation, *E*, commonly

delineate the edges of individual lava flows. Small cone at *F* is suggested by shape of constructional landform. Relatively flat, muskeg-covered flows are generally poorly drained and locally contain numerous shallow ponds, *G*, that lack any integrated drainage. The muskeg areas have a relatively light photographic tone because of the mossy vegetation and do not appear dark despite the abundance of moisture. The photographic texture of the muskeg areas is also distinctive.



Stereoscopic pair

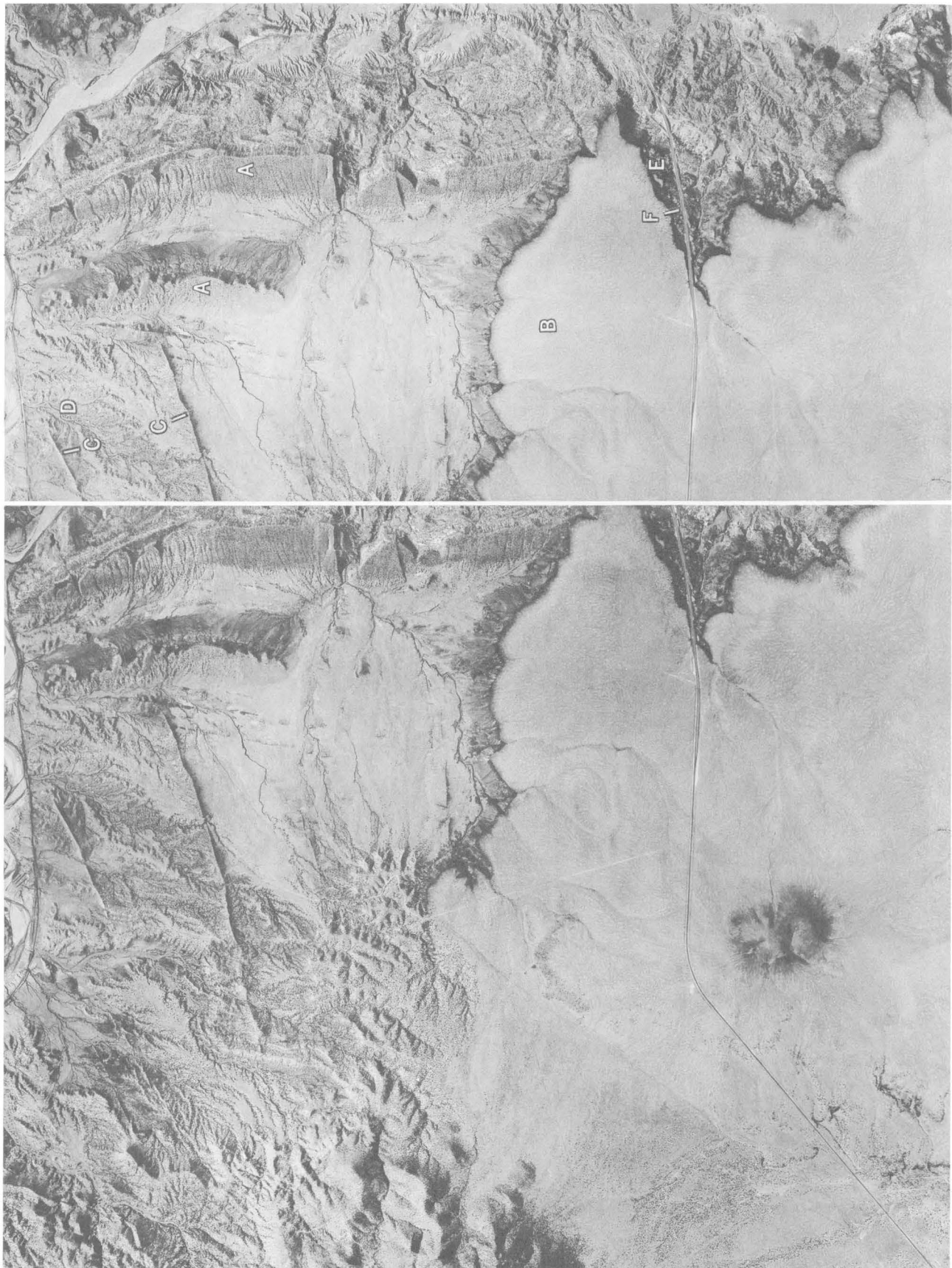
Approximately 1 mile

FIGURE 86.—AREA OF CRYSTALLINE ROCKS (WYOMING).

[Approximate scale 1 : 60,000. Photographs by Army Map Service]

Numerous widely spaced joints, typical of many intrusive masses, are conspicuous, although widely varying orientations of joints, found in most plutonic rocks, are not prominent. Drainage is markedly controlled by faults and joints; the dendritic drainage that is normally characteristic of crystalline masses is thus subdued. Although the rocks shown here are locally

gneissic, evidence of bedding of original sediments or gneissic structure is generally lacking. Major fault, *A*, marked by stream alinement, is offset by younger fault, *B*, also delineated by stream alinement. Note alinement of streams on opposite side of divide, *C*.



Stereoscopic pair

Approximately 1 mile

FIGURE 87.—LAVA FLOW LYING UNCONFORMABLY ON GENTLY DIPPING SEDIMENTARY ROCKS (NEW MEXICO).

[Approximate scale 1 : 54,000. Photographs by Army Map Service]

Resistant sandstone beds, *A*, dipping 15° are truncated by overlying lava flow, *B*. Bedding stands out where topographic and bedding surfaces coincide. Hogback landform is also prominent where resistant sandstone beds and intervening shale areas have been etched by erosion. Note how vertical exaggeration of dip causes unconformable relation between sedimentary beds and overlying lava flow to stand out. Surface of lava flow has mottled

appearance that is typical of basalt flows in many areas. Basaltic dikes, *C*, stand in topographic relief above soft shale shown by fine-textured drainage at *D*. Some landsliding has taken place at *E* where resistant lava overlies less resistant rocks. Road alignment *F* is subject to potential destructive action of additional slides.



Stereoscopic pair

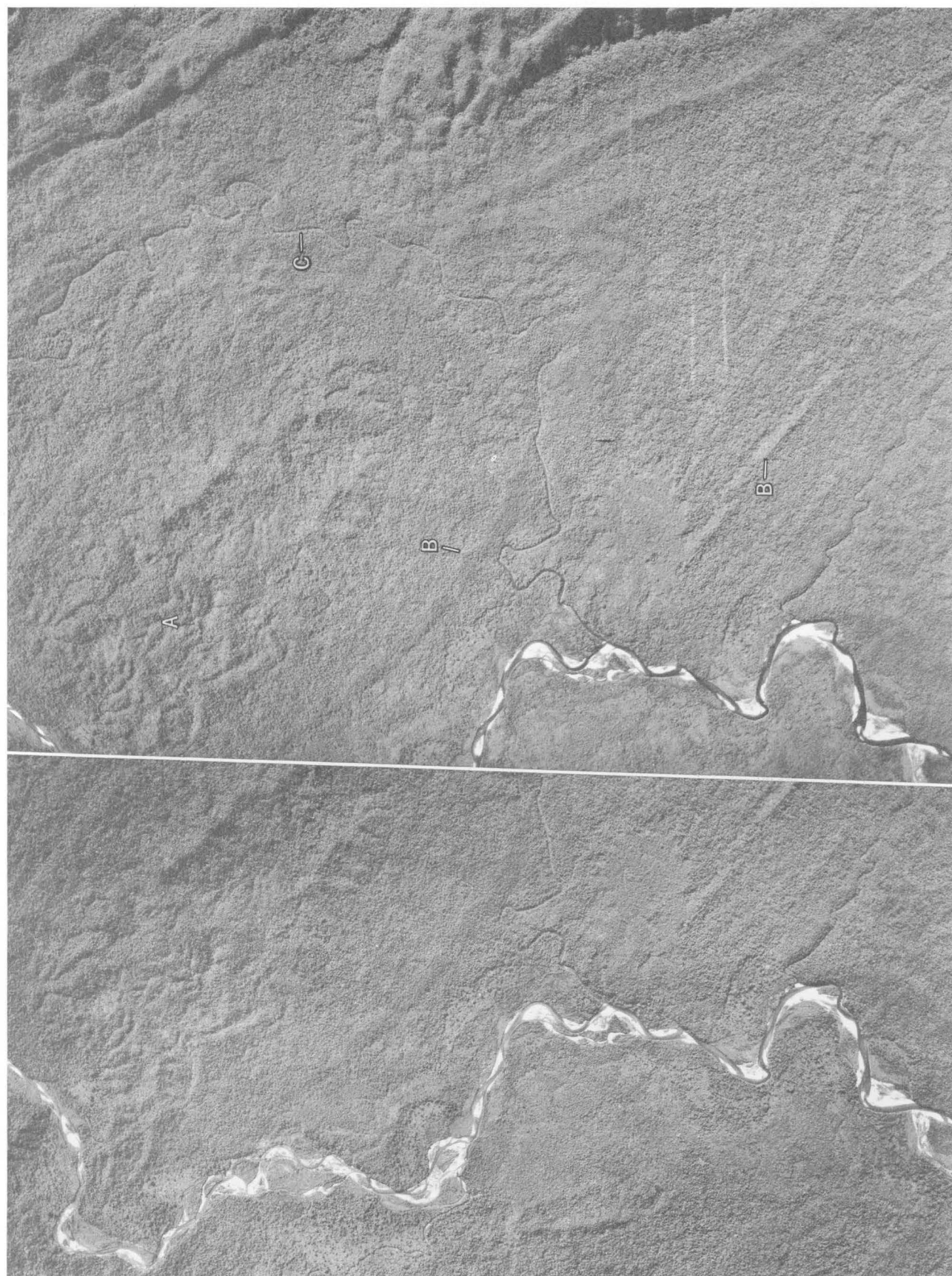
Approximately 1 mile

FIGURE 88.—GENTLY DIPPING SEDIMENTARY ROCKS OVERLAIN IN PART BY RIVER GRAVELS (UTAH).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Flat-lying gravel cap, *A*, truncates underlying sedimentary rocks. Traces of bedding below granular material of gravel cap are indicated by minor breaks in slope, *B*, accentuated by shadows. Surface drainage is conspicuously absent from well-drained broad gravel flat, *D*, which represents a

younger, lower and less dissected terrace than *A*. Gullies in silty valley-fill, *E*, exhibit near-vertical slopes where recent stream dissection has taken place. Note effect of vertical exaggeration in the stereoscopic model. True dip of beds at *C* is about 6°.



Stereoscopic pair

Approximately 1 mile

FIGURE 89.—GENTLY FOLDED SEDIMENTARY ROCKS IN HEAVILY VEGETATED AREA
(NORTHERN GUATEMALA).

[Approximate scale 1:65,000. Photographs by Army Map Service; published with permission of the Guatemala Government]

Anticlinal structural feature in heavily vegetated jungle area is indicated by erosional characteristics of terrain and by drainage. Core of anticline, *A*, is topographically higher than surrounding area and is somewhat more dissected. Bedding and direction of dip are suggested by the topographically

high bands of ground at *B*; note that tree crowns appear to fall in a dipping plane. Stream, *C*, has been deflected around the nose of the anticline; the convex side of the curve indicates the direction of plunge, but the major stream of the area has maintained its course across the anticline.



Stereoscopic pair

Approximately 1 mile

FIGURE 90.—PLUNGING ANTICLINE IN GENTLY FOLDED ROCKS (SOUTHERN UTAH).

[Approximate scale 1:37,000. Photographs by U.S. Geological Survey]

Distribution of rock types and characteristics of drainage clearly outline plunging anticline. Note that major stream curves around nose of the anticline and the convex side of the curve indicates the direction of plunge. Lithologic differences between formations are conspicuously shown by contrasts in photographic tone and erosional characteristics of terrain. Dark-toned formation, *A*, is an interbedded sequence predominantly of red sandstone and some mudstone and shale. Light-toned formation, *B*, is made up of a rather uniform weakly cemented massively bedded sandstone showing a fine-textured dendritic drainage. Drainage rills in formation *A* and *C* are

controlled in part by hard, resistant sandstone interbeds that locally channel the drainage along the interbeds. Formation *C* largely comprises a series of red to brown silty sandstone and shale. Rocks at *D* include predominantly thin-bedded red sandstone and limestone interbeds. Bedding is prominently shown because topographic surfaces and bedding surfaces coincide in many places. Dip of sedimentary beds is exaggerated as in most stereoscopic models. True dip at *E* is 5°. Dark-toned resistant basalt dike, *F*, stands in relief above light-toned rocks.



Stereoscopic pair

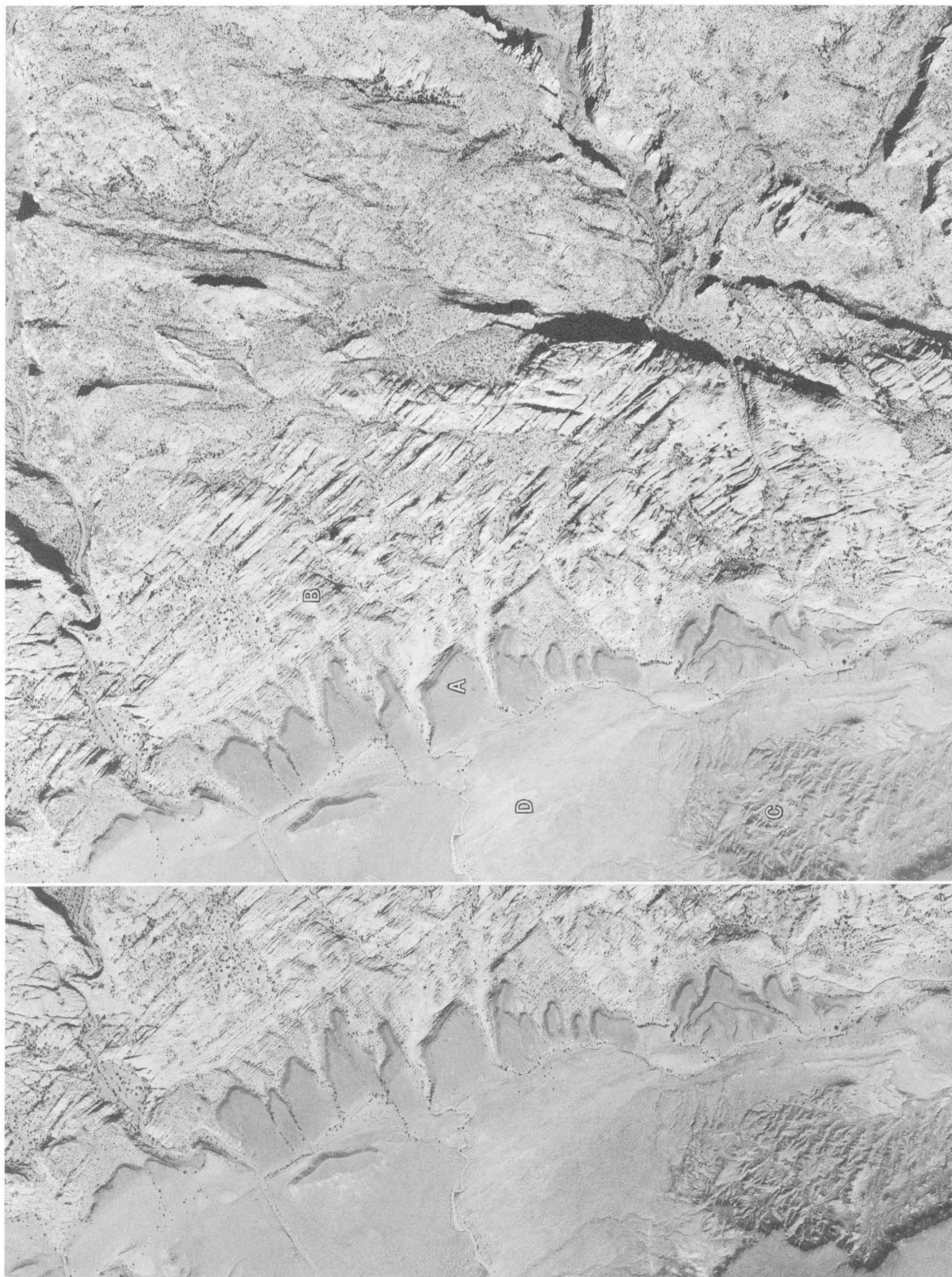
Approximately 1 mile

FIGURE 91.—STRATIGRAPHIC SECTION ACROSS GENTLY FOLDED ANTICLINE (UTAH).

[Approximate scale 1 : 20,000. Photographs by U.S. Geological Survey]

Breaching of anticline by major river has exposed cross section of the fold. Bedding is clearly represented at *A* where bedding surfaces coincide with topographic surfaces. Effect of vertical exaggeration on dip is shown on both flanks of the anticline. True dip at *A* is about 20°; at *B* the beds are horizontal; at *C* the dip is about 4°. Shale, siltstone, and fine-grained sandstone, *D*, exhibit dark photographic tones; relatively closely spaced joints

may be seen locally. Coarse sandstone with some conglomerate, *E*, has light photographic tone; widely spaced joints are present as at *F*. The coarse-grained rocks characteristically form cliffs. Where beds are nearly horizontal the fine-grained rocks have slopes that are less steep than those of the coarse-grained rocks. Where beds are dipping, the softer rocks are in many places etched out by erosion leaving hogbacks of resistant rock types.



Stereoscopic pair

Approximately 1 mile

FIGURE 92.—GENTLY DIPPING SEDIMENTARY ROCKS ON EAST SIDE OF SAN RAFAEL SWELL (UTAH).

[Approximate scale 1:20,000. Photographs by U.S. Geological Survey]

Bedding on flank of fold is clearly shown by photographic tone differences and hogback landform where dip surfaces and topographic surfaces coincide. Note effect of vertical exaggeration on dip in the stereoscopic model; beds at *A* have true dip of 6°. Massive crossbedded sandstone, *B*, has light photographic tone and widely spaced joints oriented predominantly in one direction; locally its appearance on aerial photographs is similar to some

igneous rocks. Dark-toned resistant beds, *A*, are red mudstone and lenticularly bedded medium-grained sandstone. Poorly resistant interbedded red limy sandstone, mudstone, and limestone, *C*, is easily eroded and has fine-textured drainage. Beds at *C* are flat lying. Windblown sand, *D*, is marked by absence of surface drainage channels.

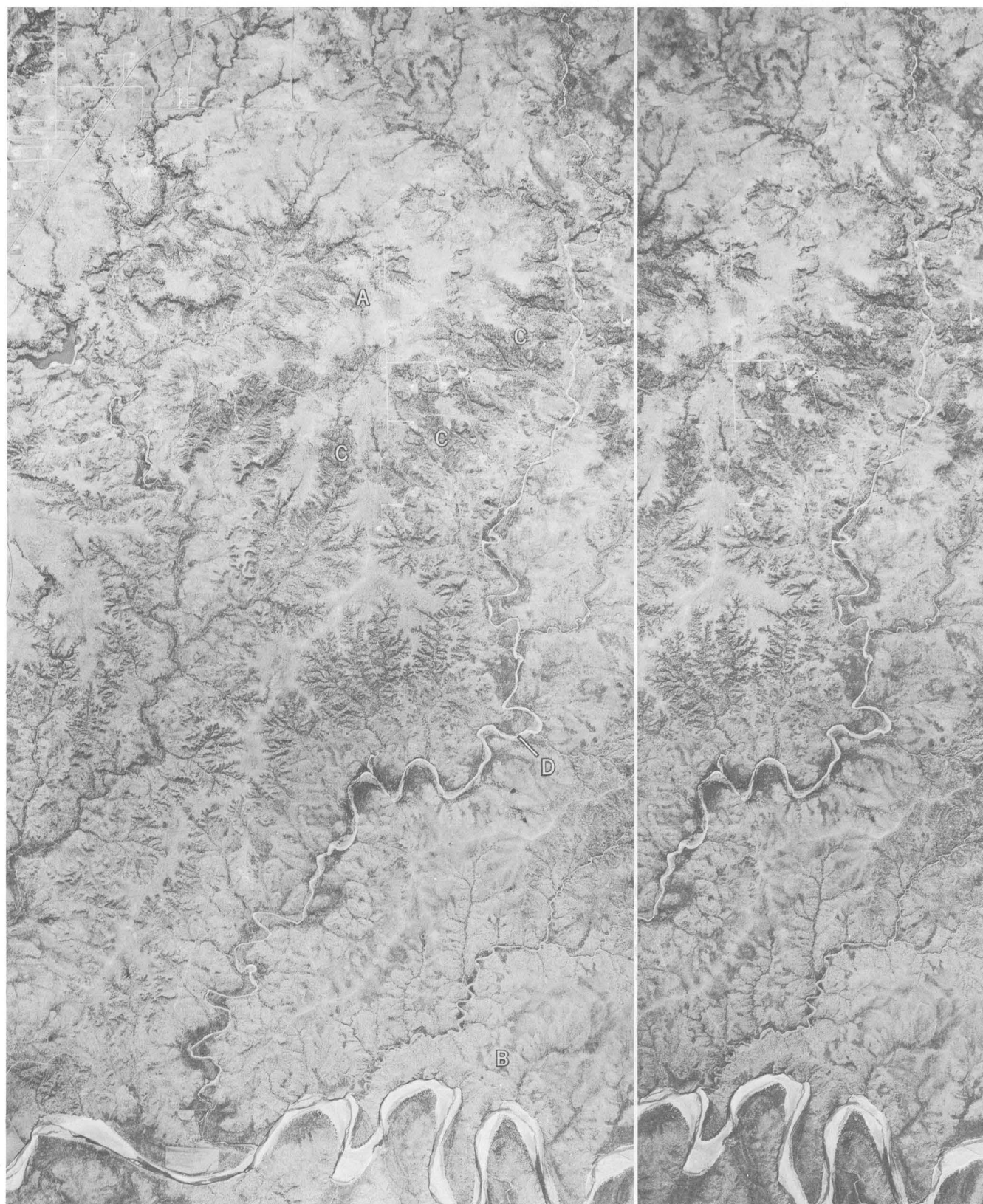


FIGURE 93.—UNCONTROLLED MOSAIC OF UMIAT ANTICLINE AREA, NORTHERN ALASKA, UNDERLAIN BY SHALE, SANDSTONE, CONGLOMERATE, AND GRAYWACKE.

[Photographs by U.S. Navy]

Curvature of streams, A, has developed on flank of anticline where hard and soft interbeds are exposed. Anticline has been breached into soft shale permitting streams developed on the more resistant dip slope to curve along

soft interbeds and not across the axis of the fold. Contrast figure 81 where stream curvature indicates position of structural axis and direction of structural plunge.



Approximately 1 mile

Stereoscopic pair

FIGURE 94.—SUBSURFACE STRUCTURE REFLECTED IN SURFACE DRAINAGE CHARACTERISTICS (TEXAS).

[Approximate scale 1 : 63,360. Photographs by Army Map Service]

Subsurface structures at *A* and *B* are suggested by drainage characteristics of the area. Streams flanking the structure at *A* curve around the structure in their headwater portions. Tributary streams drain radially off the structure (see figures 9 and 95). In addition, the crudely circular pattern of more highly dissected ground and the pattern of dark pho-

tographic tone, *C*, which results from a concentration of vegetation, suggest subsurface structure. Compressed meanders are present over a subsurface structure at *B*. Also note stream deflection downstream from *D* which is a further suggestion of subsurface structure in area *B*.



Approximately 1 mile

Stereoscopic pair

FIGURE 95.—SAME PHOTOGRAPHS AS FIGURE 94, BUT REVERSED TO SHOW PSEUDOSCOPIC EFFECT AS AN AID TO INTERPRETATION.

[Approximate scale 1 : 63,360. Photographs by Army Map Service]

Reversal of the positions of two aerial photographs of a stereoscopic pair produces the well-known pseudoscopic effect, in which stream valleys appear as ridges and hills look like depressions. This unnatural view of the terrain commonly accentuates stream characteristics, which may be significant indicators of subsurface structure, as at 4. The pseudoscopic view also commonly facilitates plotting of drainage.



FIGURE 96.—UNCONTROLLED MOSAIC OF WAINWRIGHT AREA, NORTHWESTERN ALASKA.

[Photographs by U.S. Navy]

The radial-dendritic drainage pattern shown is anomalous to the Arctic coastal plain where northward-flowing streams predominate. Local relief across the area is only a few feet per mile. The radial drainage pattern, suggestive of subsurface structure, is readily seen on the small-scale mosaic but could be easily overlooked on single photographs or individual stereoscopic pairs. Note the northward deflection of the Kugrua River; the abrupt change in direction of streamflow is believed due to subsurface struc-

ture. Seismic work indicates a structural nose plunging southeast in the north-central part of the area. Outcrops are sparse in the area and surface indications of structure, other than drainage pattern, are generally lacking. The drainage pattern of this area is similar to that of an area to the southeast where gas was found in a subsurface structure that had been defined by geophysical methods.



Stereoscopic pair

Approximately 1 mile

FIGURE 97.—AREA UNDERLAIN PREDOMINANTLY BY GENTLY DIPPING SANDSTONE AND SHALE
(NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

Sandstone beds stand out because of photographic tone, relief, and vegetation changes, as at *A*. As these sandstone beds are traced across the area they lose their topographic expression, as at *B*, and are replaced by shale of the underlying formation. The rate of "shaling" or change of facies from sandstone to shale can be calculated from quantitative studies of the aerial

photographs, and the direction of maximum thinning of the sandstone section determined. Note the effect of vertical exaggeration on dip of resistant sandstone beds; true dip is 7° to 8° in this area. Effect of vertical exaggeration is also shown at *C* where minor topographic breaks in slope, accentuated by shadows, reflecting thin resistant beds stand out.



Stereoscopic pair

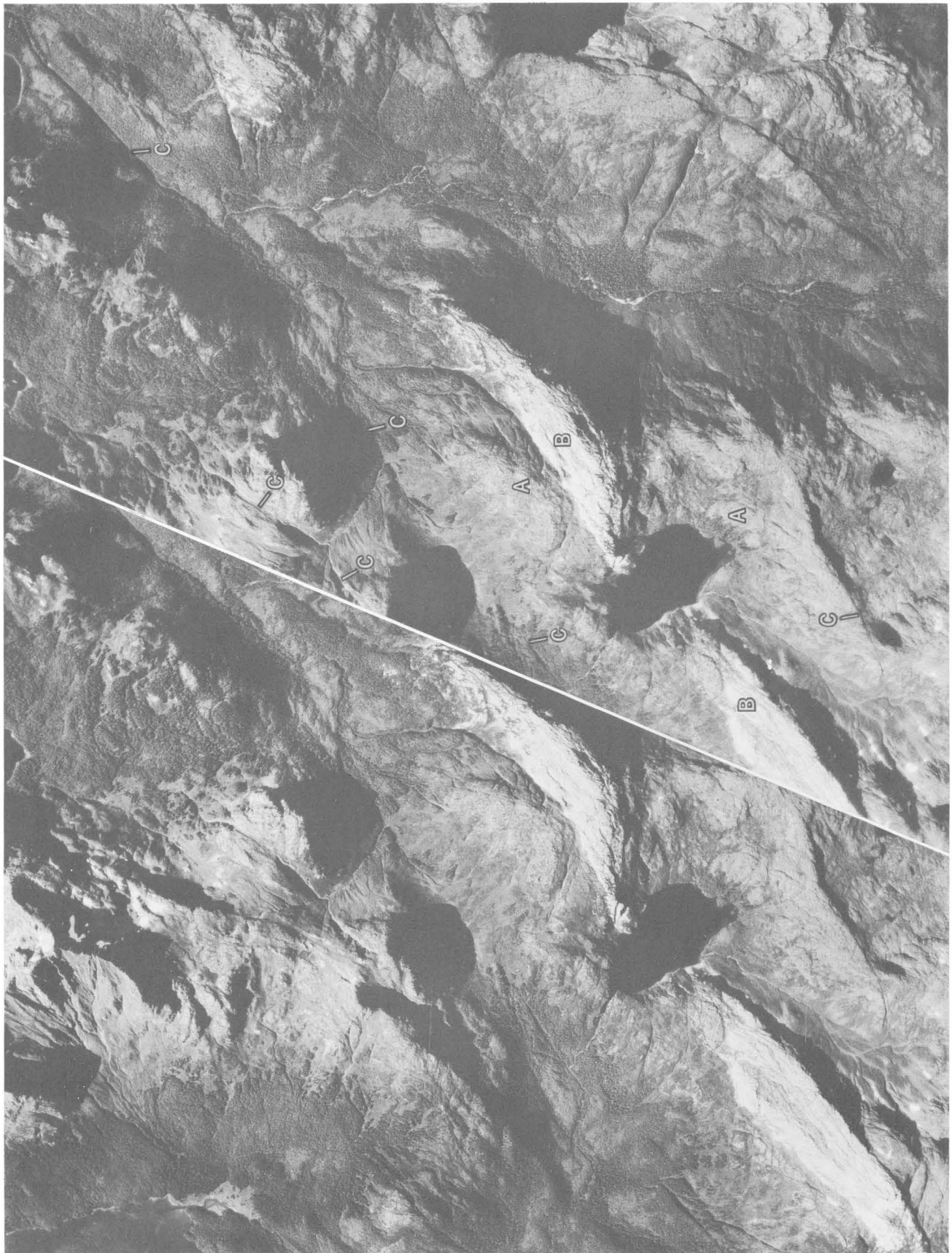
Approximately 1 mile

FIGURE 98.—GENTLY DIPPING SEDIMENTARY ROCKS CUT BY HIGH-ANGLE FAULTS (NEVADA).

[Approximate scale 1 : 20,000. Photographs by Soil Conservation Service]

Topographic expression of resistant, jointed quartzite bed, *A*, permits differentiation of quartzite and underlying carbonate sequence of rocks, *B*. High-angle faults, transverse to the strike of bedding are shown at *C* and *D* by the vertical offset of the quartzite bed. The contact of quartzite and underlying carbonate rocks is the locus of polymetal sulfide veins, but the veins cannot be seen in the stereoscopic model. Note mine dumps, *E*, mark-

ing location of crosscuts to base of the quartzite, which dips into the slope about 20° to 25°. Direction of dip is clearly indicated by *V* in outcrop pattern of quartzite bed where major stream cuts through the ridge. Trace of a major fault with several thousand feet displacement is only weakly shown parallel to slope at *F* and *G* where density of vegetation is slightly greater on the downhill side of the fault trace.



Stereoscopic pair

Approximately 1 mile

**FIGURE 99.—COMPLEXLY FOLDED AND FAULTED AREA OF GREENSTONE, SCHIST, LIMESTONE AND MARBLE
(SOUTHEASTERN ALASKA).**

[Approximate scale 1:40,000. Photographs by U.S. Navy]

Relatively dark-toned highly fractured rocks, *A*, are greenstone and greenstone schist. Light-toned profusely fractured rocks, *B*, are limestone and marble. Prominent lineations, *C*, are representative of faults along which

rich gold-quartz veins have been found in this area. Note that fault lineations characteristically are rectilinear depressions.



Stereoscopic pair

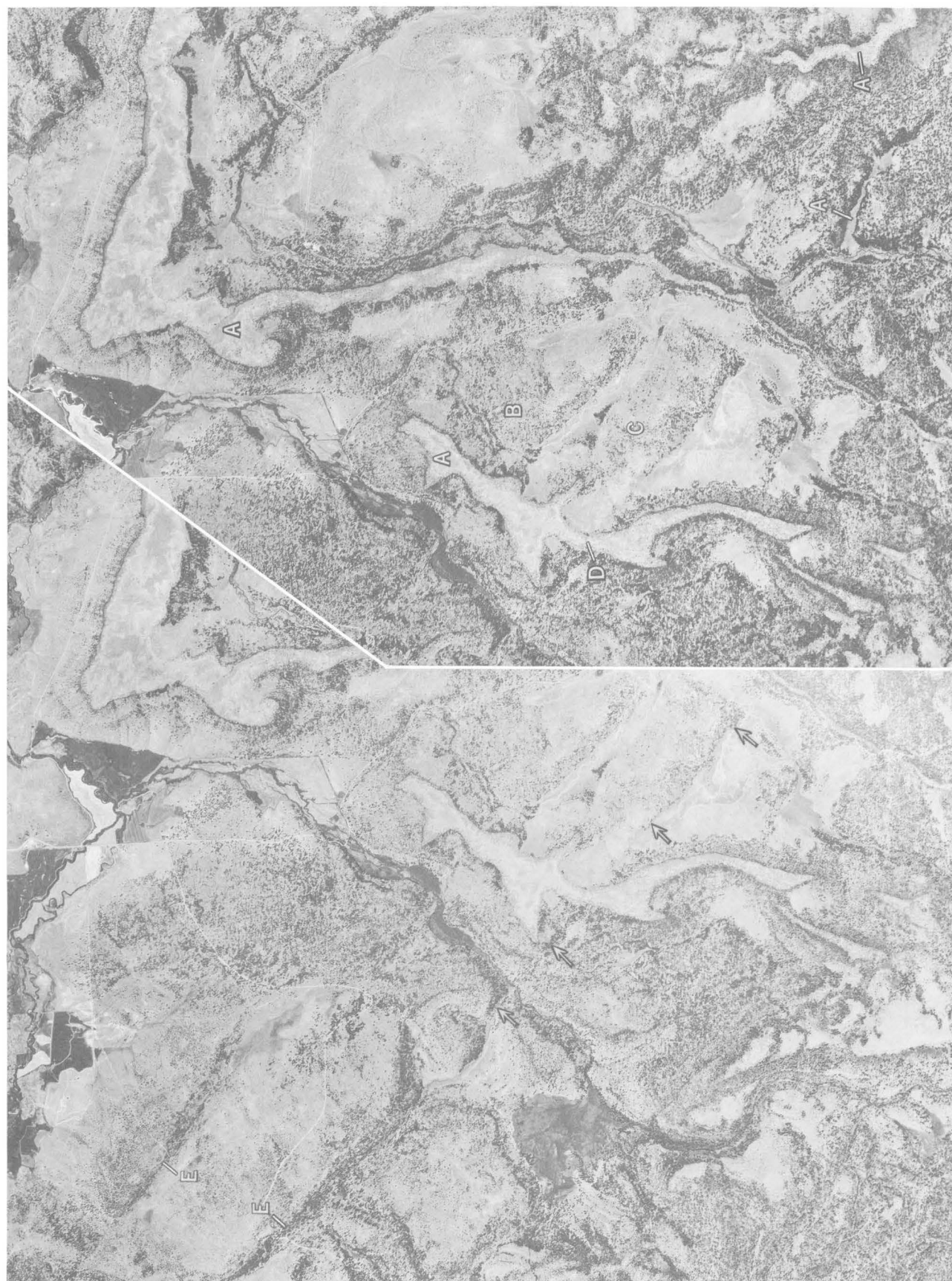
Approximately 1 mile

FIGURE 100.—IGNEOUS AND METAMORPHIC TERRAIN (SOUTHEASTERN ALASKA).

[Approximate scale 1:40,000. Photographs by U.S. Navy]

In this area lead and silver deposits are found locally along the contact of intrusive quartz diorite and metamorphic rocks. Smooth slopes, *A*, are underlain by metamorphic rocks. The closely spaced parallel ridges and depressions, *B*, reflect foliation in the metamorphic rocks. Depressions, *C*, probably represent solution cavities in carbonate interbeds. Lineations, *D*,

transecting the foliation direction are believed to be expressions of faults. The uneven surface, *E*, cut by a crisscross of joints is underlain by quartz diorite. This pattern of lines representing joints is typical, but not necessarily diagnostic, of intrusive rocks. The contact of igneous and metamorphic rocks is in the conspicuous saddle between *A* and *E*.



Stereoscopic pair

Approximately 1 mile

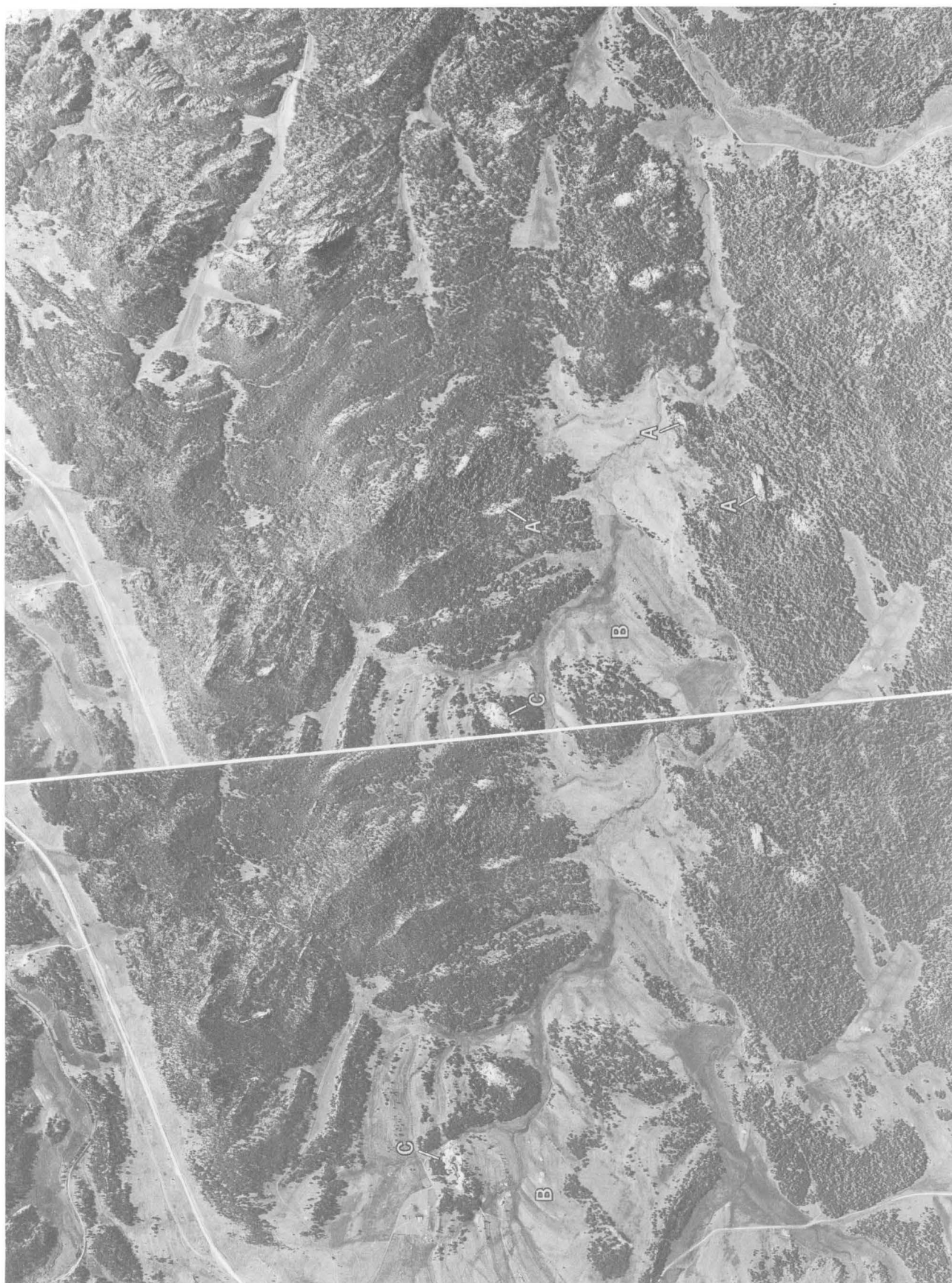
FIGURE 101.—GENTLY TILTED AND FAULTED LAVA FLOWS (OREGON).

[Approximate scale 1 : 54,000. Photographs by Army Map Service]

Perched remnants of basaltic lava, *A*, form skeletal dendritic pattern, which suggests that lava filled former stream valleys. In some areas perched lava remnants are known to cover older auriferous stream gravel. Several faults are indicated by alinements of stream segments, vegetation lines, and photographic tone contrasts (see alinement of arrows). Dip on flow surfaces, as at *B*, may be readily estimated or measured from aerial photographs because of the relatively large area examined in a single view, and because of vertical exaggeration of the dip slope. Note that the younger

flow, *A*, has a gentler dip than the older flows, *B* and *C*. Surfaces *B* and *C* may be correlative and separated by a fault in the intervening valley. At point *D* the younger perched lava flows are also faulted, but throw is considerably less than where older lava flows are displaced by the same fault. In some areas faults displace only the older rocks and do not offset the most recent flows. A long period of fault activity is thus suggested. Note that in monoscopic view fault alinements, *E*, accentuated by vegetation, are striking.

©



Stereoscopic pair

Approximately 1 mile

FIGURE 102.—AREA OF PEGMATITE DIKES (SOUTH DAKOTA).

[Approximate scale 1:24,000. Photographs by U.S. Geological Survey]

Pegmatites in the area shown are generally concordant with schistosity and bedding of quartz-mica schist country rock. In many places the pegmatite dikes stand in topographic relief above the surrounding schist, as at A. The massive, jointed character of the larger pegmatite dikes is similar to other intrusive rocks and contrasts with the thin-bedded schistose rocks. Thin pegmatite dikes commonly cannot be distinguished in the aerial pho-

tographs and only general contact areas can be mapped for most of the wide pegmatite dikes because of the vegetation cover. Locally steeply dipping schist also stands in topographic relief; these rocks can be distinguished by the sheeted character of the outcrops. General structural trends are reflected in topographic expression of parallel ridges and in photographic tones of vegetation in fields, B. Note mining activity in pegmatite at C.



Stereoscopic pair

Approximately 1 mile

FIGURE 103.—METAMORPHOSED SEDIMENTARY ROCKS INTRUDED BY QUARTZ MONZONITE (CALIFORNIA).

[Approximate scale 1 : 47,000. Photographs by U.S. Geological Survey]

Metamorphic rocks here are generally dark toned, as at *A*, and locally show prominent banding; joints are closely spaced and are not conspicuously shown on the photographs. Quartz monzonite, *B*, is relatively light toned and lacks banding, but like most intrusive igneous rocks it has a strong development of irregularly and widely spaced joints that are readily seen in the stereoscopic model. Light-toned streaked, prominent talus slopes, *C*, have

formed where the fine-grained metamorphic rocks are present. In areas of igneous rocks the talus slopes are less well developed; locally large individual talus blocks can be observed at the bases of slopes. A fault trace is suggested by conspicuous linear feature, *D*. Note alinement of short straight linear segments, *E*, on opposite sides of divide; these linear traces may represent the trace of a fault or the prominent development of joints.



FIGURE 104.—DISTINCTIVE LANDFORM OF GRAVEL TERRACES ALONG A MAJOR STREAM
(NORTHEASTERN UTAH).

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

The steplike landform of terraces is conspicuous. Other elements of the soil pattern—vegetation, drainage, and erosional characteristics—provide significant information to the photointerpreter. Absence of surface drainage, as at *A*, suggests well-drained materials. At *A* the material is composed of coarse bouldery gravel that has good internal drainage. Vegetation, *B*, is prominent along edges of upper terrace gravel cap where water emerges from

the gravel. Lower terraces, as at *C*, are more continuous and less dissected than the older terraces at higher altitudes, although recent streams in conspicuous V-shaped gullies, *D*, dissect the edge of the terrace. Terrace deposits commonly are favorable reservoirs for ground-water storage; in addition they provide a ready source of some materials used by the construction engineer.

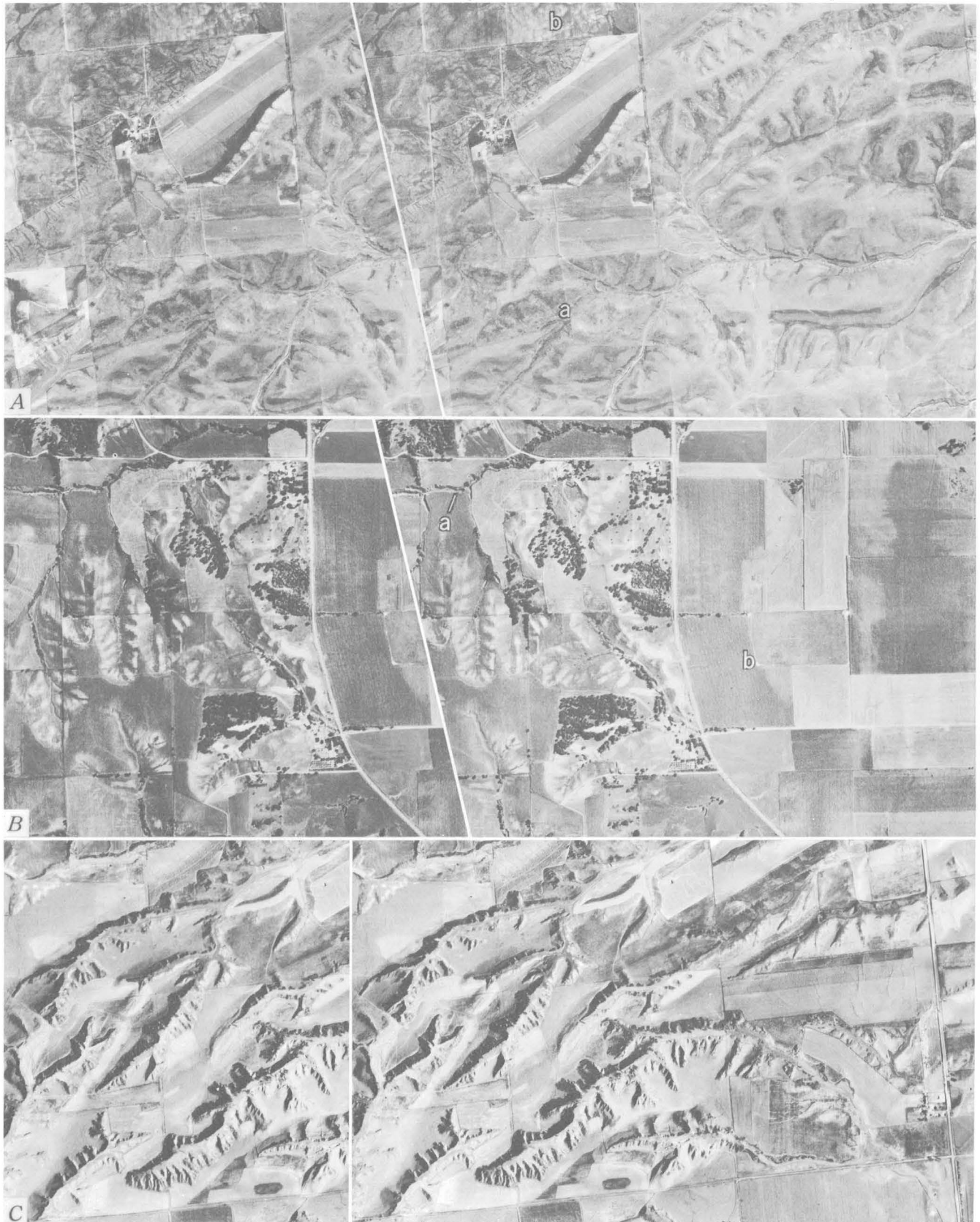


FIGURE 105.—AREAS SHOWING DRAINAGE CHARACTERISTICS IN SURFICIAL MATERIAL THAT IS PREDOMINANTLY LOESS.

[Approximate scale 1:20,000. Photographs by Commodity Stabilization Service]

Figure A. Contrasting drainage characteristics and differences in photographic tones in areas *a* and *b* suggest differences in character of the surficial materials. The modified dendritic drainage and scoop-shaped valley heads are typical of dissected loess areas, *a*. Lack of surface drainage rills is a feature of sand dune areas, *b*, where materials are coarse-grained, highly permeable, and drainage is largely internal. Note light-and-dark mottled soils in sand dune area. The fine-grain size of loess is believed responsible for the fine-textured drainage (Iowa).

Figure B. As in area shown in figure A, the dissected loess hills exhibit a modified dendritic drainage pattern. Recent erosion has cut deep narrow and sharply defined channels in

the bottoms of broad valleys, as at *a*. Gully walls are essentially vertical. Note characteristic scoop shape of side drainage and serrated ridges along some divides. Light streaks due to thin grass cover or to cultivation are typical of many loess areas. Broad, flat river flood plain, *b*, has good internal drainage and exhibits a lack of visible surface drainage channels (Nebraska).

Figure C. Deeply dissected loess hills have drainage pattern similar to areas shown in figures A and B, but erosion may have proceeded more rapidly than in other areas. Valley walls are sharply defined. Steep valley walls commonly characterize loess (Nebraska).



Stereoscopic pair

Approximately 1 mile

FIGURE 106.—AREA OF SURFICIAL DEPOSITS, PRIMARILY WINDBLOWN (CENTRAL NEBRASKA).

[Approximate scale 1 : 67,000. Photographs by Army Map Service]

Highly dissected loess hills, *A*, abut against well-drained alluvial terraces, *B*. Extensive dissection of loess has resulted in a fine texture of erosional topography and fine-textured drainage. Bottoms of many valleys in loess are notched by recent stream dissection. The modified dendritic drainage pattern is typical of loess area. Note absence of surface drainage rills in terrace alluvium, *B*, and elongate windblown sand hills, *C*, indicating the highly

permeable nature of the underlying materials. Loess is generally considered well drained internally and is thus an exception to the general association of fine-textured drainage and impermeable soils. The fine-textured drainage in loess is believed to be a result of the fine grain size. Contrast appearance here of drainage density in loess with drainage density on large-scale photographs of figure 105.



Stereoscopic pair

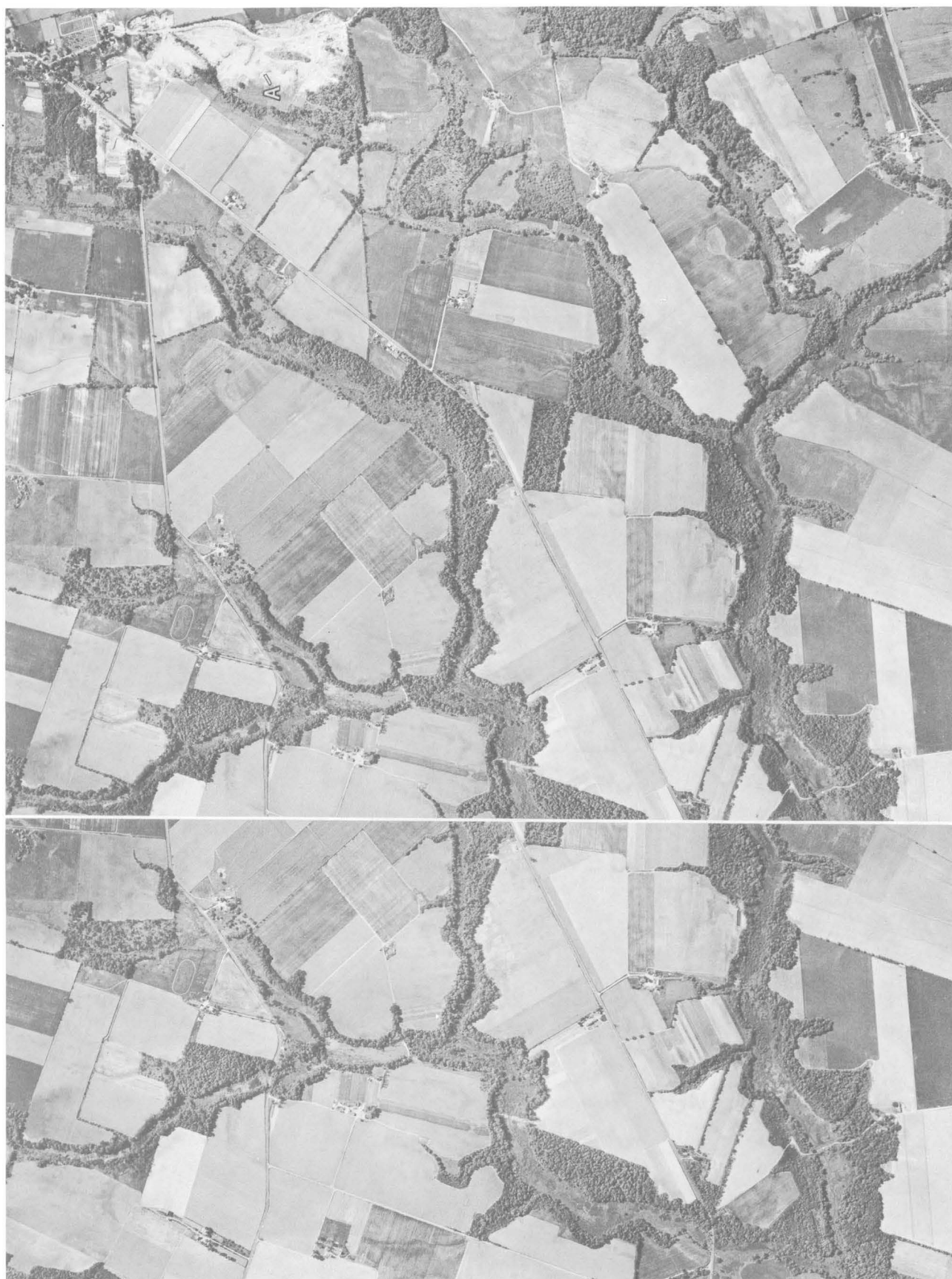
Approximately 1 mile

FIGURE 107.—MOTTLED SOILS OF DRIFT PLAIN (IOWA).

[Approximate scale 1:27,000. Photographs by U.S. Geological Survey]

Light-toned areas are generally slightly higher than surrounding dark-toned areas. High areas of light photographic tone are somewhat better drained than the intervening dark areas, and generally contain silty soils with a lesser accumulation of organic material than the depressions. Clay materials and humus have accumulated in depressions to impart dark pho-

tographic tone. Linear pattern of light-toned areas may represent minor recessional moraines. They trend across the direction of movement of ice. Near major streams the reworked glacial drift may be better sorted and locally an important source of borrow material for the construction engineer.



Stereoscopic pair

Approximately 1 mile

FIGURE 108.—COASTAL PLAIN UNDERLAIN BY CLAY, SAND, AND GRAVEL (NEW JERSEY).

[Approximate scale 1 : 20,000. Photographs by Commodity Stabilization Service]

Cultivated areas are thin cappings of sand and gravel overlying clay formation. Lack of surface drainage rills in sand and gravel indicate that the capping material is well drained internally. Except for dark-toned crop vegetation the cultivated areas also have the general light tones commonly associated with well-drained materials. Note borrow pit in granular material at A. Streams flow in clay. The steep walls and flat bottoms of gul-

lies may not be typical of plastic clays in humid regions, however. Headward extent of small gullies generally ends abruptly against contact of clay with overlying sand and gravel. Vegetation growth is conspicuous along steep sides of gullies where trees have not been cleared for cultivation. Vegetation growth is locally favored by relatively constant supply of water that flows to surface along contact of clay with overlying sand and gravel.



Stereoscopic pair

Approximately 1 mile

FIGURE 109.—POLYGONALLY PATTERNED GROUND IN PERMAFROST AREA ALONG MAJOR STREAM
(NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

The susceptibility of low, poorly drained areas to the development of polygonally patterned ground resulting from ice-wedge formation is shown conspicuously along this major stream valley. Development of polygons, primarily low-center polygons, *A*, shown with relatively dark-toned centers and light-toned marginal ridges, has followed old channel scars representative of old slip-off slopes. Some high-center polygons, *B*, are also present. The angular gully pattern, *C*, is commonly found where ice wedges are melting

out of polygonally patterned ground. Also note serrated edges of oxbow lake, *D*, and rim of river terraces were ice wedges in polygonally patterned ground have melted out. Contrast appearance of poorly drained river terraces here with river terraces in nonpermafrost areas where internal drainage is generally good. The conspicuous tilt of the oxbow lake and up-hill flow of stream meanders indicate that tilt is present in the aerial photographs.



Stereoscopic pair

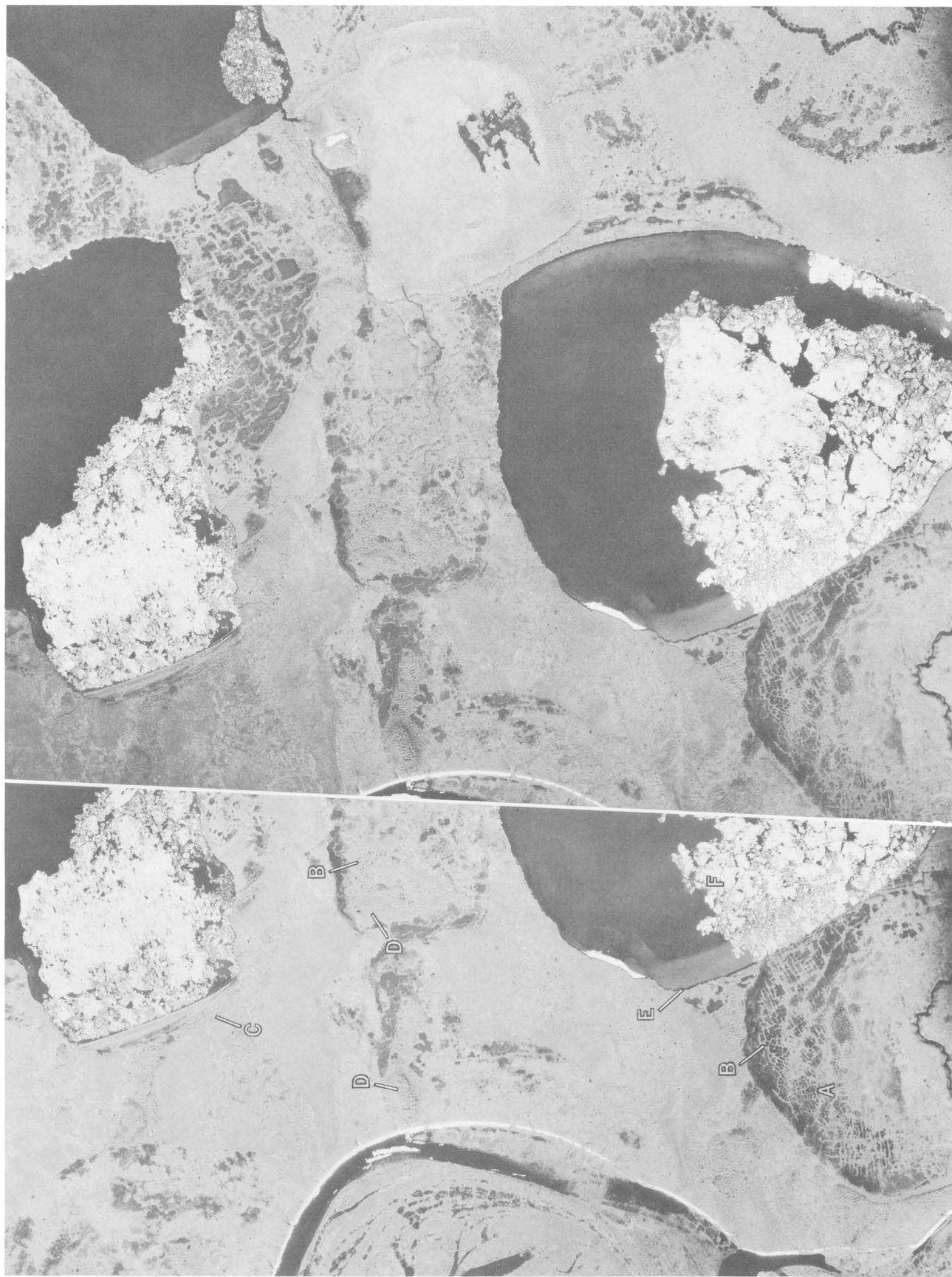
Approximately 1 mile

FIGURE 110.—WELL-DEVELOPED PINGO IN AREA OF PERMAFROST (NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

Partly drained lake basin, *A*, a particularly favorable area for development of permafrost, is conspicuous. Note old beach lines, *B*, shown by narrow bands of contrasting photographic tones and along which polygonal ground has developed. Low-center polygons having dark-toned centers and light-toned marginal ridges are abundant, as at *C*. High-center polygons

with light-toned centers and dark-toned marginal trenches, are also conspicuous in many places, as at *D*. Pingo, *E*, with a single crest crack here, is almost always diagnostic of underlying permafrost conditions. Also note pingolike forms, *F*, covered with polygonally patterned ground.



Stereoscopic pair

Approximately 1 mile

FIGURE 111.—AREA OF PERMAFROST (NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

Low, wet but drained lake basins, as at *A*, are favorable areas for the development of permafrost. Low-center polygons, *B*, shown as dark-toned depressed centers and light-toned raised edges are common. High-center polygons, *C*, exhibiting high, light-toned centers, and dark-toned marginal trenches, are also present. Pingolike forms, *D*, also covered with polygonally

patterned ground, are highly indicative of permanently frozen ground conditions. The serrated shoreline, *E*, of some lakes is typical of the thawing of polygonal ground and further suggests the presence of permafrost. Note floating ice, *F*; bottom of lake may be seen at edge of ice, and in places depth of water may be measured from the aerial photographs.

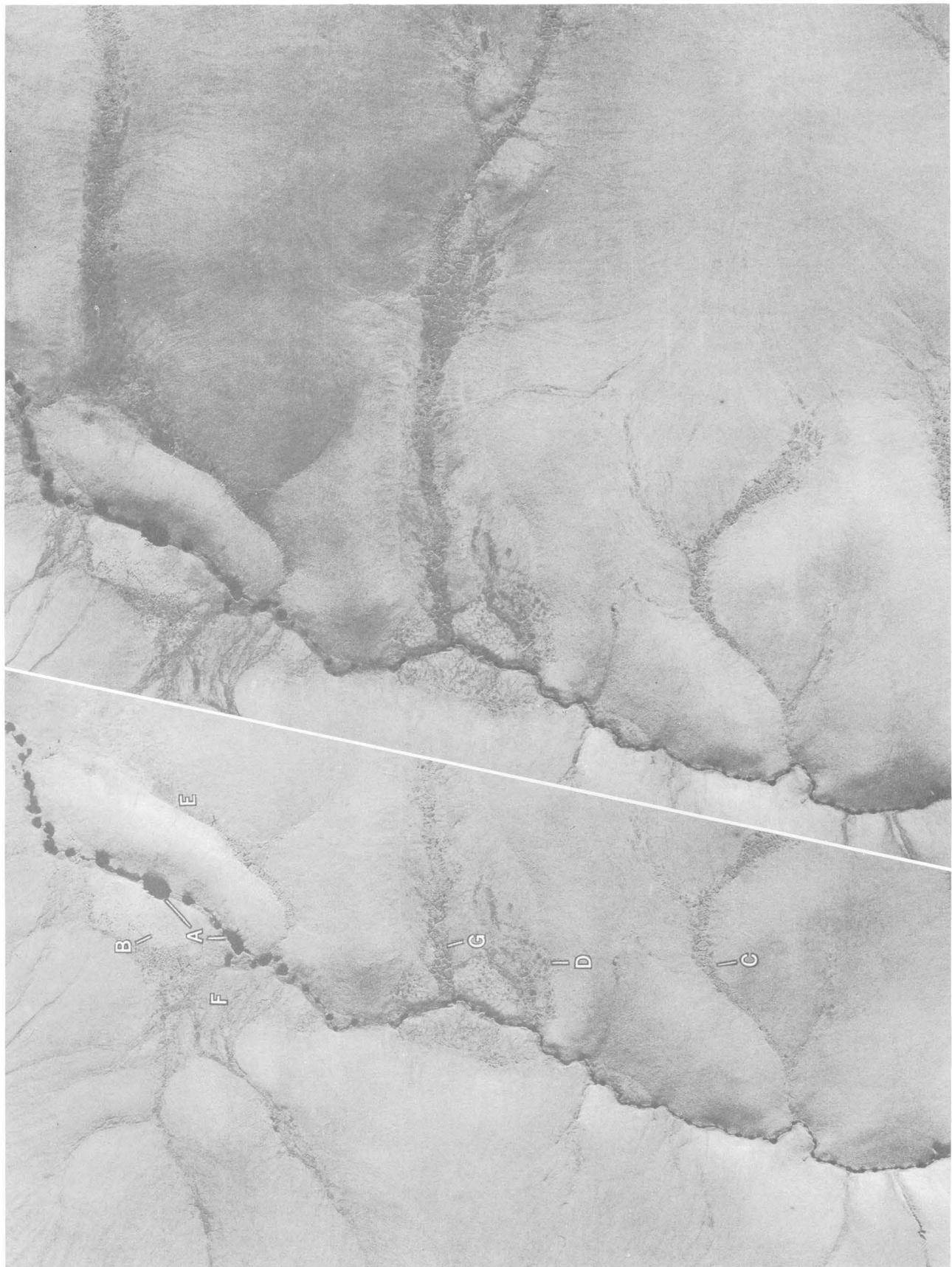


FIGURE 112.—CONSPICUOUS BEADED DRAINAGE IN AREA OF PERMAFROST (NORTHERN ALASKA).

[Approximate scale 1:20,000. Photographs by U.S. Navy]

Beaded drainage along main stream, shown as rounded pools of water connected by deeply incised watercourses, typically forms in areas underlain by permafrost. Note steep banks of pools, as at *A*, which have resulted from thawing of frozen ground and subsequent caving. Interpretation of permafrost conditions is supported by presence of high-center and low-center polygons. High-center polygons, *B*, generally are shown by relatively light-toned centers and dark-toned rims, although locally, as at *C*, the reverse tonal contrasts may be present. Low-center polygons with relatively dark-toned

depressed centers and light-toned raised rims are shown at *D*. The wetter areas, as in the partly abandoned drainage channel, *E*, or upper reaches of minor drainageways, are especially susceptible to formation of polygons. Area *F*, probably a small alluvial fan area, shows well-developed drainage. The angular pattern may indicate incipient polygon formation in contrast to the angular pattern of drainage, *G*, which is typical of areas where melting of ice wedges in polygonal ground is taking place.



Stereoscopic pair

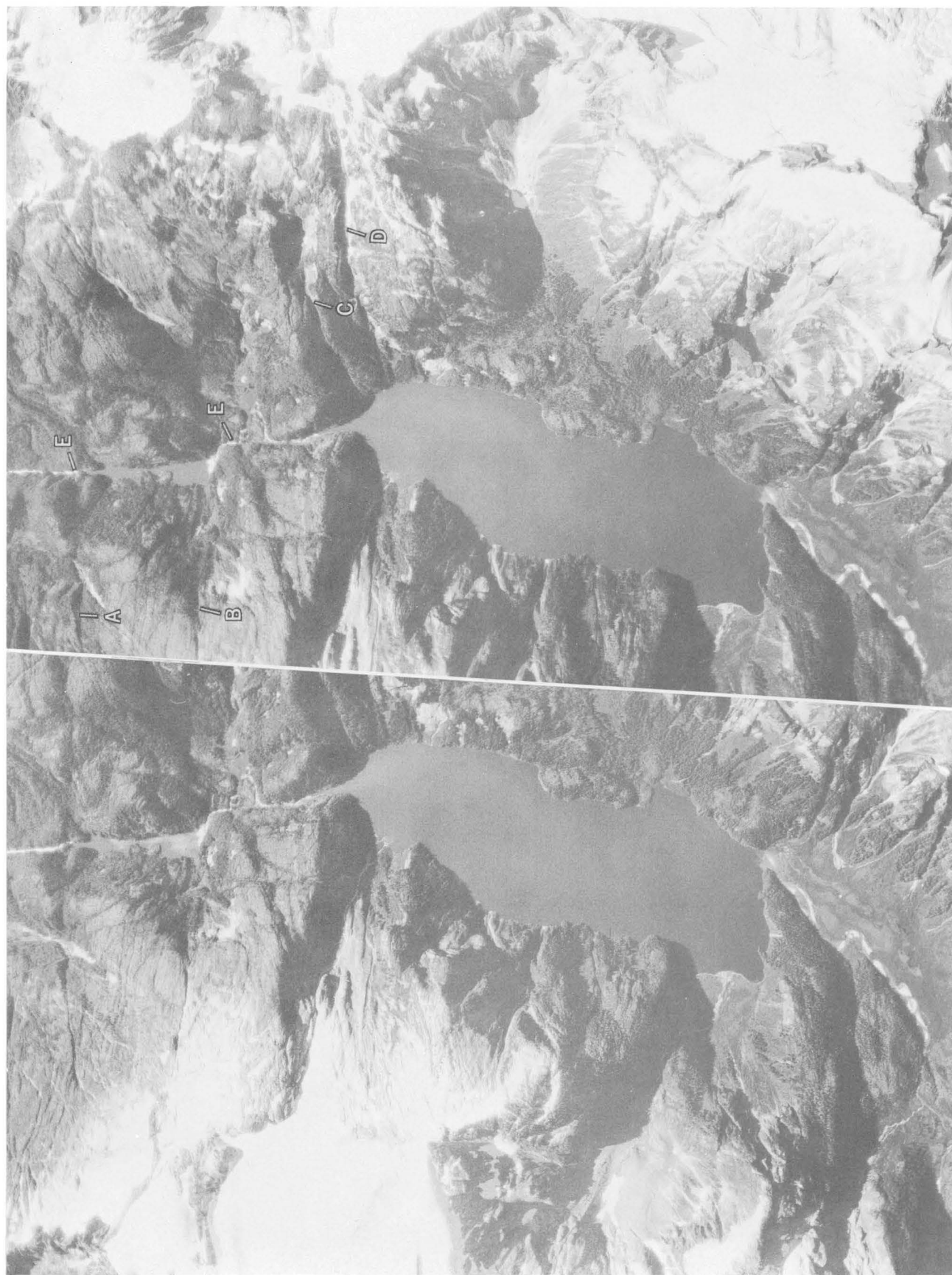
Approximately 1 mile

FIGURE 113.—LANDSLIDE AREA IN VOLCANIC AND SEDIMENTARY TERRAIN (NEW MEXICO).

[Approximate scale 1:37,000. Photographs by U.S. Geological Survey]

Resistant flat-lying basaltic lava, *A*, caps mesa underlain by weakly resistant mudstone, shale, siltstone, and sandstone, a geologic environment particularly susceptible to the occurrence of landslides. Landslides, *B*, below lava cap are characterized by hummocky topography and local lobate

form suggestive of flowage. Note buildings, *C*, constructed on toe of slide areas. Recent lava flows are indicated by the dark photographic tone and irregular surfaces, *D*. The lobate character typical of flows can also be seen.



Stereoscopic pair

Approximately 1 mile

FIGURE 114.—DAMSITE AREA (SOUTHEASTERN ALASKA).

[Approximate scale 1:40,000. Photographs by U.S. Navy]

Conspicuous faults, indicated by linear topographic depressions *A*, *B*, *C*, and *D*, are present. The outlet of the lake itself appears to flow along a fault marked by the rectilinear depression *E*; this fault is probably the most

significant geologic structure in the area because a dam would have to straddle it. Highly fractured rocks comprise metamorphic types and intrusive quartz diorite.



FIGURE 115.—GRIDDED PHOTOGRAPH.

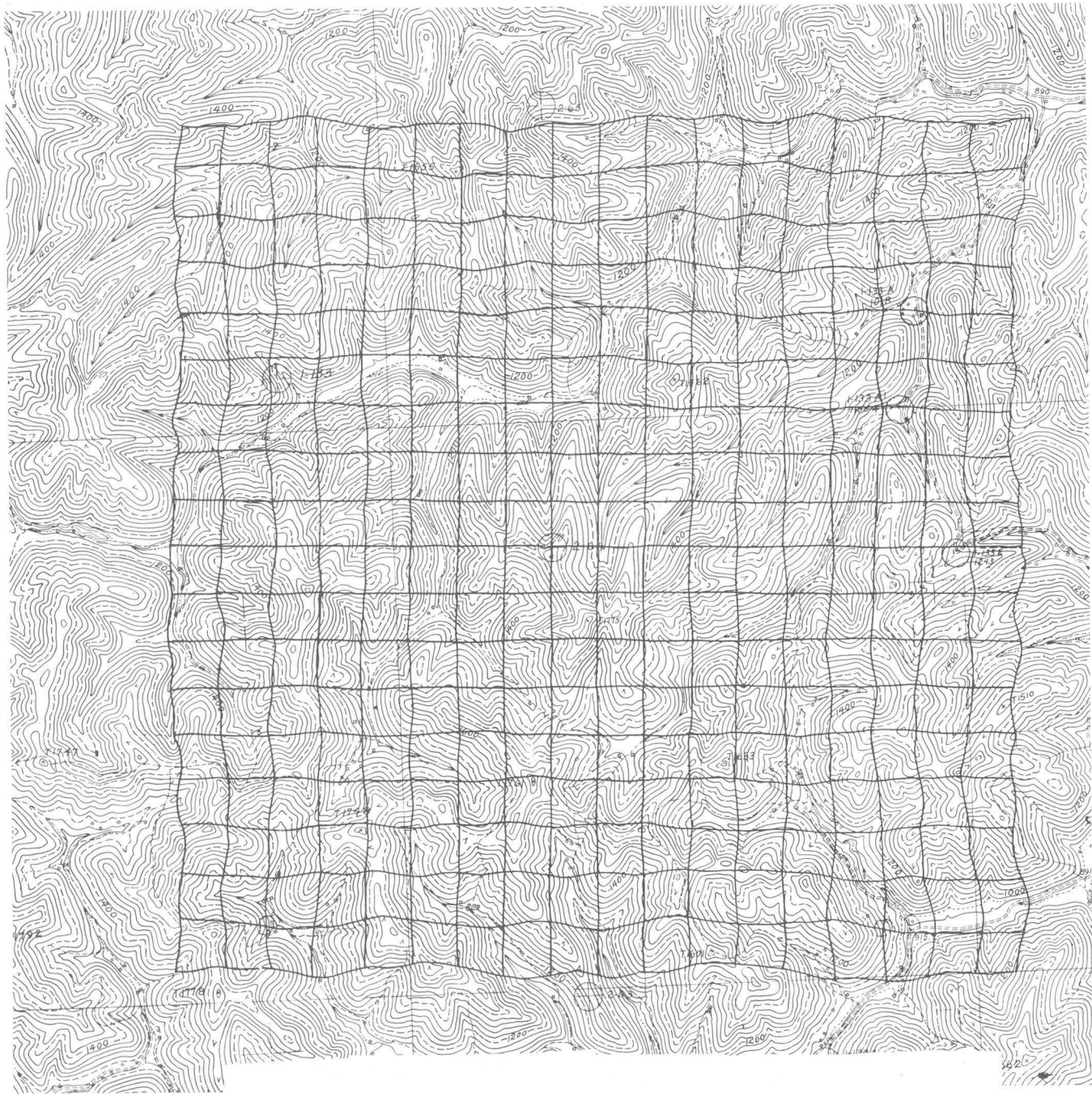


FIGURE 116.—GRIDDED BASE MAP OF AREA SHOWN IN FIGURE 115.

SOURCE AND IDENTIFYING DATA OF AERIAL PHOTOGRAPHS

The following table gives all data needed to identify the agency holding the negatives is not necessarily the the aerial photographs and also the agencies from which one that originally acquired the photographs. the aerial photographs may be purchased. Note that

Figure	Identifying photographic data					Negatives held by 1—
	Project code	Roll	Exposures	Focal length of lens, in inches	Area	
39	DKK	3	16-17	8. 25	"DKK" Gunnison area, Colorado	E
40	BAR	309	071-072	6	Alaska	A
41	DSA	2K	19-20	8. 25	Kane County, Utah	D
42	GS-WI	12	146-147	6	Utah	A
43	DIG	1F	127-128	8. 25	San Juan County, Utah	D
44	GS-RR	3	147-148	6	Arizona	A
45	AFTRC/3415TTW/ 49-10/M-1.		697VV-698VV	12	Golden, Colorado	B
46	GS-VJV	3	150-151	6	Colorado	A
47						N
48	71	60	8395-8396	6	South Carolina	A
49	138	3	489-490	5. 2	Texas	A
50	DRK	21	3-4	8. 25	"DRK" Addition to Humboldt River, Nevada.	E
51	GS-COL	3	56-57	6	California	A
52	GS-JF	6	11-12	6	Wyoming	A
53	DLG	7G	97-98	8. 25	Elmore County, Idaho	D
54	71	26	3514-3515	6	North Carolina	A
55A	73	4	117-118	6	Maine	A
B	GSM	3	31-32	5. 2	do	A
56	Mission 649		0120-0121	6	Alaska	A
57	Mission 648		0161-0162	6	do	A
58	113	16	1746-1747	6	South Dakota	A
59	GS-WI	10	102-103	6	Utah	A
60	126	18	1723-1724	6	do	A
61	CUU	8G	141-142	8. 25	Stephens County, Texas	D
62	GS-RO	1	125-126	6	Utah	A
63	GS-WI	36	68-69	6	do	A
64	GS-AZ	2	119-120	5. 2	Virginia	A
65	AQV	1D	55-56	8. 25	Northampton County, Pennsylvania	C
66	113	21	2600-2601	6	South Dakota	A
67	SEA	92	019-020	6	Alaska	A
68	138	10	1919-1920	5. 2	Texas	A
69	CNP	1C	11-12	8. 25	Gooding County, Idaho	D
70	GS-VE	5	26-27	6	South Dakota	A
71	GS-OMA	32	88-89	5. 2	Wyoming	A
72	SEA	29	028-029	6	Alaska	A
73	71	50	7084-7085	6	North Carolina	A
74	71	7	820-821	6	do	A
75	GSY	1	145-146	5. 2	Alabama	A
76	SEA	112	181-182	6	Alaska	A
77	ZF	2G	174-175	8. 25	Wabaunsee County, Kansas	D
78	CUU	8G	152-153	8. 25	Stephens County, Texas	D
79	BAR	44	61-62	6	Alaska	A
80	131	11	1711-1712-1713	6	Wyoming	A
81	BPM	11	63-64	6	Muddy River area, Utah	E
82	GS-PB	1	50-51	6	New Hampshire	A
83	GS-WI	5	156-157	6	Utah	A
84	GS-RR	17	43-44	6	do	A
85	SEA	112	077-078	6	Alaska	A
86	131	7	1187-1188	6	Wyoming	A
87	120	70	10110-10111	6	New Mexico	A
88	DRW	1K	94-95	8. 25	Duchesne County, Utah	D
89						N
90	GS-RO	4	167-168	6	Utah	A
91	GS-RR	2	64-65	6	do	A
92	GS-RR	17	64-65	6	do	A
93						N
94	138	5	867-868	6	Texas	A
95	138	5	867-868	6	do	A
96					Wainwright, area index quadrangle D-19, Alaska.	A
97	BAR	44	139-140	6	Alaska	A
98	DRK	21	197-198	8. 25	"DRK" Addition to Humboldt River, Nevada.	E

See footnote at end of table.

SOURCE AND IDENTIFYING DATA OF AERIAL PHOTOGRAPHS—Continued

Figure	Identifying photographic data					Negatives held by 1—
	Project code	Roll	Exposures	Focal length of lens, in inches	Area	
99.....	SEA.....	133	019-020	6	Alaska.....	A
100.....	SEA.....	106	125-126	6	do.....	A
101.....	109.....	43	5283-5284	6	Oregon.....	A
102.....	GS-VE.....	5	112-113	6	South Dakota.....	A
103.....	GS-QQ.....	1	89-90	6	California.....	A
104.....	DRW.....	1K	47-48	8.25	Duchesne County, Utah.....	D
105A.....	BKP.....	4G	14-15	8.25	Pottawattamie County, Iowa.....	C
B.....	BNQ.....	172	15-16	8.25	Valley County, Nebraska.....	C
C.....	BNQ.....	96	30-31	8.25	Valley County, Nebraska.....	C
106.....	128.....	5	751-752	6	Nebraska.....	A
107.....	GS-DY.....	5	40-41	5.2	Iowa.....	A
108.....	CMU.....	3R	139-140	8.25	Burlington County, New Jersey.....	C
109.....	BAR.....	72	087-088	6	Alaska.....	A
110.....	BAR.....	72	098-099	6	do.....	A
111.....	BAR.....	72	093-094	6	do.....	A
112.....	BAR.....	92	010-011	6	do.....	A
113.....	GS-VID.....	1	46-47	6	New Mexico.....	A
114.....	SEA.....	114	008-009	6	Alaska.....	A

1 Code is as follows:

A—U.S. Geological Survey, Map Information Office, Washington 25, D. C.

B—U.S. Air Force, Photographic Records and Services Division, Office of Research and Liaison, USAF Aeronautical Chart and Information Center, Washington 25, D. C.

C—Eastern Laboratory, Performance Division, Commodity Stabilization Service, U.S. Department of Agriculture, Washington 25, D. C.

D—Western Laboratory, Performance Division, Commodity Stabilization Service, U.S. Department of Agriculture, 2505 Parleys Way, Salt Lake City 9, Utah.

E—Division of Cartography, Soil Conservation Service, Agricultural Research Center, Beltsville, Maryland

N—Negatives not available.

REFERENCES CITED

- Alexander, J. B., and Proctor, W. D., 1955, Investigations upon a proposed dam site at Klang Gates, Federation of Malaya: *Colonial Geology and Mineral Resources*, v. 5, no. 4, p. 409-415.
- Alliger, J., 1955, Application of photogeology to oil exploration in western Canada: *Alberta Soc. Petroleum Geologists Jour.*, v. 3, no. 10, p. 179-184, 194.
- Aschenbrenner, C. M., 1952, A review of facts and terms concerning the stereoscopic effect: *Photogramm. Eng.*, v. 18, no. 5, p. 818-823.
- 1954, Problems in getting information into and out of air photographs: *Photogramm. Eng.*, v. 20, no. 3, p. 398-401.
- Barton, D. C., 1933, Surface fracture system of south Texas: *Am. Assoc. Petroleum Geologists Bull.*, v. 17, no. 10, p. 1194-1212.
- Bean, R. K., and Thompson, M. M., 1957, Use of the orthophotoscope: *Photogramm. Eng.*, v. 23, no. 1, p. 170-179.
- Belcher, D. J., 1944, Identifying landforms and soils by aerial photographs, in *Purdue Univ. 30th Ann. Road School Proc.*: *Purdue Univ. Eng. Bull.*, Ext. Ser. no. 56, p. 133-154.
- 1945, The engineering significance of soil patterns: *Photogramm. Eng.*, v. 11, no. 2, p. 115-148.
- 1948, Determination of soil conditions from aerial photographs: *Photogramm. Eng.*, v. 14, no. 4, p. 482-488.
- Benninghoff, W. S., 1950, Use of aerial photographs in mapping vegetation and surficial geology in subarctic regions: *Photogramm. Eng.*, v. 16, no. 3, p. 428-429.
- Bentor, Y. K., 1952, Air-photographs and geological mapping with special reference to the geological conditions in the Negev (southern Israel): *Israel Research Council Bull.*, v. 2, no. 2, p. 157-169.
- Black, R. F., 1952, Polygonal patterns and ground conditions from aerial photographs: *Photogramm. Eng.*, v. 18, no. 1, p. 123-134.
- Blanchet, P. H., 1957, Development of fracture analysis as exploration method: *Am. Assoc. Petroleum Geologists Bull.*, v. 41, no. 8, p. 1748-1759.
- Brundall, Laurence and Harder, B. P., 1953, Photogeologic evaluation in the Montana Plains area, in *Billings Geol. Soc. Guidebook 4th Ann. Field Conf.*, Little Rocky Mountains—Montana, southwestern Saskatchewan, 1953: p. 150-155.
- Butorff, Curtis L., 1958, Geomorphic anomalies, Dead Horse Creek area, Wyoming, in *Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf.*, Powder River Basin, 1958: p. 215-217.
- Cabot, E. C., 1947, The northern Alaska coastal plain interpreted from aerial photographs: *Geog. Rev.*, v. 37, no. 4, p. 639-648.
- Cady, W. M., 1945, Aerial photos as an adjunct to Arctic and Subarctic geologic reconnaissance: *New York Acad. Sci. Trans.*, Ser. 2, v. 7, p. 135-138.
- Chapman, R. M., and Sable, E. G., 1960, Geology of the Utukok-Corwin area, northwestern Alaska: *U.S. Geol. Survey Prof. Paper 303-C*. (In press)
- Christensen, D. J., 1956, Eagles of geology: *Photogramm. Eng.*, v. 22, no. 5, p. 857-864.
- Colwell, R. N., 1952, Photographic interpretation for civil purposes, in *Am. Soc. Photogrammetry, Manual of Photogrammetry*: 2d ed., Washington, D.C., p. 535-602.
- Colwell, R. N., 1954, A systematic analysis of some factors affecting photographic interpretation: *Photogramm. Eng.*, v. 20, no. 3, p. 433-454.
- Daehn, R. E., 1949, A standardized tone scale as an aid in photo interpretation: *Photogramm. Eng.*, v. 15, no. 2, p. 287.
- DeBlieux, Charles, 1949, Photogeology in Gulf Coast exploration: *Am. Assoc. Petroleum Geologists Bull.*, v. 33, no. 7, p. 1251-1259.
- DeBlieux, Charles, and Shepherd, G. F., 1951, Photogeologic study in Kent County, Texas: *Oil and Gas Jour.*, v. 50, no. 10, p. 86, 88, 89, 98-100.
- Desjardins, Louis, 1943a, Contouring and elevation measurement on vertical aerial photographs: *Photogramm. Eng.*, v. 9, no. 4, p. 214-224.
- 1943b, Measurements of dip angles on aerial photographs: *Am. Assoc. Petroleum Geologists Bull.*, v. 27, no. 11, p. 1534-1538.
- 1950, Techniques in photogeology: *Am. Assoc. Petroleum Geologists Bull.*, v. 34, no. 12, p. 2284-2317.
- 1951, The measurement of formational thickness by photogeology: *Photogramm. Eng.*, v. 17, no. 5, p. 821-830.
- 1952, Aerial photos may locate deep-seated salt domes: *Oil and Gas Jour.*, v. 51, no. 13, p. 82-84.
- Eardley, A. J., 1942, Aerial photographs—their use and interpretation: New York, Harper and Bros. Publishers, 203 p.
- 1943, Aerial photographs and the distribution of constructional materials: *Natl. Research Council, Highway Research Board, 23d Ann. Mtg. Proc.*, v. 23, p. 557-568.
- Elliott, D. H., 1952, Photogeologic interpretation using photogrammetric dip calculations: *California Div. Mines Spec. Rept.* 15, 21 p.
- 1958, Drainage analysis—Donkey Creek area, Powder River Basin, Wyoming, in *Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf.*, Powder River Basin, 1958: p. 214.
- Fischer, W. A., 1953, Photogeologic studies of Arctic Alaska and other areas, in *Selected papers on photogeology and photo interpretation*: U.S. Research and Devel. Board, Washington, D.C., p. 207-214.
- 1955, Photogeologic instruments used by the U.S. Geological Survey: *Photogramm. Eng.*, v. 21, no. 1, p. 32-39.
- 1958, Color aerial photography in photogeologic interpretation: *Photogramm. Eng.*, v. 24, no. 4, p. 545-549.
- Fisk, H. N., 1944, Geological investigations of the alluvial valley of the lower Mississippi River: *U.S. Mississippi River Comm.*, Vicksburg, U.S. Army, Corps of Engineers.
- Frost, R. E., 1946, Identification of granular deposits by aerial photography: *Natl. Research Council, Highway Research Board, 26th Ann. Mtg. Proc.*, v. 25, p. 116-129.
- 1951, Frost action in soils, in *A symposium, interpretation of permafrost features from airphotos*: *Natl. Research Council, Highway Research Board Spec. Rept.*, no. 2, p. 223-246.
- Frost, R. E., and Mintzer, O. W., 1950, Influence of topographic position in airphoto identification of permafrost, in *Soil exploration and mapping*: *Natl. Research Council, Highway Research Board Bull.* no. 28, p. 100-121.
- Frost, R. E., and Woods, K. B., 1948, Airphoto patterns of soils of the western United States: *U.S. Civil Aeronautics Admin. Tech. Devel. Rept.* no. 85, 76 p.

- Goodale, E. R., 1953, An equation for approximating the vertical exaggeration ratio of a stereoscopic view: *Photogramm. Eng.*, v. 19, no. 4, p. 607-616.
- Grantham, D. R., 1953, Aerial photography, vegetation and geology: *Mining Mag.*, v. 88, no. 6, p. 329-336.
- Greenman, R. L., 1951, The Engineer looks at pedology, in *Symposium on surface and subsurface reconnaissance*: Am. Soc. Testing Materials Spec. Tech. Pub. no. 122, p. 46-56.
- Gross, W. H., 1951, A statistical study of topographic linears and bedrock structures: *Geol. Assoc. Canada Proc.*, v. 4, p. 77-87.
- Gwynne, C. S., 1942, Swell and swale pattern of the Mankato Lobe of the Wisconsin drift plain in Iowa: *Jour. Geology*, v. 50, no. 2, p. 200-208.
- Hackman, R. J., 1956a, The graphic construction of controlled stereoscopic models: *Photogramm. Eng.*, v. 22, no. 2, p. 387-391.
- 1956b, The stereo-slope comparator—an instrument for measuring angles of slope in stereoscopic models: *Photogramm. Eng.*, v. 22, no. 5, p. 893-898.
- 1957, The "Flying Carpet"—a stereoscopic grid used in photo interpretation: *Photogramm. Eng.*, v. 23, no. 3, p. 593-594.
- Hackman, R. J., and Tolbert, G. E., 1955, Photogeologic map, Notom-15 quadrangle, Garfield County, Utah: U.S. Geol. Survey Misc. Geol. Inv. Map I-34.
- Hemming, H., 1937, Air survey as a factor in empire development: *Mine and Quarry Eng.*, v. 2, no. 7, p. 254-263.
- Hemphill, W. R., 1958a, Determination of quantitative geologic data with stereometer-type instruments: U.S. Geol. Survey Bull. 1043-C, p. 35-56.
- 1958b, Small-scale photographs in photogeologic interpretation: *Photogramm. Eng.*, v. 24, no. 4, p. 562-567.
- Henderson, L. H., 1939, Detailed geological mapping and fault studies of the San Jacinto tunnel line and vicinity: *Jour. Geology*, v. 47, no. 3, p. 314-324.
- Hittle, J. E., 1949, Air photo interpretation of engineering sites and materials: *Photogramm. Eng.*, v. 15, no. 4, p. 589-603.
- Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264-F, p. 113-146.
- Horton, R. E., 1945, Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology: *Geol. Soc. America Bull.*, v. 56, p. 275-370.
- Howard, W. V., 1940, Aerial photographic surveys' valuable on Gulf Coast: *Oil and Gas Jour.*, v. 38, no. 50, p. 194-195.
- Howe, R. H. L., 1958, Procedures of applying air photo interpretation in the location of ground water: *Photogramm. Eng.*, v. 24, no. 1, p. 35-49.
- Jenkins, D. S., Belcher, D. J., Greeg, L. E., and Woods, K. B., 1946, The origin, distribution and airphoto identification of United States soils: U.S. Civil Aeronautics Adm. Tech. Devel. Rept. no. 52, 202 p.
- Johnstone, W. E., 1953, Photogeology and mineral exploration: *Mining Mag.*, v. 88, no. 5, p. 265-270.
- Jolliffe, A. W., 1945, Aeroprospecting in the Yellowknife area: *Canadian Inst. Mining and Metallurgy Trans.*, v. 48, p. 588-609.
- Kelsh, H. T., 1952, Radial triangulation, in *Am. Soc. Photogrammetry, Manual of Photogrammetry*: 2d ed., Washington, D.C., p. 409-447.
- Kent, B. H., 1957, Experiments in the use of color aerial photographs for geologic study: *Photogramm. Eng.*, v. 23, no. 5, p. 865-868.
- Kinoshita, W. T., and Kent, B. H., 1960, Photogrammetric determinations of elevations for regional gravity surveys: *Geophysics*, v. 25, no. 2, p. 445-450.
- Krumbein, W. C., 1950, Geological aspects of beach engineering, in *Application of geology to engineering practice*: Geol. Soc. America Berkey Volume, p. 195-220.
- Lattman, L. H., 1954, The one-sided development of tributaries in tilted sedimentary rocks in eastern Allegheny Plateau of West Virginia: *Michigan Acad. Sci., Arts, and Letters, Papers*, v. 39, p. 361-365.
- 1958, Technique of mapping geologic fracture traces and lineaments on aerial photographs: *Photogramm. Eng.*, v. 24, no. 4, p. 568-576.
- Lattman, L. H., and Nickelsen, R. P., 1958, Photogeologic fracture-trace mapping in Appalachian Plateau: *Am. Assoc. Petroleum Geologists Bull.*, v. 42, no. 9, p. 2238-2245.
- Lattman, L. H., and Olive, W. W., 1955, Solution widened joints in Trans-Pecos, Texas: *Am. Assoc. Petroleum Geologists Bull.*, v. 39, no. 10, p. 2084-2087.
- Levings, W. S., 1944, Aerogeology in mineral exploration: *Colorado School Mines Quart.*, v. 39, no. 4, 77 p.
- Levings, W. S., and Herness, S., 1953, Air photo criteria of ore localization in Corbin-Wickes mining district, Jefferson County, Montana: *Photogramm. Eng.*, v. 19, no. 3, p. 450-460.
- Liang, Ta., and Belcher, D. J., 1958, Airphoto interpretation, in *Landslides and engineering practice*: Natl. Research Council, Highway Research Board Spec. Rept. no. 29, p. 69-92.
- Loel, Wayne, 1941, Use of aerial photographs in geologic mapping: *Am. Inst. Mining Metall. Eng. Trans.*, v. 144, p. 356-409.
- Lueder, D. R., 1951, The preparation of an engineering soil map of New Jersey, in *Symposium on surface and subsurface reconnaissance*: Am. Soc. Testing Materials Spec. Tech. Pub. no. 122, p. 73-81.
- 1953, Airphoto interpretation as an aid in mineral reconnaissance and development: *Photogramm. Eng.*, v. 19, no. 5, p. 819-830.
- Marshall, C. H., and Rosendale, A. B., 1953, Structure of the Discovery anticline: U.S. Geol. Survey open-file rept.
- McNeil, G. T., 1952, Map compilation with stereometer-type instruments, in *Am. Soc. Photogrammetry, Manual of Photogrammetry*: 2d ed., Washington, D.C., p. 603-622.
- Melton, F. A., 1956, Problems of the photogeologist in "flatland" regions of low dip: *Photogramm. Eng.*, v. 22, no. 1, p. 52-63.
- Miller, V. C., 1953, Some factors causing vertical exaggeration and slope distortion on aerial photographs: *Photogramm. Eng.*, v. 19, no. 4, p. 592-607.
- Minard, J. P., 1960, Color aerial photographs facilitate geologic mapping on the Atlantic Coastal Plain of New Jersey: *Photogramm. Eng.*, v. 26, no. 1, p. 112-116.
- Mogg, A. O. D., 1930, A preliminary account of the flora of Pretoria in relation to geology: *Internat. Geol. Cong.*, 15th, South Africa 1929, *Compte Rendus*, p. 651-669.
- Mollard, J. D., 1947, Airphoto mapping of Montgomery County soils for engineering purposes, in *Purdue Univ. 33d Ann. Road School Proc.*: Purdue Univ. Eng. Bull., Ext. Ser. no. 63, p. 223-226.

- Muller, S., 1947, Permafrost, or permanently frozen ground, and related engineering problems: Ann Arbor, Mich., J. W. Edwards, Inc., 231 p.
- Munk, W. H., and Traylor, M. A., 1947, Refraction of ocean waves—a process linking underwater topography to beach erosion: *Jour. Geology*, v. 55, no. 1, p. 1-26.
- Murray, A. N., 1955, Growing vegetation identifies formations: *World Oil*, v. 141, no. 1, p. 102-104.
- Parvis, M., 1947, Regional drainage patterns of Indiana, in *Purdue Univ. 33d Ann. Road School Proc.*: Purdue Univ. Eng. Bull., Ext. Ser. no. 63, p. 192-222.
- Parvis, M., 1950, Drainage pattern significance in airphoto identification of soils and bedrocks: *Photogramm. Eng.*, v. 16, no. 3, p. 387-409.
- Petrusevich, M. N., 1954, Geological surveying and reconnaissance based on photogeologic methods [in Russian]: Moscow, 108 p.
- Petrusevich, M. N., and Kazik, L. I., 1955, Aerial color photography in geological mapping: *Soviet Geol.* no. 42, 7 p. (translated by Associated Technical Services).
- Pillmore, C. L., 1957, Application of high-order stereoscopic plotting instruments to photogeologic studies: *U.S. Geol. Survey Bull.* 1043-B, p. 23-34.
- Purdue University, 1953, A manual on the airphoto interpretation of soils and rocks for engineering purposes: Purdue Univ., School of Civil Engineering and Engineering Mechanics.
- Putnam, W. C., 1947, Aerial photographs in geology: *Photogramm. Eng.*, v. 13, no. 4, p. 557-565.
- Raup, H. M., and Denny, C. S., 1950, Photo interpretation of the vegetation along the southern part of the Alaska Highway: *U.S. Geol. Survey Bull.* 963-D, p. 95-135.
- Ray, R. G., 1956, Photogeologic procedures in geologic interpretation and mapping: *U.S. Survey Bull.* 1043-A, p. 1-21.
- 1958, Color aerial photography: *Western Miner and Oil Rev.*, v. 31, no. 3, p. 35-37.
- Ray, R. G., and Fischer, W. A., 1960, Quantitative photography—a geologic research tool: *Photogramm. Eng.*, v. 26, no. 1, p. 143-150.
- Reed, J. C., 1940, The use of airplane photographs in the geologic study of the Chichagof Mining District, Alaska: *Photogramm. Eng.*, v. 6, no. 1, p. 35-44.
- Rich, J. L., 1951, Geomorphology as a tool for the interpretation of geology and earth history: *New York Acad. Sci. Trans.*, Ser. 2, v. 13, no. 6, p. 188-192.
- Ritchie, A. M., 1958, Recognition and identification of landslides, in *Landslides and engineering practice*: Natl. Research Council, Highway Research Board Spec. Rept. no. 29, p. 48-68.
- Robinson, T. W., 1958, Phreatophytes: *U.S. Geol. Survey Water-Supply Paper* 1423, 84 p.
- Sager, R. C., 1951, Aerial analysis of permanently frozen ground: *Photogramm. Eng.*, v. 17, no. 4, p. 551-571.
- Scher, M. B., 1955, Stereotemplate triangulation: *Photogramm. Eng.*, v. 21, no. 5, p. 655-664.
- Schulte, O. W., 1951, The use of panchromatic, infrared and color aerial photography in the study of plant distribution: *Photogramm. Eng.*, v. 17, no. 5, p. 688-714.
- Schultz, J. R., and Cleaves, A. B., 1955, *Geology in engineering*: New York, John Wiley and Sons, Inc., 592 p.
- Smit Sibinga, G. L., 1948, On the geomorphic and geologic analysis and interpretation of aerial photographs: *Koninkl. Nederlandsch Aardrijksk. Genootschap Tijdschr.*, p. 692-700.
- Smith, H. T. U., 1943a, Aids in teaching photogrammetry: *Photogramm. Eng.*, v. 9, no. 3, p. 167-171.
- 1943b, Aerial photographs and their interpretation: New York, Appleton-Century-Crofts, Inc., 372 p.
- 1953, Photo interpretation of terrain, in *Selected papers on photogeology and photo interpretation*: U.S. Research and Devel. Board, Washington, D.C., p. 7-53.
- Smith, K. G., 1950, Standards for grading texture of erosional topography: *Am. Jour. Sci.*, v. 248, p. 655-668.
- Spurr, S. H., 1948, *Aerial photographs in forestry*: New York, Ronald Press Co., 340 p.
- Spurr, S. H., and Brown, C. T., Jr., 1945, The multiscope—a simple stereoscopic plotter: *Photogramm. Eng.*, v. 21, no. 3, p. 171-178.
- Stoeckeler, E. G., 1952, Trees of interior Alaska, their significance as soil and permafrost indicators, in *Investigations of military construction in Arctic and Subarctic regions*: St. Paul District, U.S. Corps of Engineers, 25 p.
- Stone, Kirk, 1951, Geographical air-photo-interpretation: *Photogramm. Eng.*, v. 17, no. 5, p. 754-759.
- 1956, Air photo interpretation procedures: *Photogramm. Eng.*, v. 22, no. 1, p. 123-132.
- Summerson, C. H., 1954, A philosophy for photo interpreters: *Photogramm. Eng.*, v. 20, no. 3, p. 396-397.
- Tator, B. A., 1951, Some applications of aerial photographs to geographical studies in the Gulf Coast regions: *Photogramm. Eng.*, v. 17, no. 5, p. 716-725.
- 1954, Drainage anomalies in coastal plains regions: *Photogramm. Eng.*, v. 20, no. 3, p. 412-417.
- Tewinkel, G. C., 1952, Basic mathematics of photogrammetry, in *Am. Soc. Photogrammetry, Manual of Photogrammetry*: 2d ed., Washington, D.C., p. 309-380.
- Thompson, M. M., 1958, Photogrammetric mapping of sand beds in a hydraulic test flume: *Photogramm. Eng.*, v. 24, no. 3, p. 468-475.
- Thornburn, T. H., 1951, The preparation of soil-engineering maps from agricultural reports: *Natl. Research Council, Highway Research Board Bull.* no. 46, p. 87-95.
- Thurrell, R. F., Jr., 1953, Vertical exaggeration in stereoscopic models: *Photogramm. Eng.*, v. 19, no. 4, p. 579-588.
- Treece, W. A., 1955, Estimation of vertical exaggeration in stereoscopic viewing of aerial photographs: *Photogramm. Eng.*, v. 21, no. 4, p. 518-527.
- Turner, F. J., 1952, "Gefügerelief" illustrated by "schist tor" topography in central Otago, New Zealand: *Am. Jour. Sci.*, v. 250, no. 11, p. 802-807.
- Turner, S. F., and Skibitzke, H. E., 1952, Use of water by phreatophytes in 2000-foot channel between Granite Reef and Gillespie Dams, Maricopa County, Arizona: *Am. Geophys. Union Trans.*, v. 33, no. 1, p. 66-72.
- Twenhofel, W. S., and Sainsbury, C. L., 1958, Fault patterns in southeastern Alaska: *Geol. Soc. America Bull.*, v. 69, no. 11, p. 1431-1442.
- [U.S.] Beach Erosion Board, 1946, Beach erosion study—Lake Michigan shore line of Milwaukee County, Wis.: U.S. 79th Cong., 2d sess., House Doc. 526.
- Visser, J., 1954, The construction of the datum-correction graph for map compilation with stereometer-type instruments: *Photogramm. Eng.*, v. 20, no. 5, p. 849-853.

- Walker, G. L., 1929, Surveying from the air in central Africa: Eng. Mining Jour., v. 127, no. 2, p. 49-52.
- Wallace, R. E., 1950, Determination of dip and strike by indirect observations in the field and from aerial photographs: Jour. Geology, v. 58, no. 3, p. 269-280.
- Wengerd, S. A., 1947, Geologic interpretation of trimetrogon photographs—northern Alaska: Photogramm. Eng., v. 13, no. 4, p. 586-600.
- Wheeler, R. R., and Smith, N. C., 1952, Finding faded structures: World Oil, v. 135, no. 1, p. 73-74, 76, 82; v. 135, no. 2, p. 105-106, 108, 110, 112.
- Willett, R. W., 1940, The Invincible quartz Lode: New Zealand Jour. Sci. and Technology, v. 21, Sec. B, p. 273B-280B.
- Wilson, R. C., 1949, The relief displacement factor in forest area estimates by dot-templets on aerial photographs: Photogramm. Eng., v. 15, no. 2, p. 225-236.
- Witkind, I. J., Hemphill, W. R., Pillmore, C. L., and Morris, R. H., 1960, Isopach mapping by photogeologic methods as an aid in the location of swales and channels in the Monument Valley area, Arizona: U.S. Geol. Survey Bull. 1043-D. (In press)
- Woods, K. B., Hittle, J. E., and Frost, R. E., 1948, Use of aerial photographs in the correlation between permafrost and soils: Military Engineer, v. 40, no. 277, p. 497-499.
- Woolnough, W. G., 1934a, notes on the technique of aerial photographic survey for geological purposes in Australia: World Petroleum Cong., 1st, London 1933, Proc., v. 1, p. 210-219.
- 1934b, Results of experimental aerial survey with special reference to oil prospecting: World Petroleum Cong., 1st, London 1933, Proc., v. 1, p. 220-229.
- Zonneveld, J. I. S., and Cohen, A., 1952, Geological reconnaissance, in The use of aerial photographs in a tropical country (Surinam): Photogramm. Eng., v. 18, no. 1, p. 151-157.

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U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Image Processing Methods

*Procedures in selection, registration, normalization and
enhancement of satellite imagery in coastal wetlands*

by

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Introduction

The following report presents standard methods used at the Center for Coastal Geology for the rectification of satellite imagery and the enhancement and normalization of dn (digital number) values in all bands to permit inter-scene comparisons. Minimal pre-processing is necessary when conducting a one-time analysis of satellite imagery for land cover within a particular area. However, when a time-series of imagery is compared or when an area encompassed by many images is analyzed, accurate and compatible spatial and spectral data must be employed.

The report is divided into two chapters. Chapter 1 is written as a generic approach to image processing with explanations of how and why particular steps are conducted. Chapter 2 presents image pre-processing, step-by-step, as would be conducted with PCI, Inc. software on Landsat satellite imagery. The imagery utilized is entirely Landsat TM (Thematic Mapper) and MSS (Multi-spectral Scanner).

The first chapter includes basic image pre-processing steps in a generic format with equations for indices and calibrations. The theory and general approach may be applied to other imagery types and software. Although there will be specific references to the particulars of our own project and resources, these techniques may be creatively adapted to suit other research needs. Appendix A provides an outline of the pre-processing steps.

The second chapter covers image processing with PCI, Inc., as conducted on the Florida Big Bend coastal wetlands project. The chapter addresses software-specific parameters for each procedure, details on implementation, and includes a flow chart for PCI EASI procedures. The procedures included will

permit the subsequent pre-processing of imagery in a manner suitable for additional time-series analysis.

Satellite imagery used in the detection of change along coastlines is processed in a standardized fashion to ensure temporal, spatial, and spectral compatibility between scenes. Imagery is initially selected to correlate as closely as possible with season and time-of-year coincident with high biomass and favorable atmospheric conditions as appropriate per region. Tide level at time of overpass in coastal areas can be critical in the evaluation of between-scene differences in the intertidal zone. However, due to cloud cover and image availability, tide level variations are accepted as an inherent limitation to inter-scene compatibility.

Imagery is registered to the UTM coordinate system using GPS-collected (Global Positioning System) ground control points, achieving inter-scene compatibility of < one pixel for Landsat TM. All images meet map accuracy standards of 1:25,000. Radiometric calibration and solar atmospheric correction are performed on all images to derive surface reflectance dn values in each band. The calculation of surface reflectance permits change analysis to be based on relative spectral changes or changes in vegetation biomass with less emphasis placed on land cover category variations. A vegetation index and wetness index is calculated for each image. The resulting pre-processed imagery is ready for inter-scene comparisons.

The procedures used here represent an implementation of techniques by Dobson et al. (1995), a document which describes approaches recommended by the NOAA Coastal Change Analysis Program (C-CAP).

Chapter 1

Image processing methods

1.1 SCENE SELECTION

1.1.1 Season

Initial imagery selection includes determination of the appropriate dates and time frame for analysis. Leaf-off, or winter aerial photography, has traditionally been used in the determination of wetland habitats. However, satellite imagery does not have the same spectral and textural clues as aerial photography and must be employed in a different manner to identify land cover and change detection. Spring imagery is selected for the Gulf coast sub-tropical environment to maximize distinctions in vegetative health and quantity by providing maximum biomass during a period with a high probability of haze-free images. Biomass would not be adequately identified in winter imagery. The selection of imagery dates must be region and project-specific and should be advised by local ecologists familiar with the territory and the particular research issue.

Our primary project area is in the Big Bend region of the Florida Gulf coast (Figure 1). Two scenes are required to cover the area, and two seasons are required to fully classify the land cover. Winter imagery is used to augment the spring imagery for the distinction and classification of deciduous vegetation. A total of four coordinated scenes were acquired for the base years in the analysis (Table 1). Supplementary analysis in the time series requires contemporary spring scenes for each additional year.

1.1.2 Water Level

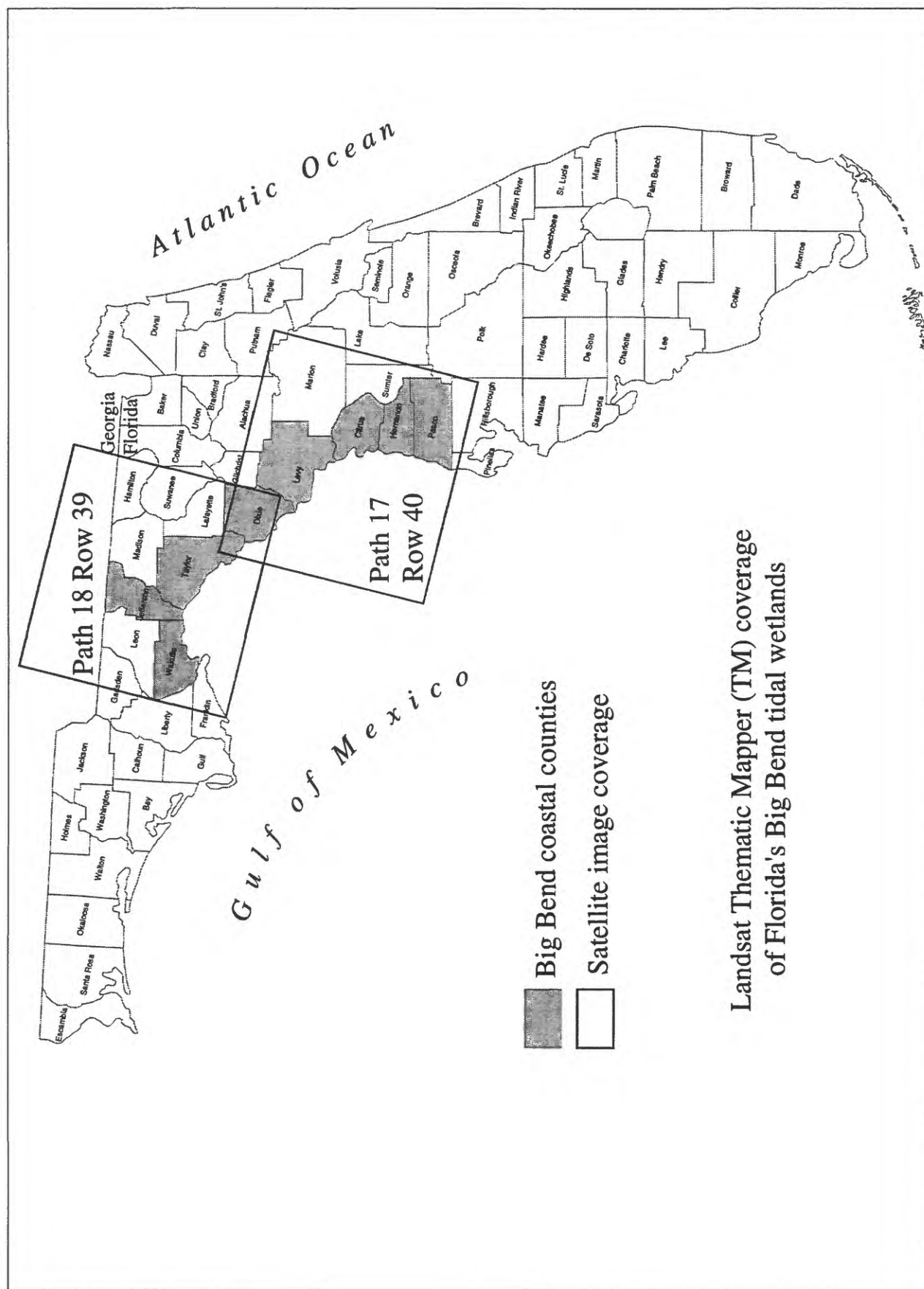
Tide levels can adversely affect the determination of intertidal environments. It is preferable to select scenes with similar low water levels to optimize the characterization of low elevation intertidal zones. Each additional decimeter of water contributes to the mis-identification of 1-1.5% of the intertidal zone as

documented by Jensen et al. (1993), and Raabe and Stumpf (1997). C-CAP recommends selecting tide levels within 0.3 - 0.6 m of mean low water (MLW), which maximizes the utility of the imagery (Dobson et al., 1995). The tide range in the study area is approximately 1 m from MLLW (Mean Lower Low Water) to MHHW (Mean Higher High Water). Although the majority of the intertidal environment along the Big Bend is high marsh, low water level at the time of satellite overpass enhances the discrimination of the low intertidal environment.

Due to a combination of factors such as cloud cover and scene availability, the imagery secured for the Big Bend does not entirely fit the C-CAP standards, but is the best available for the analysis. Some variability in water level is acceptable if two scenes per year are employed in the analysis. In the Big Bend we found that a complementary scene near MLW in the same year can facilitate the correction of differences caused by water level (Table 1). The 1986 south imagery exhibits high water level in both winter and spring, and consequently poses the greatest difficulty in identifying low elevation intertidal habitats.

Table 1. Landsat TM images and Cedar Key water level at time of overpass

Landsat coordinates path/row	Location	Date	Cedar Key water level (msl)
18/39	Tallahassee, FL	01/23/85	0.40
18/39	Tallahassee, FL	04/25/86	1.05
18/39	Tallahassee, FL	11/29/93	0.71
18/39	Tallahassee, FL	04/09/95	1.46
17/40	Cedar Key, FL	01/16/85	1.18
17/40	Cedar Key, FL	04/25/86	1.29
17/40	Cedar Key, FL	01/12/95	1.26
17/40	Cedar Key, FL	04/02/95	0.54



1.1.3 Cloud cover

Cloud cover is the most limiting parameter in scene selection. Listings may be misleading, and previews of imagery should be made whenever possible to ensure quality data before purchase. Although it is advisable to select entirely cloud-free imagery, in some cases it may be necessary to establish only that the critical study area is cloud-free.

1.1.4 Simultaneous coverage

When a study area is large and/or encompasses more than one scene, simultaneous coverage of the whole area is warranted. It is possible, under ideal conditions, to secure several images within days or at most within 3-4 weeks that cover the entire area. In the instance where a study area falls between two scenes in the same path, it is possible to order an image that straddles the image boundaries, eliminating the need to mosaic scenes together.

1.1.5 Specifications

The CD-ROM Format

Imagery obtained from the EROS Data Center (EDC) and EOSAT is now provided in CD-ROM format. The procedures that follow begin with this format. Other formats may be accommodated with minor adjustments in the initial steps. All imagery for this project is obtained in Space Oblique Mercator (SOM) and with Nearest Neighbor resampling (NN). NN resampling is recommended for studies involving spectral analyses because it minimizes alterations to the count values. Other resampling such as cubic convolution may be preferred in studies involving pattern recognition.

1.2 SCENE PREPARATION

1.2.1 Download raw imagery

The contents of the CDROM will include 7 bands of TM along with summary and header files. All 7 bands of data are extracted from the CD and converted to a readable format for image processing. The header file is also extracted at this point.

The PCI procedures, CDEOSAT and CDNLAPS, read data off the CD-ROM, create a new file on disk, write the band data, and extract header information which is written into an orbital segment attached to the new file. The orbital segment will be used in the rectification of the imagery to the UTM coordinate system. Other coordinate systems may be employed in a similar manner.

1.2.2 Check header file

The header file should accompany the scene and a readable copy of the header file is made to disk. A sample header file may be found in Appendix B. Information from the header file is used in subsequent processing steps. Trailer files may or may not accompany the imagery. Typically, the information desired from this file is the time of overpass in Greenwich Mean Time (GMT), which is noted for use in the radiometric enhancement.

1.2.3 Visual check

All new imagery is previewed, band-by-band, to determine if data lines are missing or other anomalous features exist in the scene. The visual review must be done at full-resolution. Attention is focused on identifying lines or blocks of missing data in each band for subsequent "repair." Haze or cloud cover that may render parts of the scene ineffective for analysis is noted as well. In our case the visual check is conducted in PCI Imageworks with seven image planes in the display window. Each portion of the image is displayed at full-resolution, and each band is viewed separately to identify missing data.

It is useful to examine the range and histogram of count values in each band at this time. Occasionally imagery is purchased with offset or anomalous count values. A quick evaluation now may save time later. Band 6, the thermal band, is especially prone to such errors.

1.2.4 Line replacement and destriping

Missing lines are "repaired," and other problems are resolved in each band before the scene is rectified to the UTM coordinate system. Once rectification has been conducted, errors

will no longer coincide with horizontal lines of data and are virtually impossible to fix. Image line replacement is a simple procedure that allows the operator to fill-in missing lines with the line above, below, or with an average of the two.

It also may be necessary to conduct destriping of the image if a linear pattern is prominent in the image. It is usually a more significant problem with Landsat MSS than with TM or SPOT, and affects dark objects such as water in particular. However, we have run several variations of a destriping procedure on scenes with an 8 to 9-line repetitive stripe and have concluded that the output image was not improved over the original. Although we do not conduct this procedure ourselves, it may be advisable in other situations, and, if necessary, must be attempted in this initial phase of pre-processing, before rectification.

1.3 ORTHORECTIFICATION OF IMAGERY

Rectification of the imagery requires several steps: identification of ground control within the imagery, collection of ground control points with a GPS unit, development of a rectification model, reprojection of the imagery using the model, and two accuracy checks.

Three terms are defined:

1. Rectification fixes each feature in the imagery to the correct position on the earth
2. Reprojection involves transforming and rectifying the image to a standard projection such as Universal Transverse Mercator (UTM)
3. Registration involves having features in multiple scenes exactly match each other in location

Ideally, the rectification and reprojection will inherently produce co-registered images. We use rectification and reprojection procedures which result in sufficient accuracy to produce co-registered scenes. The reprojection is critical in that it produces images in a standard projection such as UTM or state plane.

However, in some projects, a previously rectified scene might be used as reference so that

all scenes are registered to the base scene. For instance, a set of Landsat MSS scenes might be registered to a NALC (North American Land Characterization) scene. If the above or other procedures are used where a polynomial transform "rubber sheet" adjustment is employed, it is usually preferable to co-register scenes, then conduct the reprojection and rectification on all of them. Co-registration without rectification is never recommended.

1.3.1 Coordinate System

Rectification and reprojection of satellite imagery to a standard coordinate system is performed on all scenes in the project. Whether you use UTM or another coordinate system, the reprojection allows the determination of geographic coordinates for features identified in the analysis and facilitates integration with other geographic data sets. The approach used in the Big Bend project employs a PCI procedure, SORTHO, which reprojects the image based on satellite orbital information and a set of standard ground control points. The results effectively combine both inter-scene compatibility and coordinate plane rectification. To achieve co-registration without rubber sheeting, a common set of ground control points is used for all images. In this way the original data is rectified and reprojected from the Space Oblique Mercator (SOM) projection of the raw data to the Universal Transverse Mercator (UTM) coordinate system, with corresponding results in each subsequent image rectification.

1.3.2 Ground control in image

Ground control points are identified in the imagery as clearly visible point or right-angle positions, which are also accessible by road. Approximately twice as many points are identified as are ultimately required for the registration for several reasons. Some positions are not retrievable in the field, not all positions are identifiable in all imagery, and some positions are held out as part of the registration accuracy check. The operator examines a full-resolution image display to select the ground control. Preferred locations are corners at small to intermediate right-angle road intersections in rural or low-density developed areas. Highly developed areas tend to give blurred intersections and are difficult to re-locate in subsequent

imagery. The identification of visible and distinct locations in the imagery which are also accessible to a field team is a major challenge in many regions. Alternatives to road intersections and right angles may be selected based on other landscape features. For example, the end of a bridge over a stream may be suitable. Consideration is given to the clarity of the location and the possibility of re-identification of the same point in earlier and later imagery. Good judgment and careful selection ensures accurate registration of the study area.

The set of selected positions are marked on the imagery file with a vector which can be displayed on a field laptop computer for identification during the field reconnaissance. If the technology is not available, a hardcopy is printed of each potential ground control point in the imagery, and these are bound with map sheets to aid in field identification.

1.3.3 Ground control in field

Accurate ground control points are collected for each image based on pre-identified locations as described in section 3.2. A hand-held Global Positioning System (GPS) unit is employed with accuracy guaranteed 5-10 m. Positioning of < 10 m requires differential, P-code, or comparable receivers for accurate rectification of Landsat TM or SPOT imagery. Standard non-differential units do not produce the necessary sub-pixel accuracy.

Field plans should include 5-10 minutes per station for data collection and site documentation to facilitate identification of the positions in subsequent imagery. We recommend a minimum of 2-3 readings per position, and 24-30 positions per image. The ground control should be well-distributed across the image and at locations which are visible in imagery over a period of 5-10 years. As some GPS readings turn out to be poor quality, we recommend collecting multiple readings at each location. Accurate and complete field notes accompanying the collection of GPS ground control facilitate the identification of the positions in subsequent imagery. A description including county, road, and intersection names, distance from nearby intersections, directional designators, and photographs are helpful in future relocation. We have also concluded that the occupation of an intersection corner,

appropriately designated (as in "southwest corner"), is better than occupying the center of a road intersection as has been previously practiced.

Other techniques exist for the collection of ground control points and may be applied where resources are limited. For instance, low-cost, non-differential, non-P-code GPS receivers can be used, providing positional accuracy of 30-100 m. Map accuracy will be reduced from the 1:25,000 achieved in this project to 1:50,000 or more. Alternative approaches include digitization of positions from mylar 7.5 minute quadrangles, or the selection of similar positions from digital data sets including vectors, digital orthophotographs, and other imagery. Each approach carries with it inherent errors, of which the analyst should be aware. At the very least, the operator should know the error range for the input coordinates prior to the analysis. This will determine an acceptable RMS error range and whether or not the intended and final map accuracy will be achieved. The same caution applies to the selection of alternative adjustment techniques.

The PCI software in use for this project has a field version of GCPWORKS (under our investigation), which incorporates the selection of ground control in the imagery and the collection of GPS ground control simultaneously, on a field laptop computer. Although this does not eliminate the need to carefully select quality and well-distributed control within the image and in the field, it does consolidate the work, and allows the operator to evaluate the quality of the ground control *as it is being collected*. The on-site development of a rectification model eliminates costly returns to the field in the event some ground control proves useless.

The GPS unit employed in this project has a stated accuracy of ≤ 10 m, which met our mapping needs with TM and MSS. Higher resolution imagery such as SPOT and IRS may benefit from even higher accuracy ground control, available with newer GPS units at 1-5 m. Although 24-30 positions are collected per image, not every position is used in the actual rectification. In addition to the elimination of poor quality positions, other ground control points are not easily relocated in the imagery and are not used. Eight to ten positions are used to rectify the imagery, and another 10-12 are set aside to be used in the accuracy check.

1.3.4 Create model

A model is created with the ground control points. It is preferable to use a low-order polynomial transform to reduce distortion in the final image, particularly at scene edges or over large water bodies. The PCI procedure we use makes the conversion between the two systems without introducing distortion to the resulting image as is normally found in polynomial adjustments. We prefer this approach as it gives consistent spatial positioning across the image. Other registration packages are available and may be applied with varying results depending on the quality of the ground control and the amount of distortion introduced in the polynomial function.

User-entered coordinates

Imagery is brought to display on the monitor for the collection and identification of ground control points. These ground control points are part of the original set selected from the imagery at full-resolution display and subsequently collected in the field. They are spatially well-distributed over the extent of the image and show promise of being stable and easily identifiable in a time series. The GPS coordinates collected at these locations show little variation in repeat readings.

During the identification of ground control, watch the RMS (root mean square) error for each ground control point and the total RMS error in both x and y. Examine the scatter plot of the ground control to help identify positions which are in error. Within reason, it is possible to adjust the location of the ground control in the imagery to achieve optimal positioning and distortion-free rectification.

We have found with 10 m accuracy in the GPS and 30 m resolution in the imagery that the RMS of each individual position and the total RMS need not exceed 0.5 pixels (15 m). At the same time, consider that excessive adjustment of point positions to produce significantly lower RMS readings will introduce errors in the final adjustment. An RMS of 0.5 pixels indicates that the position is ± 15 m or 1/2 pixel from the optimal location. Under the circumstances, it is reasonable to expect a total RMS of 0.3-0.6 pixels, or 10 - 20 m, best fits the accuracy achievable with the given data. We have found that substantially forcing the model to lower

errors introduces regional distortion into the final image.

Model

The collection of ground control points in the imagery leads to the development of a model to adjust the full image to the new coordinate system. See Chapter 2 for detailed steps in PCI. If not running GCPWORKS, and SMODEL, follow appropriate steps for software application.

1.3.5 Satellite image rectification

The goal of image rectification is to facilitate the overlay of additional imagery and other geographic data sets. A standard map area, with boundaries set in UTM, is established for each scene, thus all image files for the same region, once rectified, will occupy the same map area. The UTM bounds for the scene are established according to the file size, the 28.5 x 28.5 m pixels (57 x 57 m pixels for Landsat MSS), and the minimum/maximum northing and easting required to contain the full scene area. These boundaries, the UTM zone and the ellipsoid are established on each newly-created empty file.

The size and initial boundaries for the two scenes in the study (Figures 2 and 3) are shown in Table 2 with UTM zone 17 coordinates for the upper left and lower right corners. The north image is cut at the Florida/Georgia border, approximately - 1100 lines (Figure 3). A new file of matching size is created for each image in the series. A matching georeference segment is established on each file. Details are provided in Chapter 2.

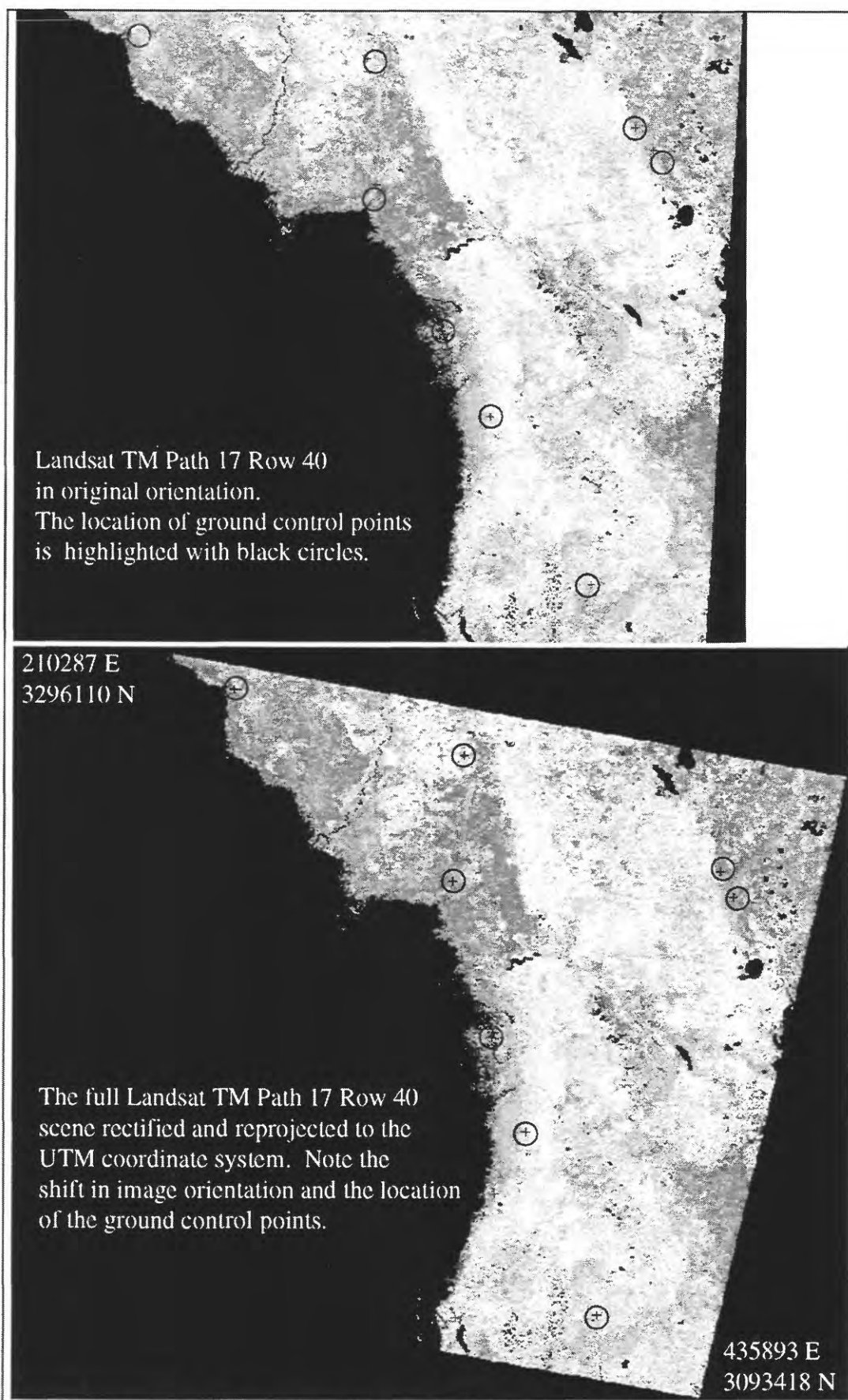


Figure 2. Rectification and reprojection from SOM to UTM, Landsat Path 17 Row 40.

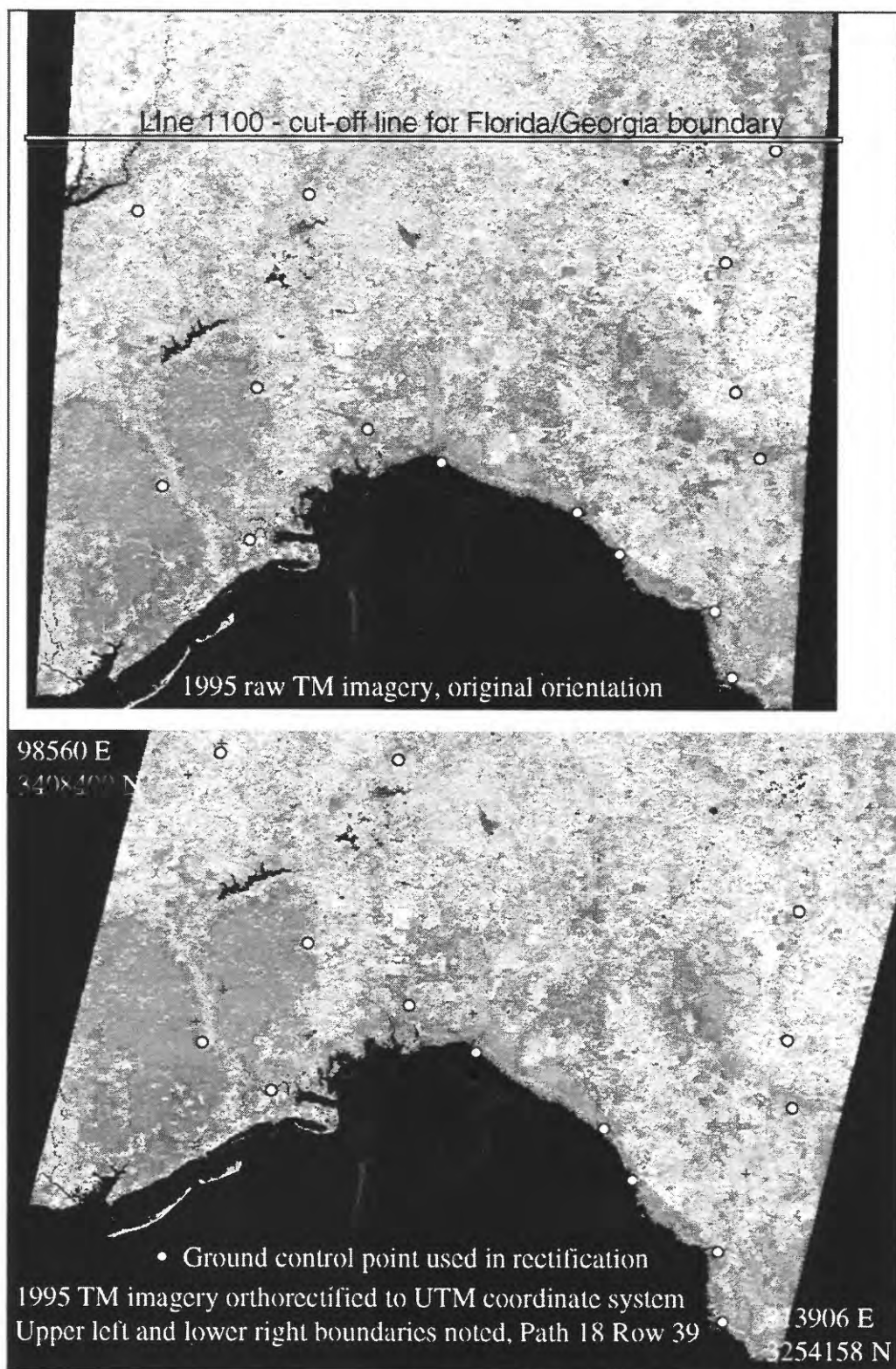


Figure 3. Rectification and reprojection from SOM to UTM, Landsat Path 18 Row 39

In the event new regions are processed under these instructions, the designation of an output file size and geographic extent will depend on project needs, although it is recommended that full, or close to full scenes are pre-processed to maximize their subsequent utility. The calculation of file size is determined by the maximum and minimum eastings and

northings of the raw image and the pixel size. Pixels in Landsat TM are 28.5 x 28.5 m, in MSS the pixel size is 57 x 57 m. Image rectification is conducted with the model segment created earlier, and the output applied to the newly-created and georeferenced image file discussed in the preceding paragraph.

Table 2. Scene size and coordinates for georeferencing segment

Landsat TM Big Bend File Information	Scene Location	
	Tallahassee	Cedar Key
Path/Row	18/39	17/40
Initial file size	6967 pixels/5965 lines	6967 pixels/5965 lines
Final file size (x/y)	7556 pixels/5412 lines	7916 pixels/7112 lines
Pixel size (x/y in meters)	28.5/28.5	28.5/28.5
Upper left coordinates (UTM)	98560 E, 3408400 N	210287 E, 3296110 N
Lower right coordinates (UTM)	313906 E, 3254158 N	435893 E, 3093418 N

1.3.6 Accuracy check

Accuracy checks involve both geographic or map accuracy, and co-registration or inter-scene accuracy. It is important to recognize that multiple scenes may meet one criteria and not the other. Two scenes may be co-registered to within a pixel, but have significant geographic error. Conversely, scenes may meet a standard map accuracy in a selected coordinate system, but have systematic errors that result in poor co-registration between scenes. Mis-registration may result from poor models or the use of high order polynomials. Evaluation of both map accuracy and image co-registration is necessary subsequent to image reprojection.

UTM or coordinate system accuracy

Image rectification is not complete without accuracy checks. If check points were not entered and evaluated as in GCPWORKS and SMODEL above, it is necessary at this point to objectively locate 8-12 check points in the rectified image. The evaluation will give a measure of the map accuracy, the percentage of the image within the standard 'x' m. Obviously the evaluation varies according to the resolution of the imagery, the accuracy of the ground

control, and the intended accuracy for the particular study. The measure obtained tells the user the expected positional accuracy of the majority of features in the image.

The check points are part of the larger set of ground control established with GPS as described in 1.3.2 and 1.3.3. Visually locate each ground control check point with the cursor in the rectified image. Note the image coordinates at the location, and evaluate how far the position is from the known x,y (UTM) coordinates. It may be difficult to conduct this step objectively. Try evaluating the *portion* of a pixel from which your visual position strays from the coordinates at which it visually should be. In our case, the goal was to accurately map 90% or more of the map features within 20 m of their known location, so we evaluate each position relative to our objective.

The accuracy check of the image to the UTM coordinate system meets our needs and is acceptable. Clearly, with only 12 check points, only one position per x/y component can exceed the established tolerance. It is worth conducting a careful check at this point to ensure good geographic correlation of data. If there is a geographic error in the image, it helps if you

have indicated in which direction it shifted with a simple $\pm$ after each x/y offset.

Inter-image accuracy

The second accuracy check is conducted on imagery which will be used in inter-scene comparisons. It has been a common practice to rectify only one image, and then register all other images to the base scene, or to co-register all scenes to a master and apply the rectification for that scene to all others. While the standard approach provides a solution to multiple-image registration, every image in the present study is rectified individually to UTM coordinate system. According to this approach, each subsequent image is rectified using the same set of ground control points, and is visually checked against the original, or first-rectified base image as follows.

The inter-scene accuracy check consists of selecting 3 to 4 areas within the image to be displayed, one by one, at full resolution with selected bands from each image. Two methods are used to check inter-scene registration: (1) a simultaneous display of the same band from both scenes, using color as a reference to examine horizontal and vertical linear features, (2) a flicker state between the two scenes with the cursor at a fixed, well-defined location. Both methods may be applied regardless of the software in use.

In the first method single bands, usually band 4 or 3, from each scene are displayed simultaneously in a red-green-blue (RGB) display. Offsets will be obvious in either the x or y direction as bands of color on either side of a vertical or horizontal roadway (Plate 1). The first evaluation gives a quick check on overall alignment of the two images.

In the second approach the bands from the base image are displayed simultaneously with the same bands from the new image in a multiple-image plane display and set to flicker state. Three to five right-angle road intersections which display true horizontal and vertical direction within the image are evaluated in each of the selected full-resolution windows. Each intersection is evaluated and recorded in a table (see Chapter 2.2.7).

Plate 2 illustrates the position of the cursor at a right angle road intersection in the base image and evaluation of the cursor position

relative to the intersection in the newly-rectified image. The cursor is placed at the center of the intersection in the base image, as if two imaginary lines were drawn N/S and E/W, taking into consideration the mixed pixel effect. The display is flickered to the newly-registered image, and the location of the intersection is compared in half pixel increments. Roads and intersections at non-right angles to the pixel/line orientation are never used in this evaluation. See Plate 3 for examples of intersections preferred for evaluation. The second method provides the operator with a detailed evaluation of inter-scene compatibility and the direction of offsets, if any.

Expected inter-scene registration is $\pm$ one pixel. A trend of greater than one pixel in x or y requires re-examination of the ground control point segment and a repeat of the whole rectification process. Consistent offsets or regional trends of greater than one pixel suggest poor quality registration and require re-rectification of the imagery with a thorough evaluation of the ground control point coordinates, positioning, and land cover changes between the imagery dates.

Again, good judgment, and a second opinion may help to eliminate operator errors or unforeseen problems. All imagery in the current project must meet the $\pm$ one pixel inter-scene accuracy before additional processing can be conducted. The goal is consistently met and presents no real problem with this particular set of imagery. We encourage other projects to develop similar methods to achieve high inter-scene positional registration.

1.4 RADIOMETRIC AND ATMOSPHERIC CORRECTIONS

Several band enhancements and corrections are applied to the rectified imagery to normalize the dn (digital number) values, facilitating direct spectral comparisons between imagery bands and a comparable set of values as input to indices and clustering programs. Radiometric calibration, conversion to reflectance or solar correction, and atmospheric correction are conducted on every image. The adjustments rely heavily on data contained within the header file, including gain, bias, and solar zenith angle. Programs have been written in-

house to facilitate the radiometric and atmospheric corrections. The aerosol adjustment still relies on a visual/manual assessment of dark water values, although it may also be automated eventually.

1.4.1 Radiometric correction

The digital counts in the image are transformed to reflectance using the calibration that comes with the files and the equations and constants of Price (1987), and Markham and Barker (1985):

EQUATION 1. REFLECTANCE CALIBRATION

$$R(\lambda) = \frac{\pi L(\lambda)}{E_0(\lambda)(1/r^2) \cos(\theta_0)} \quad 1$$

where λ is the band; the radiance, L , is determined by:

EQUATION 2. RADIANCE

$$L = G * N + BIAS \quad 2$$

E_0 is the solar constant (Price, 1987; Markham and Barker, 1985), r is the normalized earth-sun distance, θ_0 is the solar zenith angle at the image center, N is the digital count, G is the calibration slope, and $BIAS$ is the calibration offset for zero radiance. A scale factor of 500 is applied to bands 1,2,3,4,5, and 7 to convert to 1 byte per pixel (0-255). A scale factor of 100 is applied to band 6. More sophisticated computations for reflectance exist. These involve additional terms in equation 1 for atmospheric transmission, and are being considered for implementation.

1.4.2 Atmospheric correction

The atmosphere introduces two forms of path radiance into the signal, radiance from Rayleigh or molecular scatter, and radiance from aerosols or haze. These can be removed simultaneously using dark object subtractions. However, improvements in atmospheric correction offers advantages in treating atmospheric and Rayleigh corrections separately. If no dark water exists in the scene, the Rayleigh correction is critical.

Rayleigh radiance is removed before the dark object subtraction. While not critical, when dark water is present, removal of the Rayleigh path radiance permits pixel by pixel correction of aerosols for water pixels and allows better control on the adjustment for aerosols. The Rayleigh term is determined using standard equations and coefficients. Models such as LOWTRAN (Air Force) can be used for the solution.

1.4.3 Aerosol correction

The aerosol correction is performed using subtraction from bands 1-4. Because the Big Bend region has black-water lakes and rivers, water can be found that has negligible reflectance in all bands. A dark-object subtraction is used, with the reflectance of the darkest water being the value subtracted. The correction is either constant or decreases slightly with wavelength (Chavez, 1989). The dn value selected should be that corresponding to the lowest value that has a significant number of pixels. In bands 3 and 4 the dark water area should be the same region. Identifying dark water in the blue and green bands may be difficult. If a suitable area is not present, extrapolation from bands 3 and 4 may be necessary.

8	8	9	8	9
8	9	9	9	9
9	9	9	8	9
9	10	9	13	10
8	5	8	7	8

The foregoing values represent pixels in the darkest water area of a scene. The 5 and 13 values are probably artifacts of the sensor (or boats). A value of 8 would be appropriate for dark water subtraction.

Normalization of marsh for bands 3 and 4 is determined in the image overlap. By convention, we use values of zero to define missing data. A simple model is applied to all bands to restore zeroes to a value of one within the image bitmap. The non-image area surrounding the scene is eliminated from this and the index calculations by the application of an "image-only" mask, detailed in Chapter 2.3 and 2.4.1.

1.5 INDICES

Analysis includes the calculation of a vegetation index, wetness index, temperature, and water reflectance. Each index provides a means to compare a particular feature between different scenes.

1.5.1 Vegetation Index

Subsequent analysis uses band ratioing as a surrogate measure of biomass. The vegetation index is a ratio of TM bands 3 and 4. The normalized difference vegetation index (NDVI) is a quantification of green biomass. It is not meaningful for water.

EQUATION 3. NDVI (NORMALIZED DIFFERENCE VEGETATION INDEX)

$$NDVI = \frac{R(4) - R(3)}{R(4) + R(3)} \quad 3$$

where 4 and 3 are near-infrared and red bands, respectively, and R = reflectance after aerosol correction. A weight of 0.01 for the ratio denominator will scale NDVI by 100, such that an NDVI of 1.0 produces a count of 100.

1.5.2 Wetness Index

The wetness index is a measure of the wetness in the soil observable through the canopy and is particularly effective in distinguishing tidal influence in the coastal marsh zone and in areas with thin vegetation canopy. It is calculated based on the inversion of a procedure used to delineate open or standing water. We find that the gradient provided with the inverse, the "wetness index", shown here is effective in delineating the extent of tidal flooding in the coastal marshes.

EQUATION 4. WETNESS INDEX

$$WETNESS = R(5) - R(2)$$

1.5.3 Temperature

Temperature is calculated from the thermal band, TM band 6. The contrast in water temperatures is particularly noteworthy in Florida gulf coastal waters during the winter season,

when it is possible to observe the source and redistribution patterns of the relatively warmer waters of the Floridan aquifer. We convert radiance of TM band 6 to Celsius + 5. Resulting values include freezing temperatures, which may occasionally occur in the region.

EQUATION 5. TEMPERATURE IN CELSIUS

$$\text{Celsius} + 5 =$$

$$(1260.56 / \ln(60.776 / (L(6)/100) + 1)) - 268)$$

1.5.4 Water Reflectance

Water reflectance is calculated as the difference of bands 2 and 4.

EQUATION 6. WATER REFLECTANCE

$$\text{Water reflectance} = R(2) - R(4)$$

Chapter 2

Image processing software procedures

2.0 INTRODUCTION

Many of the image pre-processing steps are conducted within an image-processing software package. The Center for Coastal Geology group uses PCI, Inc. The following chapter includes specific instructions on running the procedures. It should serve as a guide to the basic steps required within this program.

Initial scene selection and ordering is conducted outside of the image processing package. A flow chart (Plate 4) is provided to help the novice follow the different kinds of steps involved and the order in which they are conducted. The check list in Appendix A should become the basis for your own notes, including adjustments and new developments.

2.1 SCENE PREPARATION

Imagery is downloaded from the CD-ROM disk with CDNLAPS or CDEOSAT, depending on the format of the disk. Important information is included in the header file. Take time to learn to read the header file with the instructions accompanying your order. Look for format (NLAPS or EOSAT), band sequential or pixel interleaved (BSQ, BIL), number of pixels and lines, date and time of acquisition, resampling scheme (NN, CC, BL), and so on.

Once downloaded to a .pix file, examine each band at full resolution for missing lines or blocks of missing data, heavy clouds, and the histogram of dn values. Each band should exhibit a normal range and distribution for the season and region covered. Now is the time to repair or return an image with serious problems.

Table 3 shows the parameters set for CDNLAPS. Table 4 shows parameters set for LRP to fix line number 100 in band 2 with the mean from the line above and the line below. The EASI procedure, LRP, requires the operator to specify the missing line(s) +1 to correctly identify the lines to be replaced. If destriping is attempted, read about DSTRIPE in EASI help.

Table 3. CDNLAPS procedure parameters

CDEOSAT CD EOSAT Fast Format	V6.0 EASI/PACE 12:31 16-Feb-97
NLAPSHD - NLAPS Header File Name	:/cdrom/cdrom1/filename.hd
FILE - Database File Name	:path/newfile.pix
CDIC - CD Input Channel List	} 1 2 3 4 5 6 7
TEX1 - Database Descriptive Text 1	:path_row_location
REPORT - Report Mode: TERM/OFF/filename	:path/newfileorb.rep

Table 4. LRP, line replacement parameters

LRP Image Line Replacement	V6.0 EASI/PACE 08:29 17-Feb-97
FILE - Database File Name	:pathname/filenlaps.pix
DBOC - Database Output Channel List	} 2
DBOW - Database Output Window	> 101
RMOD - Replacement Mode: ABOV/BELO/MEAN	
LINC - Line Increment Factor	> 1

2.2 ORTHORECTIFICATION OF IMAGERY

The orbital segment created in CDEOSAT or CDNLAPS contains information used in an adjustment between the estimated latitude/longitude of the raw imagery and the desired coordinate system. SMODEL creates a model from the orbital segment and a ground control point segment. The ground control point segment is created in GCPWORKS.

2.2.1 GCPWORKS

Imagery for the Florida Wetlands is rectified with ground control collected with GPS units and is reprojected to the UTM coordinate system. Ground control selection is described in Chapter 1, and can be conducted in any image display program, including PCI's IMAGEWORKS. Once the ground control has been identified and field collected, run GCPWORKS to enter the coordinates at their respective locations in the image. The satellite orthorectification option is selected to permit the use of the orbital segment in the model.

Select "Collect/review GCP's only", "Satellite Ortho Correction", "User Entered Coordinates", and then "Select Uncorrected Image". Enter the path and filename of the nlaps.pix file. Load three bands, usually natural color (3,2,1) or false color (4,3,2), are preferred for display. Set the units to meter, and the coordinate system to UTM, zone 17, row R and ellipsoid WGS84. Obviously, the zone and row will change depending on the region. Identify the location of 8 to 12 ground control points and enter the corresponding UTM coordinates collected with the GPS unit.

During the identification of ground control within GCPWORKS, watch the RMS error for each ground control point and the total RMS in both x and y. Within reason, it is possible to adjust the location of the ground control in the imagery to achieve optimal positioning and distortion-free rectification.

In GCPWORKS it is possible to also enter accuracy check points at this time. If not working in this program, these check points are set aside for a post-rectification accuracy check. The 10-12 accuracy check points must be of

equally high quality and well-distributed about the scene. Care is given to treat these positions and the associated error objectively, as they eventually provide a measure of the model's accuracy. These positions should be entered at the end, when the ground control points have been securely identified to avoid adjusting the model to fit the check points. When the operator is satisfied with the location of the ground control and the total RMS error, the ground control point segment is saved within GCPWORKS. Ideally, this will be segment #3.

2.2.2 GCPREP

A report documenting the ground control point segment as collected is obtained by running GCPREP. Run the procedure with ORDER set to 0. GCPREP produces a text file showing the list of ground control points, their pixel/line locations, the user-entered coordinates, and errors. The UTM coordinates of the ground control is exactly what was entered within GCPWORKS. This will change when the model is run in SMODEL. Remember, in GCPWORKS, the satellite orthorectification was selected. This forces the orbital segment to be referenced while developing the model. GCPREP does *not* refer to the orbital segment, and thus does not reflect it's influence on the ground control. The output from another procedure, GCPWRIT, may be useful in creating a vector segment. It requires a little editing and then running VREAD. The vector may be displayed in subsequent displays to help re-locate the ground control points for new imagery.

2.2.3. SMODEL

SMODEL draws on both the orbital segment and the ground control point segment to create the model, and must always be run on the whole scene. It is ineffective to run on a partial scene. If check points were entered along with the ground control, SMODEL will also produce a table showing the accuracy of the check points in meters. Run SMODEL as shown in Table 5. Both the orbital segment, 2, and the ground control point segment, 3, must be specified in the procedure. SMODEL produces a model segment, normally 4, which will be applied in the image rectification, SORTHO.

SMODEL also produces a report showing the accuracy of the check points in meters. Examine the report for values outside of the range of expected and desired accuracy (see Appendix C). Excessive values below the original 10 m accuracy of the GPS positions may introduce distortion to the final image rectification. Values greater than 20 m, or 2/3 pixel, suggest the overall registration may not meet inter-scene registration requirements. Note also that the UTM coordinates shift by the RMS error.

Values for positional accuracy in this project are acceptable between 8-20 m. The rectification of a TM scene will technically meet 1:25,000 map accuracy standards, provided that 90% or more of the individual accuracy check points are within 20 m or less of their desired location. With 12 check points, only one can be ≥ 20 m from its true location. Although we achieve the reported level of map accuracy, TM imagery will always be printed at scales of 1:50,000 or smaller to avoid the blocky appearance of the pixels.

Table 5. SMODEL procedure parameters

SMODEL	Satellite Model Calculation	V6.0 EASI/PACE	10:57 19-Feb-97
FILE	- Database File Name	:path/newfile.pix	
DBGC	- Database Ground Control Segment >	3	
ORBIT	- Orbit Segment Number >	2	
MODEL	- Satellite Model Segment >		
MODINPUT	- Modify Input	:NO	
ELLIPS	- Ellipsoid for the Earth	:E012	
ERRUNIT	- Error Unit: Pixel/Metre	:METRE	
REPORT	- Report Mode: TERM/OFF/filename	:path/smodel.rep	

2.2.4 CIM2 - New file creation

New imagery files are created in CIM2, a file format which creates a separate file for each band, all associated by the header or .pix file (Table 6). The size of a fully-processed full size Landsat TM scene makes this option appealing for ease of movement and disk-space issues. The example shows the standard size of

the north Big Bend image, path 18, row 39. The size includes the removal of ~1100 lines in the state of Georgia and the enlargement of the file to reproject the region into the UTM coordinate system (see Figure 3). All north scenes will be created in the same manner. If working in another region, establish a standard file size based on the full extent of the UTM eastings and northings and the pixel size.

Table 6. Creation of new file for rectification in CIM2

CIM2	Create Database and Image Channel Files	V6.0 EASI/PACE	14:14 16-Feb-97
FILE	- Database File Name	:path/newortfile.pix	
TEX1	- Database Descriptive Text 1	:p18r39	
TEX2	- Database Descriptive Text 2	:sorto file/northern Big Bend	
DBSZ	- Database Size: Pixels, Lines >	7556 5412	
PXSZ	- Pixel Ground-Size in Metres >	28.5 28.5	
DBNC	- No. of Channels: 8U,16S,16U,32R >	7	

2.2.5 GEOSSET - georeference segment

Every file in PCI has a georeferencing segment created automatically as segment 1.

The geographic boundaries, the UTM zone, and the ellipsoid are set in the georeferencing segment of the newly created CIM2 file with GEOSSET. An example for the north Big Bend is shown in Table 7. The coordinates given are applied to each corresponding image, making overlays and inter-scene analysis a simple task.

Table 7. Georeferencing segment set with GEOSSET procedure in PCI

GEOSSET Set Georeferencing Segment	V6.0 EASI/PACE 14:10 19-Feb-97
FILE - Database File Name	:path/newortfile.pix
UPLEFT - Upper Left Position for Database>	3317100 201900
LORIGHT - Lower Right Position for Database>	3085020 447000
MAPUNITS- Map Units: PIXEL/UTM/others	:UTM 17 R E012

2.2.6 SORTHO - satellite image orthorectification

Orthorectification of imagery is conducted in PCI with the SORTHO procedure which applies the model segment to the nlaps image file and reprojects the seven bands of data into the empty bands of the newly created and georeferenced .pix file. See Table 8 for SORTHO parameters.

Due to the minimal topographic variation along the Big Bend coast of Florida, we do not employ a DEM file. Instead, we estimate an average value for elevation as the width of one pixel with no offset (ESCALE). Elevations do not exceed ~60 m in the area, and this appears to be sufficient for positional accuracy and inter-scene registration. The need for elevation must be determined on a region-by-region basis. . The SORTHO procedure may take up to 6 hours on a SUN SPARC 20 and is usually run overnight.

Table 8. Parameters for satellite orthorectification procedure

SORTHO Satellite Image Orthorectification	V6.0 EASI/PACE 14:22 16-Feb-97
FILI - Database Input File Name	:path/nlapsfile.pix
FILO - Database Output File Name	:path/newortfile.pix
FILEDEM - Database DEM File Name	:
DBIC - Database Input Channel List	} 1 2 3 4 5 6 7
DBOC - Database Output Channel List	} 1 2 3 4 5 6 7
DBEC - Database Elevation Channel List >	
BACKLEV- Background Elevation Value	>
ESCALE - Elevation Scale and Offset	> 28.5 0
DBIW - Database Input Window	>
MODEL - Satellite Model Segment	> 4
PXSZOUT - Output Pixel Ground-Size	> 28.5 28.5
RESAMPLE- Resample Mode: NEAR/BILIN/CUBIC	:NEAR

2.2.7 Inter-scene accuracy check

The inter-scene registration accuracy check is conducted manually within an image display program. Run IMAGEWORKS with a full-resolution window ~600 x 800 with 6 image planes. Display 3-5 well-distributed regions in the window, each time loading the newly

registered image (4,3,2) and the base image (4,3,2) with the same input window.

For instance, in image planes 1,2,3 load the new image (4,3,2) with an input window of 300, 300 (x,y offsets), 600, 800 (x,y window size). Then load the base image to image planes 4,5,6 (4,3,2) using the same full-resolution window. Examine the images first with a single

band from each of the images in a RGB display mode. An example may be viewed in Plate 3. Look for truly horizontal or vertical roads and evaluate obvious offsets. A poorly registered image as shown to the left in Plate 3 is not worth evaluating further. Note the direction of the offsets, check other regions to confirm the offsets, and return to GCPWORKS to redo the ground control point segment.

If horizontal and vertical roads align well in the first input window, switch to a flicker state with each image displayed 4,3,2 as RGB. Select 3-5 right-angle road intersections for evaluation. See Plate 2 for selection of road intersections. Flicker to the base image and zoom in on a selected intersection. Place the cursor at the center of the intersection, drawing two imaginary lines N/S and E/W to determine the exact location. Leaving the cursor in position, flicker to the newly registered image. Again, mentally draw two lines and determine the exact center of the new intersection. Do not move the cursor. Evaluate if the cursor is exactly on target, off by 0.5 pixel, 1.0 pixel, or > 1.0 pixel in both the x and y directions. See Plate 1 for evaluation of cursor location.

Complete a table as follows, with 12-20 road intersections across the scene. The table

will highlight regional or full-scene offsets. In this table each region and the scene as a whole meet the requirements of $\pm$ one pixel inter-scene alignment. The newly registered file is acceptable, and image processing can proceed. If, however, a region or the whole scene exceeds one pixel offset in either direction, then GCPWORKS, SMODEL and SORTHO must be repeated. Run CLR to reset the new file channel values to 0 before running SORTHO again. The table may be used to help guide the adjustment of the ground control points.

For example in a TM scene:

Region	x offset (pixel)	y-offset (pixel)
NW 1	0	0.5 -
NW 2	0.5 +	0.5 -
NW 3	1.0 +	0.5 -
NE 1	0	0.5 -
NE 2	0.5 +	0
NE 3	0.5 +	0.5 -
SE 1	0.5 +	1.0 -
SE 2	0.5 +	0
SE 3	0	0.5 -
SW 1	0.5 +	0.5 +
SW 2	0.5 +	0.5 +
SW 3	0.5 +	0.5 +

2.3 RADIOMETRIC AND ATMOSPHERIC CORRECTION

The following sections illustrate the EASI procedures used for radiometric calibration and atmospheric correction. Information from the header file is employed in the procedures. A bitmap is created first to mask the non-image pixels of the *ort.pix file. Typically the mask can be obtained by selecting all pixels in band 1 or

band 2 with values greater than zero. The mask is subsequently used for the creation of indices and other analysis. Limiting the processing to the image area of the file shortens processing time and eliminates the formation of anomalous features outside of the image area. The EASI thresholding procedure, THR may be use for creating the bitmap (Table 9). If necessary a similar mask may be created for the non-image area by setting the COMP parameter to "ON". The complement is used to fix anomalous data sometimes found in band 6.

Table 9. Bitmap creation with THR

THR	Thresholding Image to Bitmap	V6.0 EASI/PACE 09:34 17-Feb-97
FILE	- Database File Name	:fltns/fileort.pix
DBIC	- Database Input Channel List	} 1
DBOB	- Database Output Bitmap	}
TVAL	- Threshold Value (Min,Max)	> 1 255
COMP	- Complement: ON/OFF	:OFF
DBSN	- Database Segment Name	:imageon
DBSD	- Database Segment Descriptor	:image bitmap excluding non-image border

2.3.1 TMRAD

Seven additional empty channels are added using PCIADD2. These are the output channels for the radiometrically enhanced bands, 8-14. TMRAD is an in-house EASI procedure which solves equations 1 and 2 in section 1.4.1. Sample parameters are set in Table 10. Latitude and longitude are given in decimal degrees, and

longitude is a negative value in the western hemisphere. TMSLOPE and TMBIAS may be obtained from the newer header files as Gain/10 and Bias/10, respectively. The solar constants (from Markham and Barker, 1986), and scale factors will change for different imagery and satellites. TEXT may be set to "stat" for a check on the output values (Table 11), which is also saved to a text file for reference.

Table 10. EASI procedure TMRAD

```

TMRAD - radiometric correction of TM imagery  V5.3 EASI/PACE 09:10 15-Aug-95
FILE - Database File Name      :/imagery/tm95/TM19950402
DBIC - Database Input Channel List  >  1  2  3  4  5  6  7
DBOC - Database Output Channel List >  8  9 10 11 12 13 14
DATESITE - J.day, GMT, lat, long (W<0)>  92 1511 28.8686 -82.4237
TMSLOPE - Slope for TM or MSS band  > 0.0632 0.1254 0.0964 0.0907
                                0.0125 0.0055 0.0067
TMBIAS - TM or MSS offsets for channels 1> -0.118 -0.1935 -0.1697 -0.1628
                                -0.0248 0.1238 -0.0125
TMSOLAR - TM or MSS solar constants 1 - 7> 195.7 182.9 155.7 104.7 21.93 1 7.452
SCALEF - Scale factor for units to counts> 500 500 500 500 500 100 500
TEXT - Text input               :stat

```

Table 11. TMRAD output

```

Julian Day (year-day)= 92
Time (GMT) = 1511
Lat/long = 28.8686 -82.4237
*** Solar zenith angle = 40.5686 degrees ***
*** Solar azimuth angle = 119.377 degrees ***
*** Earth-sun distance = 0.999353 a.u. ***
cos(sza) = 0.759628
band # 1 10.00133387
slope bias solar irradiance refl/ct
0.0632 -0.118 195.7 148.852 0.00133387
band # 2 20.00283185
slope bias solar irradiance refl/ct
0.1254 -0.1935 182.9 139.116 0.00283185
band # 3 30.00255726
slope bias solar irradiance refl/ct
0.0964 -0.1697 155.7 118.427 0.00255726
band # 4 40.00357806
slope bias solar irradiance refl/ct
0.0907 -0.1628 104.7 79.636 0.00357806
band # 5 50.00235428
slope bias solar irradiance refl/ct
0.0125 -0.0248 21.93 16.6802 0.00235428
band # 6 6 0.0055
slope bias solar irradiance refl/ct
0.0055 0.1238 1 0.760612 0.0055
band # 7 70.00371355
slope bias solar irradiance refl/ct
0.0067 -0.0125 7.452 5.66808 0.00371355

```

2.3.2 RAYRAD - Rayleigh radiance

The Rayleigh correction factor is calculated with RAYRAD. Calculations may be found in Stumpf (1992). The procedure requires operator input as in Table 12, and produces output as in Table 13. The scale factor should be the same as that used in TMRAD.

Bands 1 - 4 are corrected by subtracting the Rayleigh values from each band respectively.

The Rayleigh values are the last column in Table 13, rounded to the nearest whole number. Values for bands 5 and 7 are insignificant, and for band 6, irrelevant. The model used to accomplish the subtraction is shown in Table 14. The bitmap is specified with "%2" and band 8 as "%8". Keep in mind that the radiometrically enhanced bands, 8 - 14, are equivalent to TM bands 1 - 7.

Table 12. RAYRAD input

```
/pci/usgs/bin: rayrad
enter latitude (decimal degrees)
30.31
enter longitude (decimal degrees, where west < 0)
-83.92
enter time in GMT, (hhmm)
1537
enter Julian day
119
enter scalefactor (conversion of reflectance to counts for processed imagery)
500
```

Table 13. RAYRAD output

channel	radiance	reflectance	counts
1	3.5128	0.0571	28.5
2	1.6372	0.0285	14.2
3	0.7739	0.0158	7.9
4	0.1991	0.0060	3.0
5	0.0026	0.0004	0.2

solar constants	tau r	tau g
196.0	0.17110	0.01
183.0	0.08920	0.03
156.0	0.04840	0.02
105.0	0.01850	0.02
21.7	0.00110	0.00

solar declination = 14.686262184445
solar zenith angle = 31.398820329709
solar azimuth = 113.20862349932

Table 14. Rayleigh subtraction model

```

doc *****
doc Correction of the radiance values gathered from using the
doc rayrad program. This program will allow corrections of the
doc digital numbers for bands 1 through 7
doc *****
doc_end
monitor = "ON"
report = "TERM"

file = "/path/fileort.pix"
see file
MODEL ON file
35  if (%%2 = 1) %8 = %8-29
rem 36 print "29 subtracted from dn for band 1"
40  if (%%2 = 1) %9 = %9-14
rem 41 print "14 subtracted from dn for band 2"
45  if (%%2 = 1) %10 = %10-8
rem 46 print " 8 subtracted from dn for band 3"
50  if (%%2 = 1) %11 = %11-3
rem 51 print " 3 subtracted from dn for band 4"
55  if (%%2 = 1) %12 = %12
rem 56 print " 0 subtracted from dn for band 5"
60  if (%%2 = 1) %13 = %13
rem 61 print " 0 subtracted from dn for band 6"
65  if (%%2 = 1) %14 = %14
rem 66 print " 0 subtracted from dn for band 7"
ENDMODEL
100 return

```

2.3.3 Dark object subtraction

Final atmospheric correction values are selected manually from a full-resolution display of bands 1 - 4, focused on areas of dark water. This step must be conducted, visually, AFTER the Rayleigh correction has been subtracted from the bands. The dark object subtraction itself may be conducted with EASI procedure, ARI, or with a model similar to the one in Table 14. The values shown in Table 15 are in the normal range for the region of the Big Bend coast. All channel descriptors (image layer histories) are renamed using MCD to more accurately describe the contents of the channel based on the pre-processing applied.

Table 15. Dark water values:

Channel 1: 16
Channel 2: 12
Channel 3: 8
Channel 4: 6

2.4 INDICES

Several indices are calculated at the final point in processing. An additional band is added to the .pix file for each index desired. Be sure to specify the correct band number when calculating an index. The examples below are based on the radiometrically enhanced data residing in bands 1-7. It is possible to protect previously processed image channels from accidental overwrites with the LOCK procedure.

2.4.1 Bitmap creation

A mask is employed to permit processing and modeling of image-only pixels. If not already done, the mask is created by selecting all pixels with a value of > 0 in TM band 1 or 2. The new bitmap segment is on at every image pixel and off at all non-image pixels. It is important that the operator check the band at full-resolution to ensure there are no zero values in the image area itself before running this procedure. The results can be checked afterwards on full-resolution display. Failure to check may result in missing data in the index channels. The mask is created by running THR as in Table 9. The mask allows the operator to run processes on image data only, maintaining values of zero in non-image areas of the file.

2.4.2 Vegetation Index

The vegetation index, NDVI may be calculated in the EASI procedure, RTR (Table 16). Alternatively, a model can be written to take the input channels 3 and 4 and write output NDVI to channel 8. Differences in NDVI between two years may range from ~-90 to +90. These values are re-scaled to range from 1 - 200.

EQUATION 7. EASI MODEL FOR NDVI

$$\%8 = 100 * (\%4 - \%3) / (\%4 + \%3)$$

2.4.3 Wetness Index

The wetness index may be calculated with EASI procedure, ARI (Table 17). It may also be run as an EASI model:

EQUATION 8. EASI MODEL FOR WETNESS INDEX

$$\%9 = \%5 - \%2$$

2.4.4 Thermal band 6 temperature

Temperature is calculated from TM thermal band 6 (Markham and Barker, 1986) to degrees Celsius plus 5. We add 5 degrees to account for near freezing temperatures which occasionally occur in the Big Bend region. The model is run from a file as follows:

EQUATION 9. EASI MODEL FOR TEMPERATURE IN CELSIUS

```
MODEL ON "/pathname/filename.pix
if %%2 = 1 %10 =
(1260.56/ln(60.776/(%6/100)+1))-268);
ENDMODEL
```

where segment 2 is a bitmap, masking image-only pixels.

2.4.5 Water reflectance

Water reflectance can be calculated with EASI procedure, ARI, (Table 18) or as follows:

EQUATION 10. EASI MODEL FOR WATER REFLECTANCE

$$\%11 = \%2 - \%4$$

2.4.6 Brightness

Brightness is merely TM band 2 with the appropriate adjustments for radiometric enhancement and atmospheric corrections. This is sufficient for comparison of brightness between scenes.

Table 16. Calculation of NDVI using EASI RTR

RTR	Real Database Channel Ratioing	V6.0 EASI/PACE	14:54 16-Feb-97
FILE	- Database File Name	:path/fileort.pix	
CNUM	- Channels for Ratio Numerator	} 4 3	
WNUM	- Weights for Ratio Numerator	> 1 -1	
NCON	- Constant for Ratio Numerator	> 0	
CDEN	- Channels for Ratio Denominator	} 4 3	
WDEN	- Weights for Ratio Denominator	> 0.01 0.01	
DCON	- Constant for Ratio Denominator	> 0	
DBOC	- Database Output Channel List	> 8	
SMOD	- Scaling Mode: NONE/AUTO/LOGS	:NONE	
MASK	- Area Mask (Window or Bitmap)	> 2	
ZERODIV	- Value for Division by Zero	> 255	

Table 17. Calculation of the wetness index with EASI ARI

ARI	Image Channel Arithmetic	V6.0 EASI/PACE	14:34 16-Feb-97
FILE	- Database File Name	:path/fileort.pix	
OPER	- Operator: ADD/SUB/MUL/DIV/AND/OR:SUB		
CNST	- Input Scalar	> 0	
MASK	- Area Mask (Window or Bitmap)	> 2	
DBIC	- Database Input Channel List	} 5 2	
DBOC	- Database Output Channel List	> 9	
ZERODIV	- Value for Division by Zero	> 255	
AUTO	- Autoscaling mode: ON/OFF/USER	:OFF	
RVAL	- Function Min,Max, Output Min,Max>		

Table 18. Calculation of water reflectance with EASI ARI procedure.

ARI	Image Channel Arithmetic	V6.0 EASI/PACE	14:34 16-Feb-97
FILE	- Database File Name	:path/fileort.pix	
OPER	- Operator: ADD/SUB/MUL/DIV/AND/OR:SUB		
CNST	- Input Scalar	> 0	
MASK	- Area Mask (Window or Bitmap)	> 2	
DBIC	- Database Input Channel List	} 2 4	
DBOC	- Database Output Channel List	> 11	
ZERODIV	- Value for Division by Zero	> 255	
AUTO	- Autoscaling mode: ON/OFF/USER	:OFF	
RVAL	- Function Min,Max, Output Min,Max>		

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References

- Chavez, P.S., Jr., 1989, Radiometric calibration of Landsat Thematic Mapper multispectral images, *Photogrammetric Engineering and Remote Sensing* 55(9):1285-1294.
- Dobson, J.E., E.A. Bright, R.L. Ferguson, D.W. Field, L.L. Wood, K.D. Haddad, H. Iredale, J.R. Jensen, V.V. Klemas, R.J. Orth, J.P. Thomas. 1995. *NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation*. NOAA Technical Report NMFS 123, NOAA NMFS, Seattle, Washington, 92 p.
- Jensen, J.R., D.J. Cowen, J.D. Althausen, S. Narumalani, O. Weatherbee, 1993, The detection and prediction of sea level changes on coastal wetlands using satellite imagery and a geographic information system, *Geocarto International* 4: 87-98.
- Markham, B.L. and J.L. Barker, 1985. Spectral characterization of the LANDSAT Thematic Mapper sensors. *International Journal of Remote Sensing* 6: 697-716.
- Price, J.C., 1987. Calibration of satellite radiometers and the comparison of vegetation indices. *Remote Sensing of Environment* 21: 15-27.
- Raabe, E.A. and R.P. Stumpf, 1997, Assessment of acreage and vegetation change in Florida's Big Bend tidal wetlands using satellite imagery, Remote Sensing for Marine and Coastal Environments, ERIM, Proceedings of the Fourth International Conference, 17-19 March 1997, Orlando, Fl. Volume I: 84-93.
- Stumpf, R.P., 1992, Remote sensing of water quality in coastal waters, Remote Sensing for Marine and Coastal Environments Proceedings, *Needs and Solutions for Pollution Monitoring, Control and Abatement*, SPIE 1930, Vol. 1, pp. 293-305, ERIM, Ann Arbor, Michigan.

Appendix A

Image Pre-Processing Outline

I. Scene selection

- A. Season
- B. Water level
- C. Cloud cover
- D. Simultaneous coverage of multiple path/row
- E. Specifications: NN, SOM, CD-ROM format,...

II. Scene prep

- A. Download imagery and header files from CD-ROM or tape format
- B. Check header and trailer files - create orbital segment if possible
- C. Visual check of imagery - repair missing data lines where necessary
- D. Attempt destriping - abort if unsuccessful

III. Orthorectification of imagery

- A. Coordinate system
- B. Image ground control
- C. Field ground control
- D. User-entered coordinates
- E. Model of ground control and orbital segment
- F. Rectify raw imagery to new file using model
- G. Accuracy check on registration
 - 1. Check against UTM coordinates
 - 2. Check inter-scene registration

IV. Radiometric enhancement and atmospheric corrections

- A. Transform raw digital count values to reflectance
- B. Calculate Rayleigh coefficients
- C. Dark water subtraction - subtract to 0's
- D. Create image-pixel only bitmap
- E. Model image pixels of value 0 to value 1

V. Create indices

- A. Vegetation index (NDVI)
- B. Wetness index
- C. Temperature
- D. Water reflectance
- E. Brightness

VI. Data storage and documentation

Sample Header File

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Appendix C

SMODEL Satellite Model Calculation V6.0 EASI/PACE 10:34 04-Dec-96

Report File : fltns/tm88smod3.txt

Using GCPs stored in the GCP segment :

GCPID	CALCULATED GCP		RESIDUE (Metre)		
	X	Y	X	Y	RMS
1	269716.91	3284028.64	1.09	-0.64	1.26
2	328575.40	3232963.42	-10.40	0.58	10.42
3	331799.21	3266272.27	5.79	6.73	8.88
4	400117.75	3235478.61	10.25	-0.61	10.27
5	403824.55	3228838.33	-10.26	-1.93	10.44
6	339244.69	3191071.87	-6.69	-10.87	12.76
7	348310.68	3166255.36	12.32	1.64	12.43
8	370506.11	3126170.90	-2.11	5.10	5.52
	RMS	8.90	5.30	10.36	

RESIDUE ERRORS FOR CHECK POINTS:

GCPID	CALCULATED CHECK POINT		ERRORS (Metre)		
	X	Y	X	Y	RMS
-19	299418.73	3233029.69	-0.73	-7.69	7.73
-9	329124.94	3116528.16	1.06	-5.16	5.27
-10	327671.62	3126505.34	11.38	-7.34	13.54
-11	329711.82	3126556.48	-1.82	-3.48	3.92
-12	330920.87	3130030.77	2.13	-6.77	7.10
-13	330055.45	3130044.83	-0.45	-13.83	13.84
-14	339940.18	3149448.61	-5.18	-3.61	6.31
-15	343565.03	3187000.57	5.97	6.43	8.78
-16	366101.40	3197847.99	-8.40	8.01	11.61
-17	335025.94	3199333.66	-12.94	-6.66	14.55
-18	311824.53	3236336.17	0.47	-12.17	12.17
	RMS	6.63	8.36	10.68	

N02 (2 X ellipsoid normal) : 0.1276623423925591D+08
 aa (Unknown tied to earth rotation) : -.2019698071206954D-02
 ALPHA (IFOV) : 0.4250000000000000D-04
 bb (Unknown of 2nd order) : 0.5159405145974503D-08
 C0 (Scene centre column) : 0.3441000000000000D+04
 cc (Unknown of 2nd order): -.1011490548231246D-08
 COSKHI (Parameter): 0.9986239362292677D+00
 DELGAM (Unknown of 2nd order): -.5228374067336880D-08
 GAMMA (Scene orient. rel. to the North): 0.1804139211480550D+00
 K_1 (Cross track scale function): 0.1650305501958989D-05
 L0 (Scene centre row): 0.3209500000000000D+04
 P (Along track scale function): 0.2850017693250296D+02
 Q (Satellite-Scene centre dist): 0.6704364897025154D+06
 TAU (Levelling angle along track dir): -.5251493727041531D-01
 THETA (Levelling angle across track dir): 0.3593993241522756D-02
 THETAS (THETA/COS_KHI): 0.3598945620203554D-02
 X0 (Carto coord of scene centre): 0.3259051885403947D+06
 Y0 (Carto coord of scene centre): 0.3194585202192697D+07
 DELH (Radar parameter in H dir.): 0.0000000000000000D+00
 COEFY2 (Radar parameter in Y2 dir.): 0.0000000000000000D+00

EARTH ELLIPSOID USED : E012

Appendix D

DATA STORAGE

I. Naming conventions

A. Image files:

Name: fltmN950402nlaps.pix

state (2) imagery type (2) region (1) date (yyymmdd) level (nlaps, ort, cor)

B. Report and text files:

Include date and 3-letter abbreviation of process with either .rep or .txt. Use .rep in the case of reports generated by EASI itself, and .txt for reports created by the operator.

II. CD-ROM Storage/Sets

Detailed information on CD-ROM storage levels is provided on each CD-ROM. In brief:

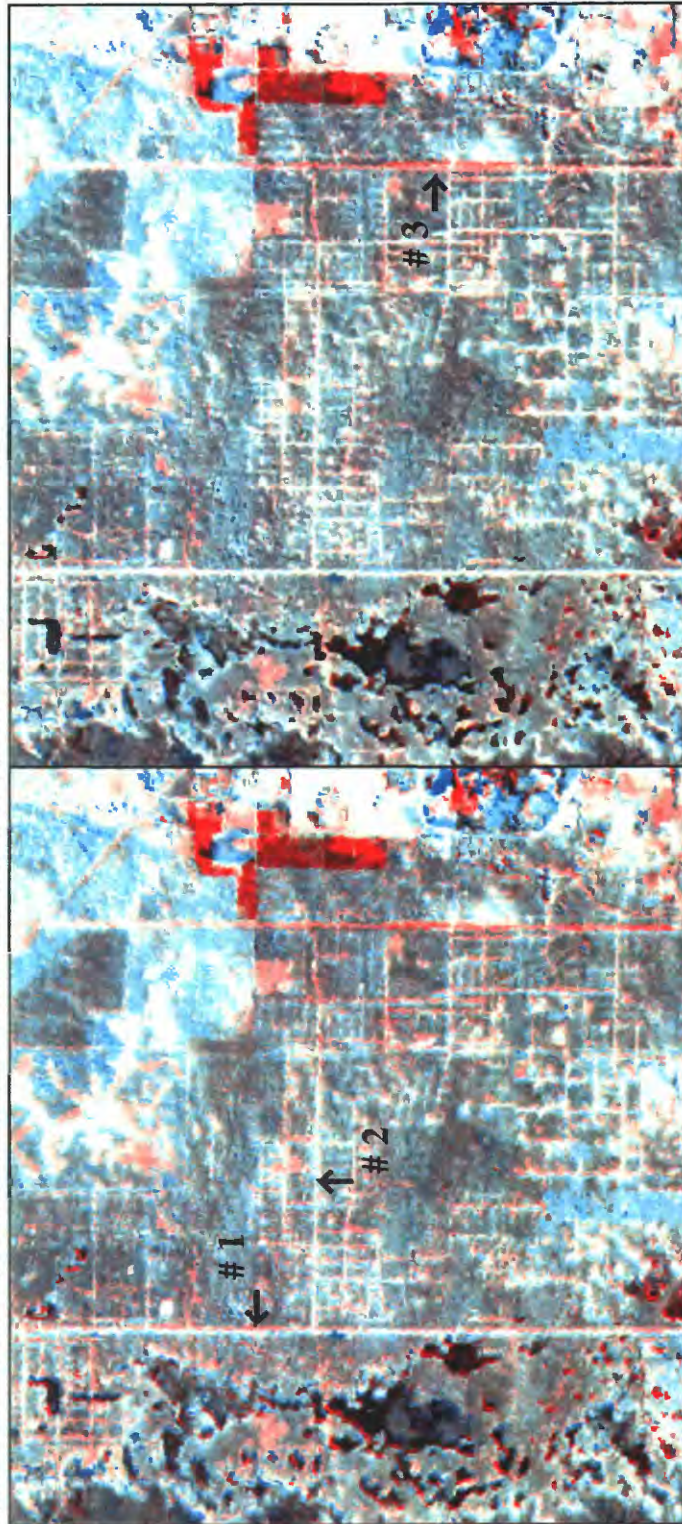
Set I contains the *nlaps file, a raw image file extracted from the original CD-ROM format and converted to a .pix format. The level I CD-ROM also contains the orbital and ground control point segments and models necessary for orthorectification of the imagery.

Set II contains the *ort file, a fully rectified image. The level II file has met accuracy standards both for inter-scene and coordinate plane map accuracies. The CD-ROM also includes all segments necessary for the rectification and all text files corresponding to the processing already completed.

Set III contains the *cor file, a radiometrically enhanced and atmospherically corrected image. The file includes four additional channels of data, vegetation index, wetness index, water reflectance and temperature. The level III CD-ROM also holds all text files pertaining to all levels of processing with summaries for ease in evaluation.

NOTES

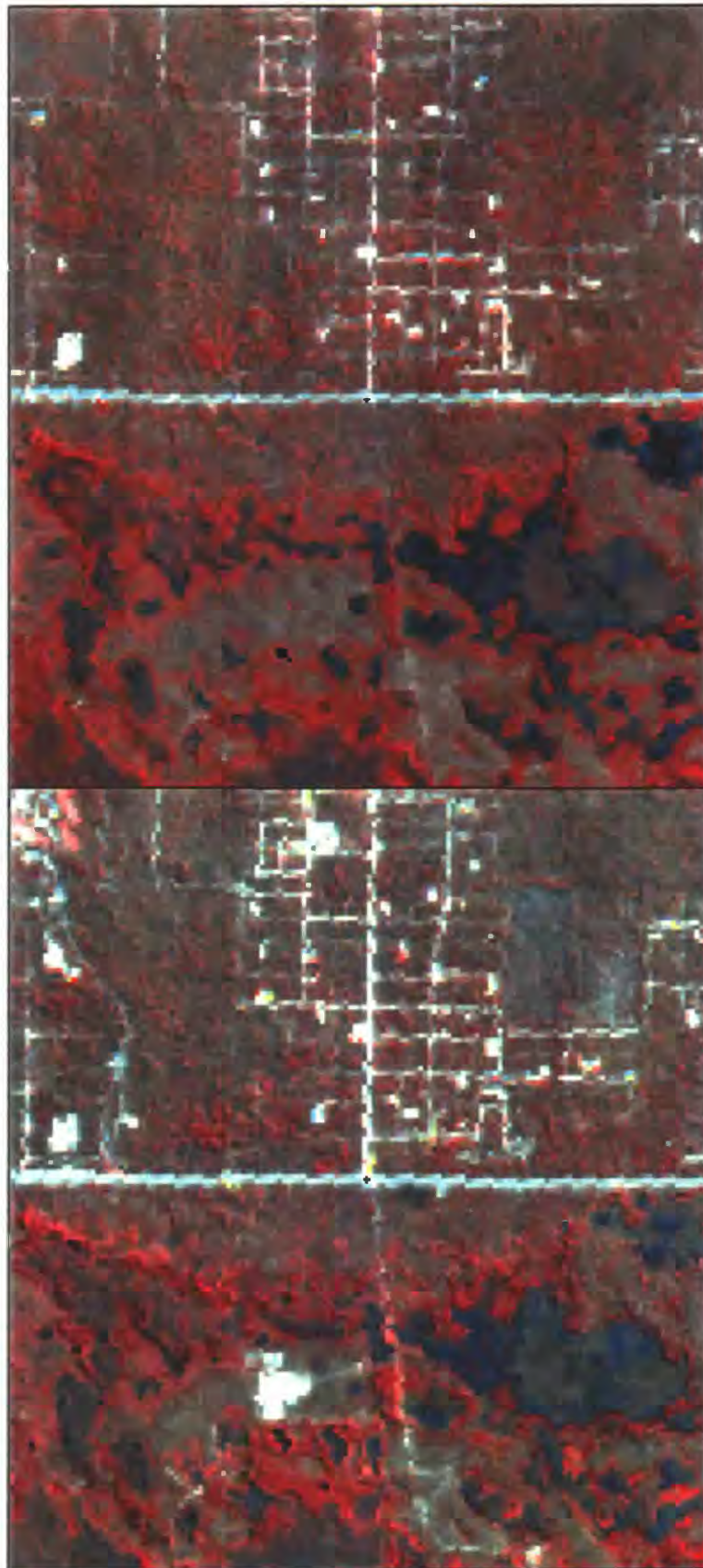
One of the images below is misregistered, > 1 pixel on the x-axis. To identify a misregistered image, look for two parallel lines, red and blue, where a road should be. Well-aligned roads will appear white or will have a mottled pattern of colored pixels (mixed-pixel effect) which occupy essentially the same line.



Misregistered 1995 and 1985 images. 1995 band 4 is displayed in the red plane and 1985 band 4 in the blue plane. Note the parallel vertical lines at arrow #1 showing poor alignment in the x-axis. A similar but less distinct offset is apparent in the y-axis at arrow #2.

Properly registered imagery does not present the double red/blue lines indicative of misalignment. However, a newly-built or significantly altered road will stand out as a single red or blue line as indicated by arrow #3. Changes in land use and vegetation are also visible in this display as shades of red and blue.

Platc 1. Misregistration and acceptable inter-scene registration for 1985 and 1995



Cursor positioned at center of 1995 road intersection

Cursor at same pixel/line position in 1985 imagery

The road intersection in the older image is satisfactory. The cursor offset is less than one pixel. The road to the right appears to have been narrower in 1985 which accounts for the 1/2 line offset in the y-axis. The x-axis is well-aligned with less than 1/2 pixel offset. Note: we do not consider the smaller road to the left in this evaluation. It lacks clarity and does not approach the intersection at a right angle.

Plate 2. Comparison of right angle road intersection for inter-scene registration.

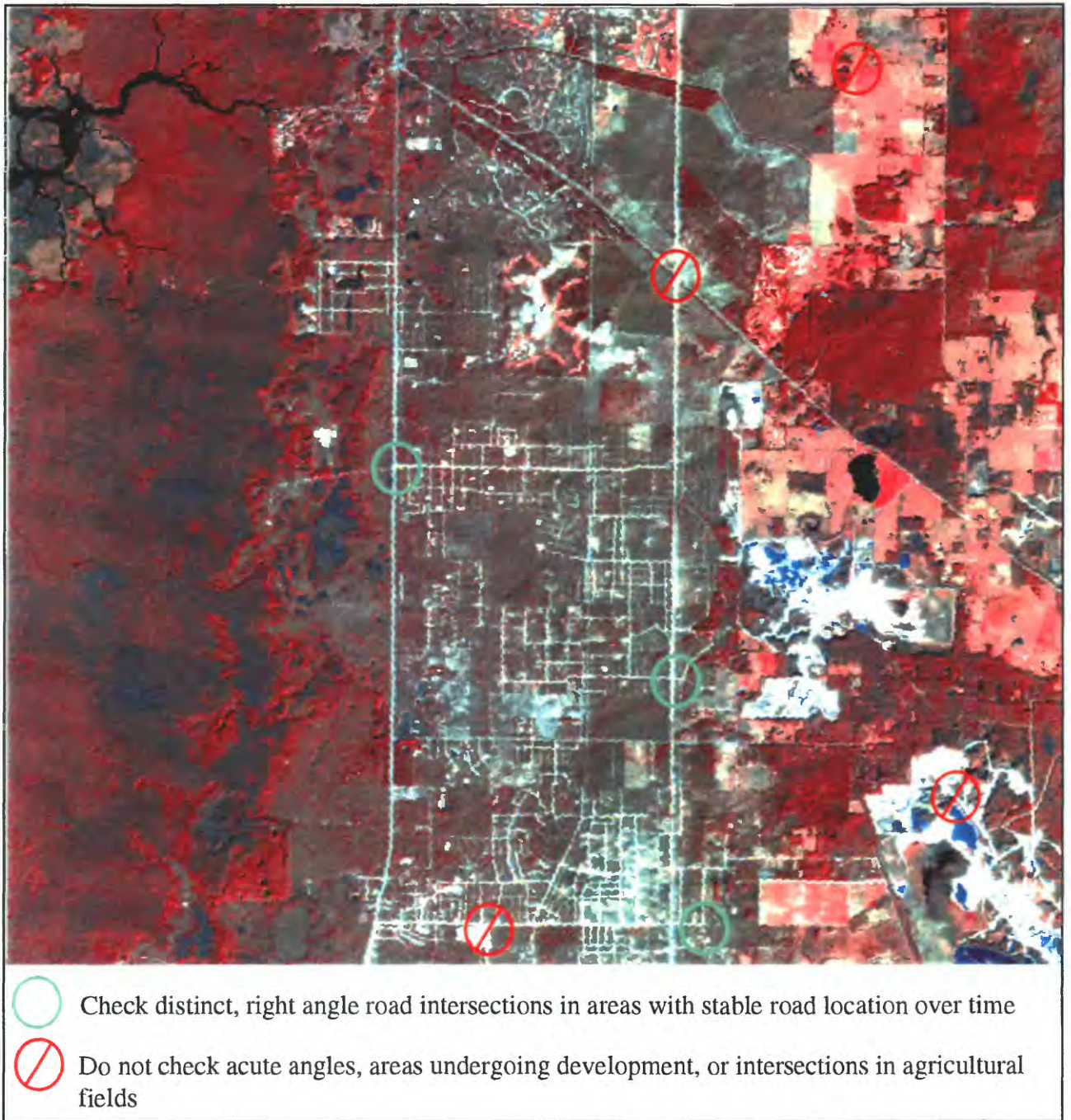


Plate 3. Preferred locations for inter-scene accuracy check, Chassahowitzka, FL, 1995.

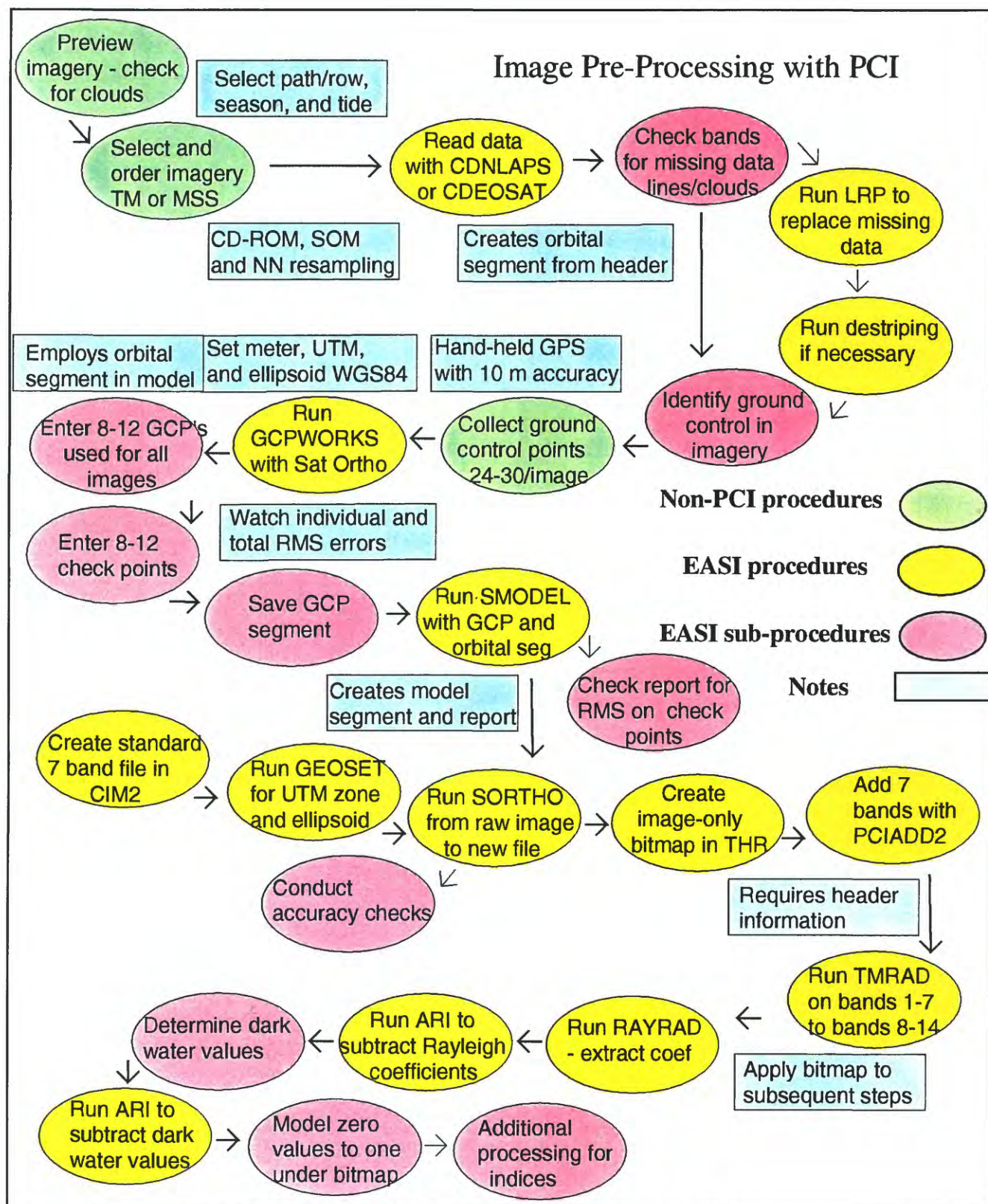


Plate 4. Flow chart for image pre-processing with PCI, Inc.

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United States
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Forest Service

Gen. Tech.
Report WO-68

September 2005



Terrestrial Ecological Unit Inventory Technical Guide: Landscape and Land Unit Scales





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Department of
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Report W0-68

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Terrestrial Ecological Unit Inventory Technical Guide: Landscape and Land Unit Scales



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Cover Photo: Landsat Thematic Mapper imagery (30 m) and digital orthophoto quadrangles were fused together to produce this high-resolution image of the Beartooth Mountains on the Custer National Forest near Red Lodge, Montana. Rock Creek drainage is in the center and Red Lodge Ski Area to the right. This perspective view was generated by draping the merged imagery over a digital elevation model (10 m).

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Foreword

This technical guide provides instruction and information on the development of the Terrestrial Ecological Unit Inventory (TEUI) for lands administered by the U.S. Department of Agriculture Forest Service. It provides a set of national standards, suggested methodologies, and a list of criteria for defining, describing, and classifying terrestrial ecological units and types.

The *TEUI Technical Guide* provides the standard for development of terrestrial ecological units at the landtype association, landtype, and landtype phase levels of the National Hierarchy Framework of Ecological Units (Cleland et al. 1997).

The *TEUI Technical Guide* is not intended to replace the correlation process of the National Cooperative Soil Survey (NCSS). It relies on the NCSS process to ensure quality control of all TEUI products, particularly soils data.

The following references may be useful in development of the TEUI and supplement the direction contained in this technical guide:

- Draft Forest Service Manual 1940, *Resource Inventories and Monitoring and Ecosystem Assessments (in press)*.
- Draft Forest Service Handbook 1909.xx, *Resource Inventories and Monitoring and Ecosystem Assessments (in press)*.
- *National Soil Survey Handbook* (USDA NRCS 2003b).
- *Soil Survey Manual* (USDA NRCS Revised 1993).
- *Keys to Soil Taxonomy* (USDA NRCS 2003a).
- *National Forestry Handbook* (USDA NRCS 2004).
- *National Forestry Manual* (USDA NRCS 2000).
- *Field Book for Describing and Sampling Soils*, Ver. 2.0 (Schoeneberger et al. 2002).

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Chapter 1. TEUI Protocol Framework

1.1 Overview and Purpose

The purpose of this technical guide is to provide specific direction and guidance for conducting Terrestrial Ecological Unit Inventory (TEUI) at the landscape and land-unit scales. TEUI seeks to classify ecological types and map terrestrial ecological units (TEUs) to a consistent standard throughout National Forest System lands. The objectives, policies, and responsibilities for TEUI are contained in Forest Service Manual (FSM) 1940. U.S. Department of Agriculture (USDA) Forest Service policy dictates that ecological units be used in natural resource inventory, monitoring, and evaluation; in land management planning; and in making predictions and interpretations for management of National Forest System lands.

This guide is one among several recently established by the new FSM 1940 and Forest Service Handbook (FSH) 1900 series direction. This direction consolidates many outdated and redundant handbooks scattered throughout the directive system for all program areas responsible for conducting inventory and monitoring activities.

The new chapter in FSM 1940, “*Resource Inventories and Monitoring*,” establishes the management framework for all integrated inventories. It codifies the broad authorities, management objectives (results), policies, responsibilities (duties and delegations), and standards that govern how the agency designs, develops, tests, conducts, reports, uses, and evaluates resource inventory systems and data. The chapter requires field units to use the various technical guides intended to provide detailed instructions for conducting inventory and monitoring work (Connolly 2001).

The new FSH 1900 series, “*Resource Inventories and Monitoring*,” covers the data standards, procedures, practices, and other protocols that govern all our resource inventory and monitoring efforts. The handbook consolidates relevant inventory and monitoring direction from existing handbooks. It does not contain detailed instructions, templates, or other information contained in technical guides (Connolly 2001).

Figure 1.1 provides a graphical sketch of the relationship of manual and handbook direction to technical guides. The technical guides contain the detailed instructions and procedures on how to conduct specific inventory and monitoring activities. They are designed to be flexible so that updates and improvements can be made annually, or as needed based on best available science. All technical guides share the same overall format and outline as identified in the FSH 1900 series.

This guide contains three chapters and several appendixes on the following subjects:

- Chapter 1 provides an overview of TEUI concepts including background information, key concepts, and roles and responsibilities.
- Chapter 2 provides detailed information on conducting TEUI at the landtype association (LTA) level.
- Chapter 3 provides detailed instruction on conducting TEUI at the landtype (LT) and landtype phase (LTP) levels.
- Appendixes contain various field forms and detailed descriptions of data elements used in the protocols. Also included are a list of citations, a glossary, and other pertinent information.

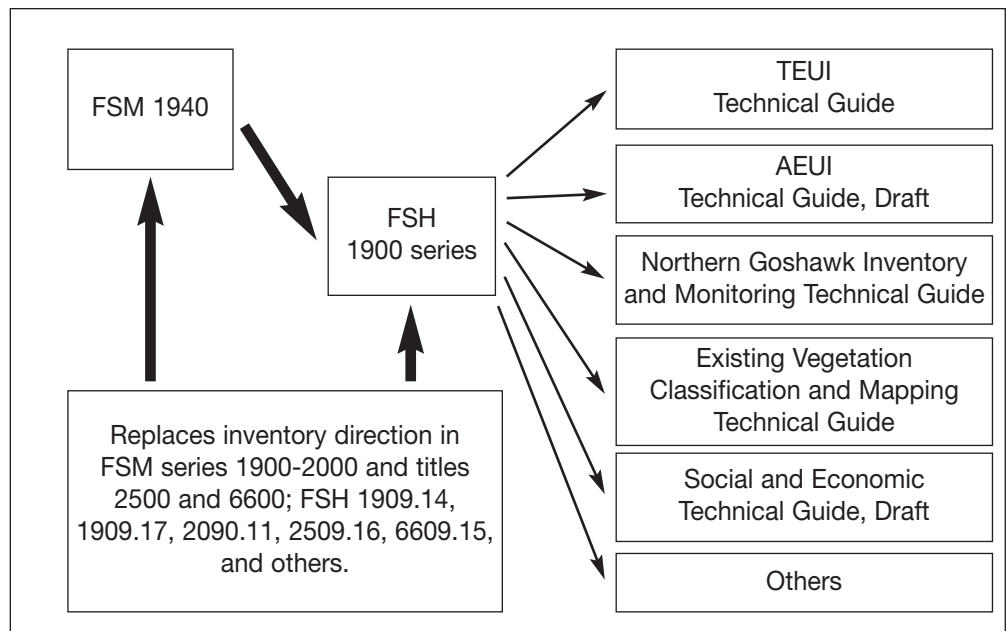


Figure 1.1. Relationship of Forest Service manual and handbook direction to technical guides.

1.2 Background and Business Needs

1.2.1 Background

Ecological classification and mapping systems are designed to stratify landscapes at multiple scales so we can understand the arrangement, pattern, and capabilities of ecosystems. With this knowledge, we strive to make informed decisions about the management of public lands throughout the United States. Wertz and Arnold (1972) developed one of the first such systems in the Northern Rocky Mountain region in 1968. Their Land Systems Inventory (LSI) provided a method by which land with similar hazards and capabilities could be inventoried or categorized into repeating map units. A system

such as LSI was especially necessary after the National Environmental Policy Act of 1970 required an inventory of all forest lands related to the identified roadless areas. The Cascade Ranger District of the Boise National Forest was the first to implement LSI in 1968; by 1980, many LSIs had been completed throughout the region. In their 1972 publication *Land Systems Inventory*, Wertz and Arnold also introduced a hierarchy of ecological units including sections, subsections, LTAs, and LTs.

This hierarchy was later refined by Cleland et al. (1997) to become known as “The National Hierarchy of Ecological Units.” The Province of British Columbia (2001) developed a similar hierarchy land classification system in 1985 called the Ecoregion Classification System. At the detailed ecosystem level, ecosystem units are mapped using the Terrestrial Ecosystem Mapping (TEM) methodology. The TEM methodology stratifies the landscape into map units according to a combination of ecological features, primarily climate, physiography, surficial material, bedrock geology, soil, and vegetation (Province of British Columbia 1998). These concepts and methods of ecological mapping form the basis for the TEUI at the land unit and landscape scales. This technical guide borrows from these original principles and concepts, refining them yet again to meet more specific guidelines and data standards.

1.2.2 Business Needs

TEUI, in combination with other standard resource layers, provides the basis for selecting suitable areas for major kinds of land-use activities, identifying areas that need more intensive investigation, evaluating various land management alternatives, and predicting the effects of a given activity on resource health or condition. TEUI maps, data, descriptions, and management interpretations provide basic land capability information necessary for ecological assessments; project planning; watershed and landscape analysis; forest plan revisions; and implementation and monitoring of forest plans. The information provided can be used for activities such as assessing resource conditions, conducting environmental analyses, defining and establishing desired conditions, and managing and monitoring natural resources.

1.3 Key Concepts

To implement ecosystem management, we need basic information about the nature and distribution of ecosystems (Cleland et al. 1997). An ecosystem consists of a community of organisms and their physical environment, which together form an interacting system or unit, and occupy an identifiable space (Lincoln et al. 1998, SRM 1998). TEUI includes classification and mapping of ecosystems. Ecological classification provides basic information about the nature of ecosystems and mapping depicts the distribution of ecosystems.

TEUI endeavors to classify and map ecosystems based on biotic and abiotic factors that comprise the physical environment. These factors are referred to as landscape elements and are illustrated in figure 1.2, which diagrams the influence of landscape elements on each other. The diagram is arranged in four levels. The elements at the top (bedrock geology, regional climate, and geomorphic processes) are largely independent variables (Daubenmire 1978). The elements in each level of the diagram are influenced by the elements in the levels above; the farther apart the levels, the less direct the influence.

If a close relationship is established between independent and dependent variables, then the independent variables may be useful predictors of the dependent variables (Webster and Oliver 1990). In figure 1.2, the variables of bedrock, geomorphic process, and regional climate do not typically have a close enough relationship with soil and PNV to be useful predictors (as illustrated in figure 1.2 by their distance from the soil and PNV elements). Landform, surficial geology, local climate, and morphometry more directly influence soil and PNV development, and thus are typically better proxy indicators of soil and vegetation, and consequently ecological types. The relative importance of these factors varies across ecoregions and may vary within an inventory area. TEUI requires determining and documenting the importance and relationship of these factors.

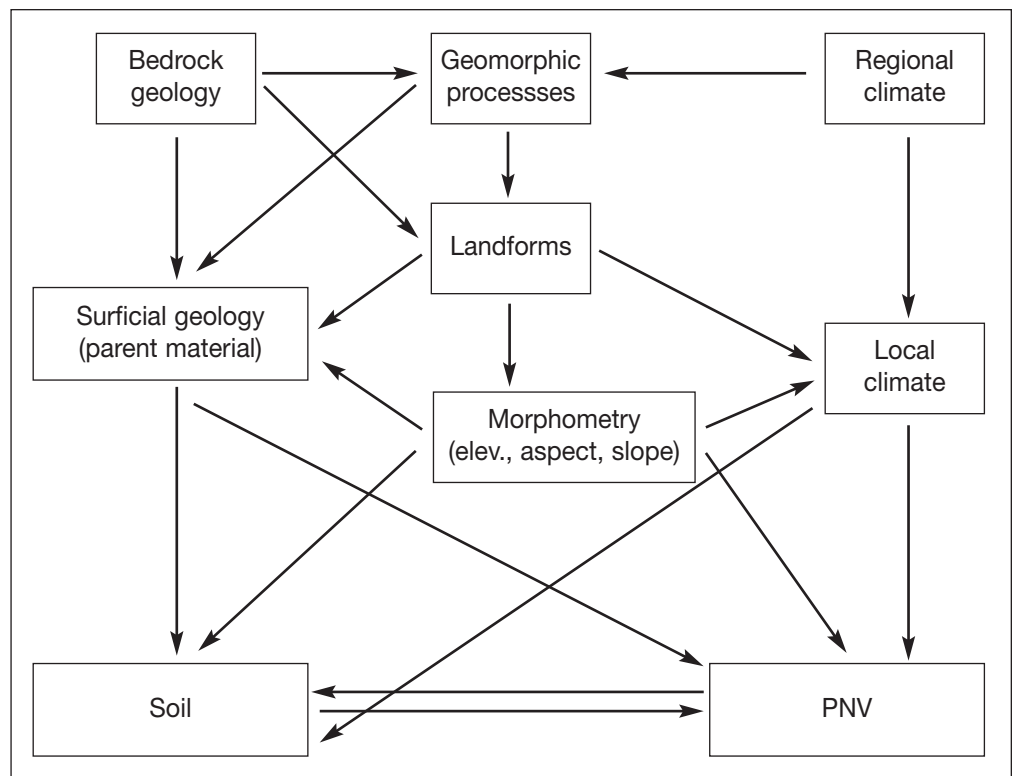


Figure 1.2. General relationships of landscape elements.

1.3.1 The National Hierarchy Framework of Ecological Units

The National Hierarchy Framework of Ecological Units (hereafter referred to as the National Hierarchy) is a land classification hierarchy that provides a framework for developing TEUs at continental to local scales. Since this is a nested hierarchy, finer-level classes are descendants of higher-level classes and have their characteristics. The hierarchy framework is organized into four “planning and analysis” scales, which are described by eight levels of ecological units. The levels in the National Hierarchy at each planning scale are described below (Cleland et al. 1997) and represented in table 1.1. This technical guide, however, only focuses on the landscape and land-unit scales. Hence, we will not discuss standards and methods for ecoregion and subregion ecological inventories.

Ecoregion

The ecoregion scale comprises three levels of ecological units (domain, division, and province), which are recognized by differences in global, continental, and national climatic regimes and gross physiography.

Subregion

The subregion scale comprises two levels of ecological units (section and subsection) characterized by combinations of regional climate, geomorphic process, topography, and stratigraphy.

Landscape

The landscape scale contains the LTA level. The LTA depicts broad patterns of soil families or subgroups, potential natural vegetation (PNV) series, and, on occasion, show successional dynamics. Top-down delineation uses other abiotic factors in addition to, or in lieu of, soils and PNV. These factors may include dominant geomorphic process, landforms, surficial and near-surface geologic formations, and local climatic effects. The relative utility of these elements for delineating the LTA varies with ecological province. The LTA can also be designed and delineated bottom-up by aggregating the LT based on the above factors.

Land Unit

The land-unit scale comprises two levels of ecological units (LT and LTP) characterized by repeating patterns of one or more ecological types. LTs and LTPs represent the largest scale (land unit) and most detailed levels of the National Hierarchy.

LTs are subdivisions of LTAs. They can be used to refine top-down LTAs in which they occur based on comparison of their component ecological types and incorporation of their finer scale delineations. Composition of LTs can be summarized to describe the composition of LTAs.

Table 1.1. *Suggested level of detail used for classification and mapping at the landscape and land-unit levels of the National Hierarchy (modified from Cleland et al. 1997).*

Planning and analysis scale	Ecological unit levels	Geology	Geomorphology	Soil	Potential natural vegetation
Landscape	Landtype association (LTA)	Primary lithology or groups of secondary lithology	Geomorphic process and subprocess types	Great group and subgroup	Series and subseries
Land unit	Landtype (LT)	Secondary lithology	Landforms, element landforms, and morphometry	Subgroups, families, and series	Subseries and plant associations
	Landtype phase (LTP)	Secondary lithology	Landforms, element landforms, and morphometry	Series and phases of series	Plant associations and plant association phases

1.3.2 Classification, Map Unit Design, and Map Unit Delineation

The purpose of TEUI is to classify ecosystem types and map land areas with similar capabilities and potentials for management (Cleland et al. 1997). Because of their management significance, soils and vegetation, including historic and potential, form the primary criteria for classifying ecosystems and designing ecological map units at finer scales. Other landscape elements are driving factors in the development of soils and vegetation and are used primarily as delineators of ecological units at these scales. In areas where geologic hazards limit management options, bedrock and/or surficial geology may become classification and design criteria.

Relationship of Classification and Mapping

Soil scientists and vegetation ecologists have long sought to have their respective products serve as the basis of fine-level units (Nowacki 2003).

Soil science has emphasized soil classification and mappings of soil components on the landscape, while vegetation ecology has focused on classification using multivariate methods. TEUI is an attempt to combine the strengths of these two disciplines and more fully integrate climatic and geologic factors to more effectively classify and map ecosystems.

Multivariate analysis is also helpful in developing ecological classifications when relationships between PNV, existing vegetation, soils, and other landscape elements are obscured by other ecological or biological phenomena. These may include climate change and vegetation inertia (Collinson 1988, Pielou 1991), changes in a species indicator value because of genetic variation and geographic changes in associated species (Mueller-Dombois and Ellenberg 1974), and differing rates of soil and vegetation development following large geologic or geomorphic events (Pielou 1991). Multivariate analysis can also focus on specific soil properties instead of soil taxonomy, which still has many inherent agricultural biases (USDA Soil Conservation Service 1994).

The above issues make multivariate analysis essential for ecological classification at the LT and LTP levels. It can also be useful in developing ecological classifications for bottom-up LTAs.

Cleland et al. (1997) indicate that at coarse scales ecosystem landscape elements can be analyzed and mapped separately, and then combined using the Geographic Information System (GIS) to produce ecological unit maps. At fine scales, landscape elements are evaluated simultaneously to classify ecological types, which are then used to design ecological map units. This process is used because of the importance of biotic factors, the level of discernible detail, the number of landscape elements, and the number of variables used to characterize elements progressively increase at finer scales (Cleland et al. 1997).

Map Unit Delineation

PNV and soils share an important property in relation to mapping. Neither can generally be seen on aerial photos, satellite imagery, or digital elevation maps. Soil cannot be seen because it is underground. PNV often cannot be seen because existing vegetation is usually not at potential because of natural or human disturbances. Moreover, it can be difficult to identify plant species other than trees on photos or imagery.

Because soils and PNV cannot be delineated directly, we rely on other landscape elements, as surrogates, such as landform, morphometry, and surficial geology in combination with existing vegetation to map them. Those elements serve as map unit delineation criteria, but not necessarily as map unit design criteria. Map unit design involves deciding which elements we want to depict spatially and how detailed, both thematically and spatially, that depiction will be. Map unit delineation criteria are selected to implement the map unit design.

Ecological Classification

An ecological type is a category of land with a distinctive combination of landscape elements, differing from other types in the kind and amount of vegetation it can produce and in its ability to respond to management actions and natural disturbances. The ecological classification process is used to define, quantify, and document relationships among abiotic landscape elements, existing vegetation types, and PNV types. These relationships are used to develop a classification of ecological types. Different combinations of landscape elements that do not differ in PNV, successional dynamics, or management capabilities do not always constitute separate ecological types.

Traditionally, landscape elements have been classified separately. Some classifications deal with qualitative attributes, while others emphasize quantitative attributes. Classification of ecological types requires integration of numerous qualitative and quantitative attributes. The methods of multivariate analysis are best suited for this task. However, use of an interdisciplinary team to select analysis variables is required to ensure the process is objective.

Gauch (1982) states that, “multivariate analysis is the branch of mathematics that deals with the examination of numerous variables simultaneously. The need for multivariate analysis arises whenever more than one characteristic is measured on a number of individuals, and relationships among the characteristics make it necessary for them to be studied simultaneously. The purpose of multivariate analysis is to treat multivariate data as a whole, summarizing the data and revealing their structure.” Put another way, multivariate analysis is used “to make large, unwieldy masses of multivariate field data comprehensible and interpretable” (Pielou 1984).

In summary, classification of ecological types organizes knowledge about relationships between ecosystem elements and the significance of those elements and relationships for land management. This knowledge can be used to design ecological map units that “identify land . . . areas at different levels of resolution that have similar capabilities and potentials for management” (Cleland et al. 1997). Ecological classification can help determine both the thematic and spatial resolution needed to address management issues. Once the detail level of the map units has been determined, the relationships documented in the ecological classification can be used to select delineation criteria for those map units. Thus, classification of ecological types can greatly improve both map unit design and map unit delineation.

1.3.3 Geology

Geology is an important element of TEUI because it is one of the abiotic elements and the foundation for the biotic elements. Geology greatly influences soil formation, provides nutrients for plant uptake, and often affects water transport and availability. Geologic information is essential for predicting the occurrences and distributions of ecological types. The geology element of TEUI should be documented during the mapping and classification procedures. Initial data should be collected as part of the literature search step during the initial steps of TEUI.

The primary sources for existing geologic data and maps are the U.S. Geological Survey (USGS) and State geological surveys. Local university geology departments may also have an archive of unpublished mapping for the inventory area.

Bedrock and Surficial Geology Classification and Description

Both bedrock and surficial geology are described for each ecological type. Bedrock data collection will conform to the standards described in *Geology in the Field* (Compton 1985), sections 1-4, 3-1, 3-2, 3-5, 3-6, 5-1, 5-2, and 5-3 with additional guidance from chapters 6 and 7. Surficial materials data collection will conform to the *Soil Survey Manual* (1993, 73–80).

Describe and classify bedrock geology by lithology (i.e., rock class or name) using *Classification of Rocks* (Travis 1955). In addition, if the bedrock's stratigraphy (i.e., formation or member, and geologic age) is known or suspected to correlate with ecosystem character and function, it must also be determined.

Lithology and Surficial Materials

TEUI uses primary and secondary lithology as defining elements. Primary lithology is the class to which a rock belongs: igneous extrusive, igneous intrusive, sedimentary, or metamorphic. Secondary lithology is the specific rock type (e.g., basalt, granite, sandstone, gneiss); each implies one and only one primary lithology. If TEUI is composed of many rock types (e.g., a mix of basalt, andesite, and tuff), it may be best to classify at the primary lithology level (e.g., igneous extrusive).

Bedrock characteristics (i.e., texture, weathering, chemistry, fracture interval, competence, structure type, azimuth, and inclination) will be described for those integrated plots where bedrock is encountered and for “stops” on geologic traverses. See appendix D, Geology and Geomorphology Form.

Surficial materials are in the “unconsolidated” primary lithology class. They are defined as nonlithified deposits lying on bedrock or occurring on or near the Earth’s surface. Surficial materials are characterized by their depositional environment (“kind”) and the rock type (secondary lithology) from which they came (“origin”). Some examples: glacial till from granite, alluvium from sedimentary rocks, landslide deposit from limestone, and volcanic ash of basalt composition. Another important factor in characterization is the material’s texture (e.g., bouldery, sandy, clayey). Texture terms are applied during the integrated-plot description. Multiple surficial materials, if present, should be noted (e.g., loess, over colluvium, over residuum). See appendix D.

Stratigraphy

According to Salvador (1994), “Stratigraphy is the description of all rock bodies forming the Earth’s crust, and their organization into distinctive, useful, mappable units based on their inherent properties or attributes. It includes the classification, naming, and correlation of these units to establish their relationship in space and succession in time.” At the land unit scale, this description usually consists of a geologic age and a stratigraphic-unit name followed by a specific rock type, or by the term “formation” if the unit contains more than one rock type. Formations may be divided into “members” or aggregated into a “group.”

When a formal stratigraphic map unit exists, it may be used to help describe a TEU. The primary sources for stratigraphy are published geologic maps that conform to the USGS Code of Stratigraphic Nomenclature. Refer to the legend and geologic map unit descriptions to identify the geologic time units and formations in an area.

Stratigraphic names, descriptions, ages, and references should be included in the TEUI manuscript, and incorporated in regional code tables of the corporate database. It is important to note that variations in lithology and thicknesses of specific stratigraphic units may exist within a survey area, or in regional settings. Therefore, one description of a particular lithology may not represent those strata across a survey area.

1.3.4 Geomorphology

The primary reference and data standards for the geomorphology components used in the development of TEUI are contained in the USDA Forest Service publication *A Geomorphic Classification System, version 1.4* (Haskins et al. 1998).

Geomorphology, as described in the above publication, includes three primary components:

- 1. Geomorphic Process.** The dominant internal or external geologic force that has interacted with the existing geologic structural framework to shape the Earth’s surface.

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2. **Landform.** “Any physical feature of the Earth’s surface, having a characteristic, recognizable shape and produced by natural causes” (Bates and Jackson 1980, 1987).
 3. **Morphometry.** “The measurement and mathematical analysis of the configuration of the Earth’s surface and of the shape and dimensions of landforms” (Bates and Jackson 1980, 1987).

Landform, in this classification hierarchy, is directly linked to geomorphic process. Process is implied by selection of a particular landform. A landform choice, therefore, carries with it the process that was responsible for its development (reflected in the list of valid values found in appendix D).

Morphometry is used to quantify the land surface and describe further the variability in landforms. It can be used to predict changes in slope hydrology, soils, and plant communities. The following measurements or characterizations are elements of morphometry: relief, elevation, aspect, slope gradient, slope position, slope shape, slope complexity, landform width, dissection frequency, dissection depth, drainage pattern, and drainage density. Not all parameters are applicable at all levels. In addition, these parameters can be expressed as ranges of values, averages, or means. See appendix D for definitions.

Geomorphic Process

The appearance of a landscape is a result of the geomorphic processes that have shaped it in the past, and that continue to shape it today. The history of a landscape may be complex, with many geomorphic processes overprinting one another. This overprinting occurs when two or more dissimilar geomorphic processes have operated on an area at different times because of the influences of climatic change and/or tectonics. Such complexity is documented using geomorphic generation, which identifies the status of all the processes that operated on any given location.

The Great Sand Dunes National Monument in southern Colorado represents an easily understood example of landscape (and landform) correlation with generations of geomorphic processes. The sand dunes occupy a portion of the still-active Rio Grande rift along the margin of the San Luis Valley, which was formed by tectonic and fluvial geomorphic processes. The present day landscape, however, is dominated by eolian (dune-forming) processes.

Landforms may be characteristic of a combination of geomorphic processes; for example, talus forms by weathering, erosion, and downslope movement. Landforms also may be characteristic of more than one geomorphic process. Canyons form through fluvial processes but also are typically characterized by mass wasting (landslides and rock falls).

Determination of the geomorphic generation of each landform will identify the relationship between the landforms and the status of the process, which formed or continues to form the landforms. The appropriate terms used to identify geomorphic generation are active, dormant, and relict.

Appendix D lists the valid values to be used in TEUI classification and characterization.

Use in Mapping

The *National Soil Survey Handbook* (NSSH), part 627.02, (USDA NRCS 2003b) describes the delineation of major landform units and landform components as a preliminary procedure in field mapping. The next step is the identification, description, and classification of the kinds of soils associated with the landform components. The *NSSH* (USDA NRCS 2003b) states that because “soil patterns commonly coincide with major landforms and individual soils with individual landform components, the objective of identifying and understanding the relationship between landforms and soils is to enable a soil scientist to predict the kind of soil on the landform.”

The relatively larger scale of the landform component is often useful for stratifying the landscape into segments having similar climate, physiography, geomorphology, and parent materials from which further predictable delineations of geology, soils, and PNV can be made.

Application

In complex landscapes, the landform often serves as the primary delineation criterion for identifying TEUs. Landforms and morphometry are important in defining the way water and materials translocate over and through watersheds. Landforms and morphometry are important for influencing watershed storm precipitation response, sediment routing, erosion rates and volumes, groundwater and materials storage and recharge, and duration and intensity of solar radiation.

Landforms and their associated geology also enable us uniformly and consistently to predict and interpret properties such as hydrologic behavior, slope stability, and sediment storage, for assessing land-use potential, capabilities, limitations, and hazards.

Geomorphology often changes where natural patterns of the landscape change. Consideration of whether a change is significant and should be delineated separately from surrounding landforms depends on many factors. For example, changes in morphometry may signal a significant coincidental change in geomorphology.

An understanding of geomorphic processes and their resultant landforms provides the mapper the ability to predict and extrapolate TEUI element distributions.

1.3.5 Soil

The soil element of an ecological type must be described, classified, and characterized according to the standards defined in the *Soil Survey Manual* (USDA NRCS 1993) and the *NSSH* (USDA NRCS 2003b).

Characterization

Document soil properties (both chemical and physical) that are the basis for classification. Include soil properties that significantly influence ecosystem character and function. Describe and establish the range of significant soil properties. It may be desirable to phase those soil properties that influence the character or interpretation of each component.

Characterization should be based on observed ranges from all samples collected for that ecological type. Characteristics not observed but estimated or derived (such as available waterholding capacity) should be designated as such and methods documented.

Soil Classification

A national soil classification system provides the definitions and nomenclature necessary for classifying soil. The official soil series descriptions provide definitions, procedures, and nomenclature for establishing soil series. See the *NSSH* (USDA NRCS 2003b), Part 614. Classify the soils according to the most recent edition of *Keys to Soil Taxonomy* (USDA NRCS 2003a). Classify soils at the soil series or family level of soil taxonomy. For highly variable areas, such as riparian areas, disturbed areas, or steep slopes, classify soils at a higher level of soil taxonomy.

Soil classification is used to provide the following elements:

- A connotative naming system that enables those users familiar with the nomenclature to recognize selected properties of soils.
- A means for understanding the relationships among soils in a given area and among different areas.
- A means of communicating concepts of soil and soil properties.
- A means of projecting experience with soils from one area to another.
- Names that can be used as reference terms to identify map unit components.

Application

The information assembled about soils in the TEUI map unit descriptions and associated data tables are used to predict or estimate the potentials and limitations of soils for many specific uses. The predictions serve as a basis for judgment about land use and management for areas ranging from small tracts to regions of several million acres. These estimations must be evaluated along with economic, social, and environmental considerations before recommendations for land use and management become valid. Many standard and locally defined interpretations are available from the TEUI (see chapter 3, tables 3.6 and 3.7).

1.3.6 Vegetation

The vegetation element of an ecological type must be described, classified, and characterized. Historic vegetation, disturbance regimes, existing vegetation, PNV, and state and transition models are typically documented for each ecological type. Guidelines for classifying and mapping ExistingVegetation are described the *Existing Vegetation Classification and Mapping Technical Guide* (Brohman and Bryant 2005).

Use in Mapping

Existing vegetation is often used to delineate ecological map units, however, care must be taken, as existing vegetation does not always reflect historic or potential vegetation. Historic vegetation, disturbance regimes, and potential vegetation are typically not mapped because it cannot be readily identified on aerial photography. Rather, the relationship between existing vegetation and association of landscape elements are used to predict these important vegetation characteristics. The text that follows gives guidelines for determining historic vegetation, disturbance regimes, PNV, and developing state and transition models.

Historic Vegetation and Disturbance Regimes

As primary producers of living tissue (biomass), vegetation is a fundamental component of ecosystems. Human and animal existence and welfare are ultimately derived from vegetation. Humans have manipulated vegetation over the course of thousands of years for food and fiber production, and continue to do so. Since resource management largely involves vegetation alteration in one-way or another, successful land stewardship is predicated on understanding various aspects of vegetation: its composition, structure, dynamics (successional changes), and potential.

The Earth's vegetation is a complex patchwork, reflecting an amalgamation of abiotic and biotic interrelations across time and space. Vegetation communities are a result of

interaction within and among (1) biota (species evolution, adaptation, gene flow, physiological traits, competitive abilities, and resiliency; herbivory), (2) physical environments (e.g., climate, topography, geology, soils), and (3) disturbances (wind, fire, insects, disease, etc.) including human activities. The inherent complexities of vegetation dynamics (e.g., how vegetation originated in an area and how it might change in the future) require several lines of inquiry for adequate understanding. These core components include historic vegetation, disturbance regimes, existing (current) vegetation, and PNV. All are important for understanding vegetation patterns and processes at various spatial and temporal scales and are essential for vegetation management, particularly for preparing desired future conditions, silvicultural prescriptions, and ecological restoration plans.

Historic Vegetation

Vegetation communities are as much a product of past events as they are contemporary processes; thus, ecologists who overlook the past are likely to misinterpret the present (Whitney 1994, 4). Indeed, “stepping back to look forward” is a rationale way of understanding the historical milieu that has led to current vegetative conditions (Foster 1998). Not only do stand histories help explain the origin of current forest conditions (Carvell 1986), but knowledge of past or historic vegetation (compositions, structures, dynamics) proves crucial in the restoration of ecological systems that have been negatively altered by human or natural disturbances. Recent compilations by Fulé et al. (1997), Balee (1998), Swetnam et al. (1999), and Egan and Howell (2001) provide overarching principals of historical ecology and its relevance to resource management and ecosystem restoration.

Trends in historic vegetation can be displayed over long time periods spanning thousands of years. The relevance of ecological data diminishes the further back in time one goes due to increasing differences in ecological conditions (e.g., climate, disturbance regimes, species distributions). Thus, a more narrow, ecologically relevant time period is sought in order to capture past vegetation conditions for land management objectives (e.g., document native communities, assess historic vegetation changes; set ecological restoration goals). A 500-year period immediately preceding European settlement is a reasonable time period for reference conditions. By focusing on vegetation characteristics (composition, structure, and dynamics) of this time period, we document those conditions immediately prior to major landscape changes wrought by European settlement (Whitney 1994). Historic vegetation can be reconstructed using a variety of approaches, either singly or, more robustly, in combination (Noss 1985; Whitney 1994, chapter 2).

- 1. Historical Accounts and Notes.** Written observations (chronicles, journals, diaries, newspapers, etc.) from early explorers, surveyors, and settlers serve as fundamental descriptions of past vegetation. Examples of early descriptive accounts for interpreting original forests include Bromley (1935, southern New England) and Nelson (1957, Georgia).

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- 2. Early Land Surveys.** This probably represents the best and most frequently used information source for reconstructing pre-European vegetation, especially in forested areas. There are two principal types of land surveys conducted in the United States.
- a. The metes and bounds system was the primary land survey method in Colonial America. This system led to indiscriminate and irregular divisions of the land, often shaped in deference to the owner desires, using trees, rock outcrops, post and stone monuments, river and stream courses, and ridgelines as boundary markers (Ernst 1979, Abrams and Ruffner 1995, Black and Abrams 2001a). Representative excerpts from early land surveys can be found in Spurr (1951). Because it was an unintentional vegetation survey, a number of biases and errors may occur in the tree data (Whitney 1994, Black and Abrams 2001a). Witness-tree data should be used cautiously because of known biases of corner tree selection, including economic value, ease of inscription, size, vigor, longevity, and age. Where it exists, other ancillary data, such as trees marked for road surveys, can be used to assess for bias (Whitney 1994, Burgi and Russell 2000). Often pre-European forest composition is reconstructed using simple tallies of corner trees. These data, in turn, can be compared to contemporary vegetation surveys to depict historic vegetation changes (Nowacki and Abrams 1992, Abrams and Ruffner 1995) or correlated with soil-site factors to document species-environmental relations (Black and Abrams 2001a). The tree data are not as conducive to statistical analysis as later systematic (rectangular) land surveys and thus are less reliable in quantifying pre-European settlement forest conditions.
 - b. Through the Land Ordinance of 1785, Congress established the rectangular system for surveying public lands (Stewart 1935, Ernst 1979, White 1991). Designated the General Land Office (GLO) Survey, the majority of the United States was surveyed via this system, except for the original 13 States, Kentucky, Tennessee, Vermont, and Texas (Ernst 1979). This land survey method consists of a nested grid consisting of townships (36-mile squares), sections (36-mile squares; 360 acres), and quarter sections (9-mile squares; 90 acres). Surveyors were instructed to blaze and inscribe two to four “bearing” or “witness” trees (one per compass quadrant) at quarter-section corners. “Line” trees encountered between corners along survey lines were also marked. Pertinent ecological data recorded from these trees, known collectively as “witness trees,” include species, diameter, and distance to the survey corner.

The systematic collection of witness-tree data fosters the use of statistical analyses for forest reconstruction and the detection of possible surveyor biases. The proper

use and limitations of witness-tree data are thoroughly summarized by Hutchinson (1988), Schulte and Mladenoff (2001), and Whitney and DeCant (2001). Statistical procedures used to assess for surveyor bias and variability have been proposed by Bourdo (1956), Delcourt and Delcourt (1974), and Manies et al. (2001). Due to landscape heterogeneity and data-point-density limitations, caution needs to be employed when using GLO survey data to recreate pre-European settlement vegetation at fine scales (i.e., less than several townships or areas less than 10^4 ha) (Manies and Mladenoff 2000). GLO survey data are best compiled to form vegetation units of a quarter mile (160 acres) to 1 mi² (640 acres) (Delcourt and Decourt 1996). This unit-size is reasonable for assessing post-European settlement changes at the landscape scale.

GLO survey data often have been extrapolated spatially onto the landscape by coupling it to soil surveys forming discrete forest type maps (see Shanks 1953, Lindsey et al. 1965, Crankshaw et al. 1965, Siccama 1971). Substantial improvements in spatially projecting GLO survey data have been made by employing fuzzy logic to produce superior forest type classifications and maps (Brown 1998). Qualitative GLO survey data provided by written descriptions of vegetation (and disturbance patches) along transects between corners can be used to collaborate quantitative results from bearing-tree data (Nowacki et al. 1990, table 7).

GLO Survey provides forest structure data to reconstruct the spatial arrangement and size-class distribution of trees, although again some sampling bias may exist (Bourdo 1956). Statewide maps of pre-European settlement vegetation composition exist for Indiana (Lindsey et al. 1965), Michigan (Veatch 1959), Minnesota (Marschner 1974), Ohio (Sears 1925, Gordon 1969), and Wisconsin (Finley 1976). Digital pre-European settlement maps for the Upper Great Lakes States are available on the Internet (<http://www.ncrs.fs.fed.us/gla/>). By integrating past survey data with land-use histories and current inventories, important shifts in vegetation composition and structure can be documented and explained (Whitney 1990, White and Mladenoff 1994, Abrams and Ruffner 1995). Silbernagel, Chen, et al. (1997) and Silbernagel, Martin, et al. (1997) have done a particularly superb job of integrating pre- and post-European settlement vegetation and land-use data with a spatial hierarchy to describe historic vegetation changes within a landscape context.

3. **Photography.** Nothing is more self-evident than providing visible portrayals of the past. As the old adage goes: “A picture is worth a thousand words.” Through repeat photography, vegetation changes over time can be sequentially documented and catalogued (Progulske 1974, Gruell 1983, Gary and Currie 1977, Reid et al. 1980, Strickler and Hall 1980, Skovlin and Thomas 1995).

4. Statistical Series.

- a. Land-use data (Marks 1942, Brender and Merrick 1950, Moore and Witham 1996, McWilliams et al. 1997).
- b. Timber, agricultural, and fuel accounting books (Reynolds and Pierson 1942, Dinsdale 1965, Gates 1976, Johnson and Gerland 1996, Simard and Bouchard 1996).

5. **Studies of Primary, Original, or Old-Growth Forests.** In certain areas where disturbance regimes are equivalent to that of the past, present-day vegetation compositions and structures may closely resemble pre-European settlement conditions. Examples of this direct method include boreal forests of Minnesota (Heinselman 1973), conifer-northern hardwoods of Upper Michigan (Frelich and Lorimer 1991), and spruce-hemlock forests of southeast Alaska (Nowacki and Kramer 1998). See Nowacki and Trianosky (1993) for a listing of published old-growth manuscripts covering the Eastern United States.
6. **Archaeological Evidence.** Archaeological sites can provide an ethnobotanical record of surrounding local vegetation (Delcourt et al. 1998). There are known restrictions since materials reflect human collections of plants used for food and medicinal purposes. Tankersley et al. (1996) provides a good example of using archaeological information to determine a segment of prehistoric vegetation.
7. **Paleoecological Data.** This data provides long-term vegetation trends, sometimes spanning tens of thousands of years, and includes pollen, macrofossil, and charcoal/sediment analyses (Wright 1974, Clark 1990, Foster and Zebrek 1993, Motzkin et al. 1993, Russell et al. 1993, Rhodes and Davis 1995, Baker et al. 1996, Clark and Royall 1996, Kearsley and Jackson 1997, Delcourt et al. 1998, and Pitkanen 2000) and physical evidence of trees buried *in situ* (Pregitzer et al. 2000).
8. **Soil Phytoliths.** Phytoliths are “jewels of the plants world,” representing hydrated silica imprints of plant cells (Fredlund 2001). These microscopic fossils can be used as a means to reconstruct past vegetation (Birkeland 1974). Due to differences in silica content (grasses are high in silica content whereas most tree leaves are low), some plants may be over represented while others under represented (Fredlund 2001). Due to their enhanced ability of silica production, grasslands are the best biomes for using this line of evidence.

9. Traditional Ecological Knowledge/Native Oral Histories. Although downplayed or overlooked in the past, the application of traditional ecological knowledge for understanding past conditions is rapidly gaining momentum (Kimmerer 2000). A full issue of *Ecological Applications* (October 2000) is dedicated to this line of research (Ford and Martinez 2000).

Disturbance Regimes

The role of natural disturbance in shaping forest composition, structure and function is recognized globally (Pickett and White 1985, Attiwill 1994, Reice 2001). Many forest characteristics are better understood as responses to different kinds of disturbances rather than the result of successional change towards equilibrium (Brubaker 1987). As such, disturbance ecology is extremely relevant to resource management, providing an important conceptual framework for understanding our environment (Engstrom et al. 1999). Natural disturbance alter ecosystem characteristics that matter to managers, including species composition and structure, biodiversity, resource productivity, and incidence of disease. Managers themselves respond to and introduce disturbances all the time. Since disturbances have so profoundly influenced the biotic portion of ecosystems (e.g., species evolution and adaptations; vegetation compositions and structures), it stands to reason that disturbance regimes can be used as a template to design our management activities upon – that is, emulating those processes that have led to native biodiversity and other ecological attributes (Attiwill 1994, Swetnam et al. 1999). Silviculture stands to benefit substantially through emulating natural disturbance regimes (Kimball et al. 1995, Walker et al. 1996, Nowacki and Kramer 1998, Cissel et al. 1999, Bergeron et al. 2002, Seymour et al. 2002), although there are caveats to consider (Patch 1998, Lorimer 2001). This topic is thoroughly explored in a special issue of *Forest Ecology Management* (Mitchell et al. 2002). Disturbance ecology includes human effects (land-use histories) that have influenced today's vegetation characteristics (Brender 1974, Whitney and Somerlot 1985, Christensen 1989, Glitzenstein et al. 1990, Orwig and Abrams 1994). Lorimer (1985; list modified below) itemizes a variety of quantitative methods for ascertaining forest disturbance history.

1. External Physical Evidence

- a. Fire scars. Exposure to recurrent fire causes the scarring of tree boles, thus forming a record of past disturbance events in pyrogenic systems (Buell et al. 1954, Johnson 1979, Dieterich 1980, Guyette and McGinnes 1982, McBride 1983, Swetnam 1993, Gutsell and Johnson 1996, Loope and Anderson 1998). Fire periodicity and extent can be reconstructed using fire-scar data.

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- b. Forest floor. Physical evidence can be used to trace developmental histories of forest stands (Henry and Swan 1974, Oliver and Stephens 1977).
 - c. Paleoecological data. Pollen, macrofossil, and charcoal assemblages in bog and lake sediments can be used to reconstruct past disturbance regimes (Clark 1990, Larsen and MacDonald 1998). Armed with pollen, charcoal, and ethnobotanical data, Delcourt et al. (1998) established strong linkages among prehistoric human occupation, plant domestication, and increases in local fire.

2. Demographic Evidence

- a. Tree-age and size distributions and time-since-disturbance maps. See Heinselman (1973), Johnson and Larsen (1991), and Reed et al. (1998) for examples.

3. Physiological Evidence

- a. Radial growth patterns. Tree rings are a natural data storage system containing valuable ecological and historical information (Creber 1977, Banks 1991). In dense temperate forests, tree-ring growth is often linked to competition for growing space/resources rather than climatic factors (Phipps 1982, Blasing et al. 1983, Cook and Kairiukstis 1990, chapter 3). In these situations, radial growth patterns have been successfully used to detect and quantify disturbance events (Lorimer and Frelich 1989, Payette et al. 1990, Nowacki and Abrams 1997, St. George and Nielsen 2000, Rentch et al. 2002).

4. Structural Evidence

- a. Canopy structure.
- b. Diameter distributions. See Heinselman (1973) for landscape-level reconstructions of disturbance events.

Additional information can be obtained through:

- 5. Historical Accounts.** Journals, chronicles, diaries, etc., from early explorers, surveyors, settlers, and early newspaper reports can be used to document pre- and post-European disturbance regimes (Day 1953). Historical maps (Van Wagner 1988, Payette et al. 1989).
- 6. Early Land Surveys.** Pre-European settlement disturbance regimes (disturbance types, sizes, intensities, frequencies) have been successfully chronicled by GLO Survey (Grimm 1984) or equivalent survey data (Seischab and Orwig 1991).

Disturbance regimes have been described for conifer-northern hardwoods (Lorimer 1977; Dunn et al. 1983; Canham and Loucks 1984; Whitney 1986, 1987), pine forests (Whitney 1986, 1987), swamp conifer forests (Whitney 1986, 1987), and boreal forests (Lorimer 1977). Early government land surveys can be used to estimate pre-European settlement fire frequency in pyrogenic landscapes (Lorimer 1980). The effects of Native American disturbance on pre-European forests have been traced through catchment analysis of witness-tree data (Black and Abrams 2001b).

Existing Vegetation

While *existing* vegetation information is also critical for sound forest planning, it serves a different purpose than TEUI. Whereas TEUI seeks to identify differences in the inherent potential of land units to generate ecosystem diversity and maintain its functions, existing vegetation maps reflect the current state of ecosystem structure and floristic composition. Potential and existing vegetation maps therefore provide different— but related and equally important— sets of information for forest planning. Protocols for classifying and mapping existing vegetation are described in the draft *Existing Vegetation Classification and Mapping Technical Guide* (Brohman et al. 2005).

Potential Natural Vegetation

PNV is *the vegetation that would become established if all successional sequences were completed without human interference under present climatic and edaphic conditions* [adapted from Tüxen (1956) as translated by Mueller-Dombois and Ellenberg (1974)].

Environmental conditions include climate, geology, geomorphology, and soil characteristics. Although it is important in classifying PNV to separate potential vegetation from these and other environmental variables, environment of course strongly influences development of PNV. “Present climatic and edaphic conditions” includes conditions created by past human activities (Tüxen 1956 as cited by Mueller-Dombois and Ellenberg 1974), such as soil loss. PNV may include naturalized, non-native species. Introduced species capable of displacing native species represent a change in floristic conditions that changes the PNV of a site. These new species may have been introduced by natural migration or by human actions.

Utility of Potential Natural Vegetation

Historically, the completion of the successional sequence (the sere) in the above definition was seen as progressing toward a stable, climax state limited only by climatic constraints. In recent years, this concept of climax as a single stable state has been shown to be overly

simplistic (Cook 1996). Following disturbance, vegetation on similar sites can proceed toward multiple possible future conditions. Our objective in classifying and using PNV, however, is not to promote the climax concept as a certain, rigid endpoint to succession. Rather, our goal is to capture the land's capability to support certain vegetative ecosystems by using potential vegetation as a concise, easily communicated and validated "shorthand" to describe this capability. PNV, then, is best thought of as the vegetation expressing its potential on the land, and can occur at all scales from site to region.

PNV should always be seen in the context of existing and historic vegetation. Our understanding of landscapes is likely to be incomplete without a full understanding of how existing, potential, and historic vegetation relate to each other. Existing and historic vegetation have been described previously in this document.

The objective of PNV classification is to concisely describe the capability of land to produce vegetation and support other ecosystem processes and functions through a well-defined vegetation description. Although this approach is only approximate, or may be overly simplified in some cases, this does not mean that PNV is not useful. Indeed, there may be value in this simplification, provided we are fully aware of its weaknesses, because information that is too detailed or complicated quickly loses currency with land managers. PNV is one of the most useful integrated expressions of environment we have that is related directly to vegetation. It has been widely and successfully used for planning at project, national forest, and river basin scales.

PNV is a more permanent feature of the landscape than is existing vegetation and sets the context in which a variety of structural and compositional stages of vegetation may occur. Consider an acre of PNV forest on deep soils adjacent to an acre of PNV grassland on shallow soils. Vegetation structure and composition of each acre can vary within the environmental constraints of each site. The PNV grassland acre of shallow soils is incapable of supporting a forest, but the PNV forest acre may support a variety of grassland, shrubland, and forested communities. The acre of PNV grassland will only support a limited variety of grass and forb communities. The PNV classification of the 2 acres would always be different, but they may at times support the same existing vegetation.

When PNV is coupled with other key landscape elements (soil, landform, climate, and geology) to identify an ecological type classification, PNV becomes more useful. For example, the geographically widespread subalpine fir/grouse whortleberry (ABLA/VASC) plant association occurs on a variety of sites. When soils and landform are used along with this plant association to classify ecological types, more precise descriptions of site potentials emerge.

In summary, PNV classification is a pragmatic shorthand means of understanding and communicating vegetative site differences. It is used along with landscape elements to classify ecological types. See 1.3.2 Ecological Classification for further details.

Potential Natural Vegetation Classification Criteria

The plant association is the fundamental unit of vegetation taxonomy for both potential and existing vegetation. Other levels of vegetation classification are derived from the association. The FGDC (1997) *Vegetation Classification Standard* specifies that the term “association refers to existing vegetation, not a potential vegetation type.” In other words, the term association does not necessarily refer to a climax plant community. This usage predominates in vegetation ecology (Krebs 1972, Mueller-Dombois and Ellenberg 1974, Barbour et al. 1980, Collinson 1988). In contrast, the USDA Forest Service (1991b) and USDA Natural Resources Conservation Service (NRCS) (1997) have used the term ‘plant association’ to refer to a climax or potential natural plant community, following Daubenmire (1968). The FGDC standard mandates that term ‘association’ or ‘plant association’ not be used to imply a climax plant community. However, it is acceptable to classify PNV at the association level of vegetation taxonomy.

Community composition is the “kinds, absolute amounts, or relative proportions of plant species present in a given area or stand” (Brohman and Bryant 2005). In practice, we recommend use of absolute areal percent cover as the best method to capture the amount of a species present. Areal percent cover is the fraction of a sample plot covered by the species of interest. This has the advantages of both simple data collection and good correlation to changes in site characteristics.

A vegetation classification in itself does not include abiotic factors. (The direct combination of a vegetation classification taxon and its abiotic counterparts defines an ecological type.) In developing a PNV classification, however, both plant abundance and environmental data are critical, since relating the amount of a species to site characteristics—soil moisture and nutrient status, aspect, elevation, etc.—defines the threshold separating one community from another. For example, 3-percent areal cover of shield fern is used in southeastern Alaskan western hemlock forests to characterize an ecosystem with well-aerated, nutrient-rich soils. Sites with less than 3-percent cover of shield fern have typically not reached this threshold of soil nutrient availability, and are classified as a different association. Such a classification would not be possible without correlating the vegetation data to soils data. This is a core principle of classifying potential vegetation: characterizing vegetation by changes in environmental thresholds rather than the simple abundance of each species. These changes reflect a species’ change in abundance along

environmental gradients (species amplitude). This is also why the modern concept of PNV centers on capturing the diagnostic structure, function, and composition of an ecosystem—its potential—rather than identifying a climax plant community state.

Diagnostic species are “any species, or group of species, whose relative constancy or abundance clearly differentiates one [vegetation] type from another” (Jennings et al. 2004). This definition implies that diagnostic species must be determined empirically through analysis of plot data (Mueller-Dombois and Ellenberg 1974). Identifying diagnostic species is an inherent part of classifying associations and alliances. Diagnostic species include dominant, differential, character, and indicator species. These are defined as follows:

Dominant species—“the species with the highest percentage of cover, usually in the uppermost ... layer” (Kimmins 1997 as cited in Jennings et al. 2004). Dominant species represent a quantitative difference in composition between vegetation types. Two stands or types may have identical floristics (plant species present) but differ in dominant species.

Differential species—“a plant species that, because of its greater fidelity in one kind of community than others, can be used to distinguish vegetation units” (Gabriel and Talbot 1984 as cited in Jennings et al. 2004). A differential species is usually present in one vegetation type but absent in other types. They constitute a floristic or qualitative distinction between vegetation types.

Character species—“a species that shows a distinct maximum concentration (quantitatively and by presence) in a well-definable vegetation type” (Mueller-Dombois and Ellenberg 1974). Character species constitute a quantitative difference in composition between vegetation types.

Indicator species—“a species whose presence, abundance, or vigor is considered to indicate certain environmental conditions” (Gabriel and Talbot 1984 as cited in Jennings et al. 2004). Indicator species may represent either a qualitative or quantitative distinction between community types.

Dominant species are generally self-evident. Other diagnostic species are typically determined empirically through analysis of species abundances and environmental data. Plots are grouped on or by species composition. This is often done with an algorithm to objectively search for groups of species that occur together repeatedly across the landscape. The diagnostic value of a species may change from one part of its geographic range to another because of genetic variation, compensating environmental factors, or changes in associated species.

Potential Natural Vegetation Hierarchy

PNV can be classified at four hierarchy levels: series, subseries, plant association, and plant association phase. The four taxonomic levels are defined as follows:

- A **series** is a taxonomic unit of PNV classification that aggregates plant associations that share the same climax species in the dominant layer. In forested vegetation this is typically the most shade tolerant tree species capable of occupying a site. The term series traditionally has been applied only to climax vegetation. Analogous terms for existing vegetation include *dominance type* and *alliance* (Jennings et al. 2004).
- A **subseries** is a taxonomic subdivision of a series that groups plant associations that share diagnostic species which show similar relationships to major environmental gradients (Mueller-Dombois and Ellenberg 1974). Regional terminology equivalent to the subseries concept may include *Plant Association Groups* and *Habitat Type Groups*, although in practice these groups sometimes contain members from different series. Analogous terms for existing vegetation include *alliance* and *suballiance*.
- A **plant association** (or association) is “a recurring plant community with a characteristic range in species composition, specific diagnostic species, and a defined range in habitat conditions and physiognomy or structure” (Jennings et al. 2004). Although the FGDC (1997) Vegetation Classification Standard specifies that the term “plant association” does not imply a climax plant community, it is acceptable to classify PNV at the association level of vegetation taxonomy. Plant associations are named after diagnostic tree, shrub, and herb species. *Habitat Type* serves as a loosely equivalent term to plant association in some regions.
- A **plant association phase** is a taxonomic subdivision of a plant association based on one or more diagnostic species. *Habitat Type Phase* serves as equivalent terminology to the plant association phase concept used by some regions.

The hierarchy is applied as illustrated in table 1.2, which shows examples of three levels in the PNV hierarchy. Any PNV identification within the hierarchy infers all PNV in levels above, but not the reverse. For example, the Big Sagebrush/Bluebunch Wheatgrass p.a. is a shrubland in the Big Sagebrush Series by definition. Conversely, the Big Sagebrush Series does not necessarily imply the Big Sagebrush/Bluebunch Wheatgrass p.a. as there are other plant associations within the Big Sagebrush Series. Coding for individual species is taken from the NRCS PLANTS database.

Table 1.2. *Potential natural vegetation hierarchy examples.**

Series	Subseries	Plant association	Plant association phase
White fir (ABCO)	Reserved	White fir—Douglas-fir/Rocky Mountain maple (ABCO-PSME/ACGL)	Creeping barberry phase (ABCO-PSME/ACGL, MARE11)
Quaking aspen (POTR5)	Reserved	Quaking aspen/Beaked hazelnut (POTR5/COCO6)	Western Brackenfern phase (POTR5/COCO6, PTAQ)
Twoneedle pinyon—Utah juniper (PIED-JUOS)	Reserved	Twoneedle pinyon—Utah juniper/Utah serviceberry—alderleaf mountain mahogany (PIED-JUOS/AMUT-CEMO2)	Greenleaf manzanita phase (PIED-JUOS/AMUT-CEMO2, ARPA6)
Sagebrush (ARTR2)	Reserved	Big Sagebrush/Idaho fescue (ARTR2/FEID)	Sticky purple geranium phase (ARTR2/FEID, GEVI2)
Tufted hairgrass (DECE)	Reserved	Tufted hairgrass—Slender wheatgrass (DECE-ELTR7)	N/A
Porter's wild lovage (LIPO)	Reserved	Porter's licorice-root—lodgepole lupine (LIPO-LUPA8)	N/A

*Examples are adapted from Johnston (1989). Symbols for species are from PLANTS (USDA NRCS 2004).

Types of Potential Natural Vegetation

Different combinations of macroclimate, topography, and soils can result in similar growing conditions and support the same PNV. However, the same PNV may reflect a different limiting factor in each case. Differences in limiting factor can result in different responses to vegetation management, even though the PNV is the same. It is, therefore, useful, to identify the environmental factors influencing vegetation development.

Based on Tansley's (1935) "polyclimax" theory, Daubenmire (1968) describes categories of climax vegetation based on which environmental factor most directly influences vegetation composition and structure. Similar categories are useful for describing the environmental factor most strongly influencing PNV on each ecological type. Although Daubenmire underestimated the role of natural disturbances (Cook 1996), the categories are useful for describing the effects of a given disturbance. The following discussion and terms are based on Daubenmire's (1968) treatment.

PNV types that reflect climatic, edaphic, and/or topographic conditions have been referred to as *primary PNV types*. PNV types that depend for their maintenance on periodic natural disturbance are called *secondary PNV types*. Primary PNV reflects the effects of inherent physical ecosystem attributes (or landscape elements) such as climate, geology, geomorphology, and soil properties. Secondary PNV is maintained by a specific type of ecosystem process (i.e., natural disturbances such as wildfire). By definition, vegetation maintained by periodic human activity is not PNV.

Categories of primary PNV include the following:

Climatic PNV—Any PNV type that reflects macroclimatic conditions and shows no dependency for its maintenance on periodic natural disturbance. Seasonal air temperatures, the amount and distribution of precipitation, and light intensity are the predominant elements of macroclimate.

Edaphic PNV—Any PNV type that differs significantly from the climatic PNV of an area due to soil properties not related to slope or topographic position. Examples of soil properties that may override the influence of macroclimate include depth, stoniness, texture, pH, and nutrient status. Many of these properties are affected by geologic parent material and geomorphic process.

Topographic PNV—Any PNV type that differs significantly from the climatic PNV of an area due to microclimatic conditions created by topographic characteristics. These can include steep slopes, north or south aspects, and areas of snow accumulation or loss.

Topo-edaphic PNV—Any PNV type that differs significantly from the climatic PNV of an area due to a combination of microclimatic and soil conditions created by topographic characteristics. An example is an aspen grove growing in a kettle where fine sediments accumulate, creating finer-textured soils. Drifting snow accumulates in the kettle, creating a wetter microclimate.

Categories of secondary PNV include the following:

Pyric PNV (or fire PNV)—Any PNV type that differs significantly from the primary PNV of an area due to periodic wildfire. A pyric PNV maintains its composition and structure only as a consequence of periodic natural burning, which eliminates fire-sensitive species and maintains fire-tolerant or fire-dependent species.

Zootic PNV—Any PNV type that differs significantly from the primary PNV of an area due to repeated native animal activity (such as grazing, trampling, burrowing, etc.) or periodic infestations of native insects or diseases.

A particular site may be described in terms of both a primary PNV and a secondary PNV type. For example, many areas in the Great Basin were dominated by big sagebrush with a 20- to 40-year fire return cycle prior to settlement. Since settlement, fire suppression has greatly lengthened the fire return interval, which has allowed juniper to dominate these areas. On such sites juniper is the climatic PNV and big sagebrush is the pyric PNV.

In another widespread example, cheatgrass has become the pyric PNV on many areas where big sagebrush is the climatic or edaphic PNV. The presence of highly flammable cheatgrass has shortened the fire return interval from 20 to 40 years to less than 10 years, which effectively prevents the reestablishment of sagebrush.

State and Transition Models

Understanding vegetation dynamics as influenced by soil, climate, topography, and time is essential for accurately classifying, mapping, and interpreting ecological types. As soil and plant community develop on a site, succession occurs. The state and transition model is one successional model that describes how different disturbances (fire, flooding, grazing, mechanical, air pollution, insects) and stresses (drought, increased precipitation, climate change and variability, exotic species) affect changes in the plant community. This model assists in developing successional pathways (transitions) and plant communities (states) that evolve under various climates and management practices. State and transition models are conceptual and based upon nonequilibrium ecology and depicted through box-and-arrow diagrams in which boxes represent observed or theoretical ecosystem states and arrows represent the observed or theoretical transitions among these states (figure 1.3). They are essentially a means of mapping system behavior in the absence of adequate predictive models (Westoby et al. 1989). Traditional theories of plant succession leading to a single climax community have been found to be inadequate

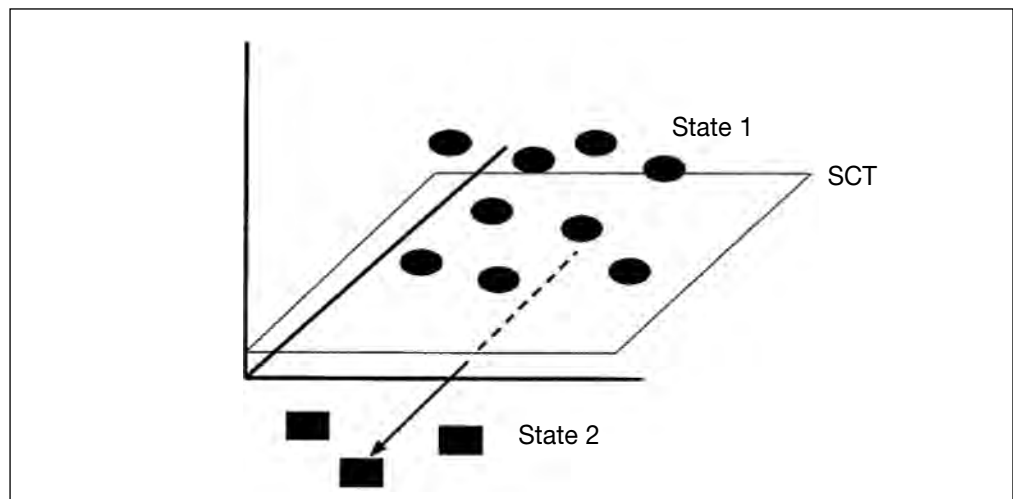


Figure 1.3. Broad application of the state and transition concepts. Derived from the Society for Range Management (SRM) Task Group on Unity in Concepts and Terminology (1995). The plane labeled SCT (site conservation threshold) represents a change from one ecological site to another and may also be considered a threshold between two states. The individual boxes or ovals represent plant communities or seral stages that exist within one state (Stringham et al. 2001).

for understanding the complex successional pathways of semiarid and arid ecosystems. Plant succession as influenced by arid and semiarid environments change at different temporal and spatial scales than communities growing within moister more humid and colder environments. These communities often exhibit nonlinear dynamics and are beyond the basic description using linear Clementsian climax theory.

A state is the general description of the known ecological type characteristics and properties. It is a recognizable, resistant, and resilient complex of two components: the soil base and the vegetation structure. The vegetation and soil components are necessarily connected through integrated ecological processes that interact to produce a sustained equilibrium, or stability, that is expressed by a specific suite of vegetative communities and is not simply reversible in the linear successional framework. Stability refers to the capability of the state to return to its original vegetative structure when stresses or disturbances are removed.

As the characteristics and properties or function significantly change there is a transition to a new state. A transition is a trajectory of the system change triggered by natural events, management actions, or both that will not come to rest until a new equilibrium is established. The processes that cause a shift from one state to another are called transition pathways. Transitions can be transient or persisting depending upon the frequency, magnitude, and extent of the disturbance. Regardless of the rate of change the system does not stabilize until the transition is complete.

Through inventory and analysis it is important to differentiate between processes that influence variation within states and those processes that result in crossing thresholds between states. Thresholds are boundaries in space and time between any and all states, or along irreversible transitions, such that one or more of the primary ecological processes has been irreversibly changed and must be actively restored before return to a previous state if possible (Stringham et al. 2001). This change is not reversible on a practical time scale without substantial inputs of energy. These processes need to be assessed and documented.

Characterization and Classification

The characterization and classification of plant communities for state and transition model development will follow standard sampling and description protocols as outlined in this guide. Document local agreement for development of this information in a memorandum of understanding (MOU) and/or work plans. The first vegetation state to describe using this model is the historic climax plant community. From this state, other states known to occur on the site and the transitions that lead to and from each state are devel-

oped. Vegetation composition, canopy cover, and structure are essential data elements for characterizing plant communities that can lead to classification of an ecological state. Documentation of these conditions is critical for establishing a framework for describing, understanding, and predicting ecosystem dynamics. Abiotic and flora characteristics and properties are fundamental in categorizing or classifying the ecological type as related to state and transition modeling.

Use in Mapping

Incorporating state and transition modeling into the TEUI mapping process requires considerable thought and planning to ensure scale and cartographic integrity are consistent with objectives of the inventory. Use the MOU and/or work plan to address the requirements of the TEUI mapping process. States of plant communities should be readily observable and documented. These states should be delineable at an appropriate scale and repeat to the extent that there is more than one area where the vegetative state can be located and observed. Similar vegetative states that are similar in composition, cover, and structure and separated by geographic features are mapped as the same repeating ecological type and ecological unit.

Application

Within the state and transition model, states can approximate seral stages or phases of vegetation development. Both narrow and broad interpretations of states can be made depending upon the establishment of thresholds.

Broadly applied, states are climate/soil/vegetation domains that encompass a large amount of variation in species composition. For example a grassland state would include many seral stages of the overall grassland community. These seral stages are within the amplitude of natural variability characteristic of the state and represent responses to a disturbance that do not force a breach of the threshold (Stringham et al. 2001). It is assumed that the domination of successional processes determines the boundary of the grassland state. In the broad definition of state, the range of natural variability characteristic of the plant communities within a site is the result of, and contributes to, the current functional integrity of the site's primary ecological processes.

The narrower interpretation of states allows for far less variation in plant community composition (figure 1.4). States are typically depicted as seral stages or vegetation development. A state change does not necessarily represent a movement across a threshold.

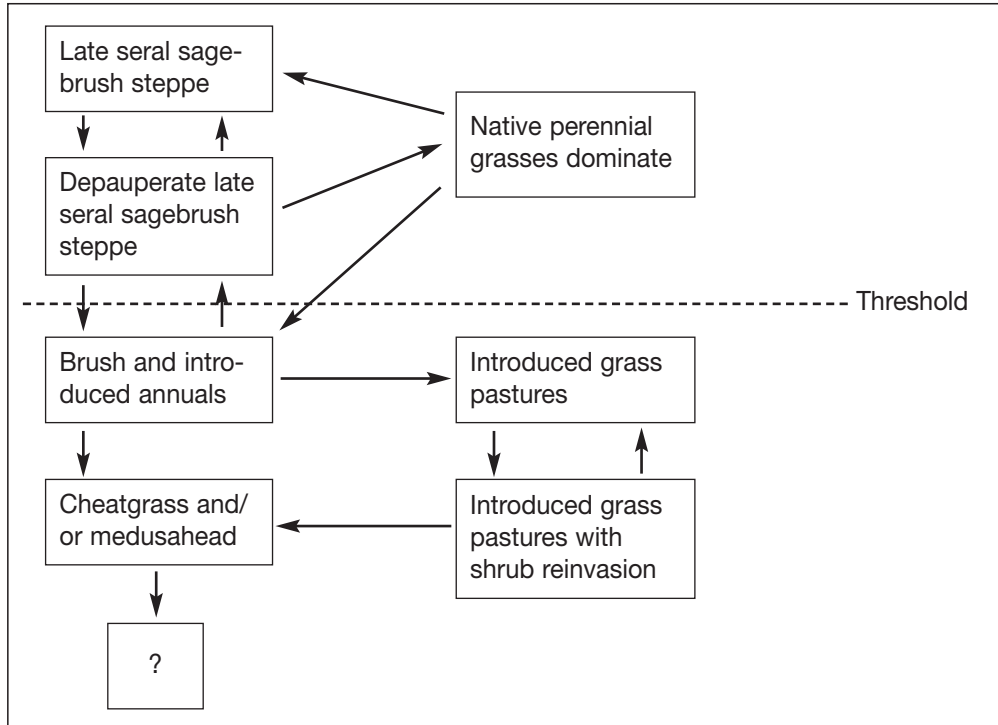


Figure 1.4. *Specific, or narrow, application of states with each state (box) representing one phase or seral stage of vegetation development. Transitions between states are indicated by arrows, and the dashed lines represents a threshold. The dashed transitional line signifies the requirement of substantial energy input to move the state back across the threshold (Stringham et al. 2001).*

The management and natural mechanisms responsible for community phase shifts and transition initiation must be included in the model description as applied in the TEUI process. The description of these mechanisms should contain information on their impact on primary ecological processes and the resulting change in the biotic community and system function. Typically, the change in the biotic community is documented, not the causal mechanism. Causes of vegetation change should be determined and the effects of this activity described. It is likely a combination of factors is responsible for these dramatic shifts.

1.4 Roles and Responsibilities

1.4.1 National Responsibilities

- Developing the TEUI program and implementing it as part of the agency's Inventory and Monitoring Framework.
- Developing classification and characterization standards for ecological types and ecological units and ensuring compatibility of any USDA Forest Service-generated descriptions across regional lines.

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- Providing direction for the classification, inventory, and evaluation of ecosystem capability.
 - Ensuring consistency for national application and interpretation of ecological units.
 - Ensuring regions are completing the soils portion of TEUI to NCSS standards.
 - Ensuring regions are accountable for completion of TEUI to national standards and protocols and as scheduled in inventory and monitoring program plans.
 - Ensuring the incorporation of servicewide GIS data standards in the TEUI program.
 - Ensuring regions are collecting data that is compatible with corporate databases.

1.4.2 Regional Responsibilities

- Implementing the TEUI program to national standards and protocols.
- Developing TEUI information in advance of assessments, forest plan revisions, and monitoring as scheduled in the regions' inventory and monitoring program plan.
- Providing development of regional and local interpretations of ecosystem relationships, responses, diversity, productivity, and sustainability.
- Ensuring ecological type and map unit information is developed consistently across administrative units and major land resource areas. Coordinating with other agencies for correlation of ecological type descriptions and map units.
- Providing standards for application and interpretation of ecological types and map units, and ensuring consistency of standards and interpretations between regions and field units.
- Performing quality control so that performance measures and outcomes are accomplished for TEUI through instituting field review of TEUI products to assure consistency and quality.

1.4.3 Forest Responsibilities

- Implementing the TEUI program to national standards and protocols.
- Ensuring that TEUI is accomplished according to schedule.
- Collecting information to characterize ecological types and map units.

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- Providing day-to-day quality control of mapping and data collection process.
 - Ensuring that ecological information is used in forest planning and assessments, and in project implementation on National Forest System lands.

1.5 Relationship to Other Federal Inventory and Monitoring Programs

1.5.1 Natural Resources Conservation Service

Soil Survey Program

The soil survey program of the United States is conducted under several statutory authorities. Public Law 89-560 directs the Secretary of Agriculture to (1) make an inventory of soil resources of the United States, (2) keep the inventory current, (3) make the information available in a useful form by preparing reports and interpretations, and (4) provide technical assistance and consulting services to promote the use and application of soils information. NRCS has lead responsibility for this effort (USDA NRCS 2003b).

The soil data collected through implementation of the *TEUI Technical Guide* will meet the following NCSS standards:

- Classification as found in *Keys to Soil Taxonomy* (USDA NRCS 2003a);
- Description, as found in *The Field Book for Describing and Sampling Soils* (Schoeneberger et al. 2002); and
- Documentation described in the *NSSH*, Part 627.08 (USDA NRCS 2003b) with exception of a TEUI map instead of a soil map.

The soil component of TEUs is verified in the field, and the soil correlation process in TEUI provides for consistent soil classification, naming, and interpretation. MOU and/or work plans serve as a cooperative agreement with NCSS partners and govern the management and administration of the soils portion of the TEUI and address how NCSS standards will be achieved.

National Soil Information System

The National Soil Information System (NASIS) is a corporate database that stores soil survey data. Many of the data elements and attributes for soils identified in this technical guide are identical with those in NASIS. Methods of sharing these data between agencies can be accomplished through data cross walks and migration routines.

Ecological Site Information System

The Ecological Site Information System (ESIS) is the NRCS repository for data associated with the collection of forest land and rangeland plot data (vegetation) and the development of ecological site descriptions (ESD). While the data elements collected for TEUI and NRCS ecological sites are similar, they differ in that the ESIS data are not integrated, collected, or mapped as part of the soil survey program. ESIS is organized into two applications and their associated databases described below.

Ecological Site Description

The ESD application provides the capability to produce automated ESDs from the data stored in its database. The ESD application is the official repository for all data associated with the development of forest land and rangeland ESDs by the NRCS.

Ecological Site Inventory

The Ecological Site Inventory application provides the capability to enter, edit, and retrieve range, forestry, and agro-forestry plot data.

1.6 Quality Control and Assurance

Quality control and assurance are addressed for each protocol in chapters 2 and 3.

1.7 Change Management

1.7.1 Update Schedule

The *TEUI Technical Guide* will be updated as needed or as directed by Washington Office staff with the concurrence of the national and regional TEUI program leaders.

1.7.2 Process

The updated *TEUI Technical Guide* will be released for a 3-month review period. Regional TEUI program leaders will compile and consolidate reviews from their respective regions and submit edits to the national TEUI program leaders for consideration.

Peer Review

The *TEUI Technical Guide* will be reviewed by all involved in TEUI, including soil scientists, geologists, and ecologists throughout Government agencies and universities. A current list of reviewers is available in appendix G.

Regional Supplements

Regions may supplement the information in this technical guide with methods or guidance required for meeting specific issues or needs of the region.

Chapter 2. Landtype Associations Protocol

2.1 Objective

The objective of this protocol is to provide consistent standards for the mapping and documentation of landtype associations (LTAs).

The development of standard ways of delineating, classifying, and describing LTAs across broad geographic regions will increase the reliability and interpretation of these units for broad-scale analysis. In lieu of standards, LTAs become less defensible scientifically because of lack of peer review, and less defensible legally because adjacent entities, such as national forests, will be inconsistent in addressing the same or similar resource management issues (DeMeo et al. 2002).

2.1.1 Business Requirements

LTA maps and descriptions are primarily used in the land management planning process as analysis units to organize broad areas by suitability, identify restoration priorities, and serve as a coarse filter for protecting biodiversity (Almendinger et al. 2000). Because LTAs describe both the abiotic and biotic elements of ecosystems, they provide an excellent analysis unit for determining forest-level effects. For example, the Rio Grande National Forest Plan Final Environmental Impact Statement and Supplemental Information Report projected changes in vegetation structure class by LTA over time for each alternative, enabling the analysis of effects from timber harvest. LTAs were also used to prioritize areas of fuel treatment, determine suitable areas for livestock grazing, and analyze cumulative effects (USDA Forest Service 2002).

Perhaps the most useful application of LTAs is as a stratification tool to quickly organize the planning landscape and rank areas by relative suitability or concern. This application was demonstrated for addressing habitat needs of a rare species in DeMeo (2002), resulting in considerable savings in field inventory costs.

LTAs proved useful addressing many other land management issues such as mapping natural disturbance regimes, managing wildlife populations, and developing integrated landscape models (Smith 2002).

LTAs also are used as the initial stratification for the premapping of the landtype (LT) level mapping described in chapter 3. Because the landscape elements for LTA maps are classified at broader levels, they are effective in organizing the LT survey area for further stratification.

Finally, because they are fairly broad landscape units (hundreds of thousands of acres), LTAs can be grouped by forest vegetation zone, geology, or other factors and easily communicated to the public and land managers.

2.1.2 Products

LTA mapping generates a Geographic Information System (GIS) map layer, designed for display at the 1:100,000 scale with supporting data and map unit descriptions. For an overview of a national forest or subregion, maps at 1:250,000 are also useful, but not as a substitute for the 1:100,000 product. The attribute data for LTAs are similar to those of the LT, but classification of the landscape elements are made at a broader level. Table 2.1 describes the recommended level of classification for each of the landscape elements. Required and recommended map unit attributes (for LTAs only) are listed in table 2.2.

Table 2.1. *Comparison of elements for ecological units at landscape and land-unit scales.*

Planning and analysis scale	Ecological unit levels	Geology	Geomorphology	Soil	Potential natural vegetation
Landscape	Landtype association (LTA)	Primary lithology or groups of secondary	Geomorphic process and subprocess types	Great group and subgroup	Series and subseries
Land unit	Landtype (LT)	Secondary lithology	Landforms, element landforms, and morphometry	Subgroups, families, and series	Subseries and plant associations
	Landtype phase (LTP)	Secondary lithology	Landforms, element landforms, and morphometry	Series and phases of series	Plant associations and plant association phases

2.2 Planning and Design

Plan LTA development in advance of forest plan revisions or other broad-scale assessments.

LTAs are developed using an integrated top-down/bottom-up approach. Top-down refers to subdividing subsections into LTAs using available resource maps, remote sensing, and expert knowledge. Resource maps may include geologic, soils, vegetation, and shaded relief. Bottom-up refers to aggregating LTs into LTAs based on common attributes and ecological interactions. Both methods are acceptable, and both should be used to verify the LTAs are scientifically sound. For example, if LTAs were delineated top-down, use bottom-up information from LTs to verify the larger scale units are coherent. Similarly, bottom-up aggregation of LTs must be rigorously checked to ensure the attributes are described at landscape scale, and are not simply a list of fine-scale unit attributes.

Table 2.2. *Required and recommended attributes (elements) to describe landtype association map units.*

Required	Example	Recommended	Example
Map unit code	M221Aa01	Local climate	See below ¹
Map unit long name	North Fork Mountain/River Knobs	Elevation range	1,000 ft to 2,500 ft above sea level
Bedrock geology: primary	Sedimentary	Geomorphology: landform	Anticline
Bedrock geology: secondary	Sandstone/shales	Disturbance regime(s)	See below ²
Bedrock geologic age	Ordovician (sandstone) Silurian (shales)	Aquatic systems and types	Few intermittent streams
Surficial geology: primary	Unconsolidated	Drainage density patterns	Low density, trellis pattern
Surficial geology: secondary	Colluvium/residuum	Geologic formation	Brallier, Pocono, others
Surficial geology: origin	Sandstone/shale		
Geomorphology: geomorphic process	Tectonic		
Geomorphology: geomorphic subprocess	Folding		
Soil	Lehew-Dekalb-Hazleton complex		
Potential natural vegetation	Mixed oaks vegetation zone		

¹Annual precipitation: 30 inches. Mean temperature April through September: 64.0° F. Mean temperature October through March: 38.6° F.

²Historic 10-year average fire return interval (frequent low-intensity). Largely removed with fire suppression over past 70 years. Gypsy moth current disturbance; hemlock wooly adelgid entering area.

Top-down maps should be field verified to check LTA composition. Transects across the landscape, organized in a stratified random design, may be most effective. LTAs assembled from LTs should be rigorously reviewed to ensure they reflect processes and composition at LTA scale, and that the interrelationships of the LTs are understood. Remember to stay true to the processes and composition at landscape scale. LTAs are not simply the aggregation of finer scale units. LTs may be grouped in different ways, but only cohesive LTAs are consistent with landscape scale and processes.

2.2.1 Map Unit Design

At landscape scale, LTA map units are broad, ranging from 1,000 to hundreds of thousands of acres. Ecological types apply as they do at LT scale. Map units can therefore be made up of components of ecological types. Bear in mind, however, that these types must be made up of taxonomic units appropriate for the scale. For example, the potential vegetation attribute of the ecological type at this scale should be described at series or subseries scale—not plant association scale. Because LTAs are landscape units, the map polygons will repeat less often (or not at all) when compared with LT scale.

2.2.2 Standards

- Mapping scale is 1:100,000. Use top-down, bottom-up identification team approach and map unit design criteria in National Hierarchy (Cleland et al. 1997).
- Map unit size ranges from 1,000 to hundreds of thousands of acres.
- Attribute standards are detailed in tables 2.1 and 2.2.
- LTA are correlated within subregions and peer reviewed.

Naming Landtype Associations

No national standards are set for naming LTAs. Geomorphology, however, is often the major driver in delineating an LTA; thus, broad landforms are typically used in the name.

2.2.3 Map Unit Legend

The LTA map unit legend consists of a map unit symbol and a map unit name. LTAs are designated using codes that incorporate the section and subsection of the LTA, as well as a two-digit numeric code for the LTA. For example, the M221Aa01 code denotes the Ridge and Valley section (M221A), Northern Ridge and Valley subsection (a), and North Fork Mountain LTA (01).

Using such mnemonic devices makes the codes more easily recognizable. One drawback is that concatenating information from different hierarchy levels can make analyzing the data more difficult—consider sorting the data by subsection, for example, when the subsection codes are embedded—but generally relatively few LTAs exist per national forest, so the problem is not burdensome.

Valid Values and Codes for Terrestrial Ecological Unit Inventory Elements

It is useful to develop a list of valid values and codes for each inventory area that reflects the range available for each of the landscape elements for that area. These lists are developed based on the best available information and knowledge of the inventory area. They are updated throughout the life of the inventory based on additional knowledge gained through the inventory process. Use appropriate levels of classification listed in table 2.1 as guidelines for each element.

2.2.4 Delineation Criteria for Landtype Association Map Units

Delineation of ecological map units is not always a straightforward process. The delineation process attempts to create meaningful ecological units and break these units where ecological changes occur on the landscape. Fortunately, dependency among landscape elements allows the mapper to delineate significant changes in unseen elements such as potential natural vegetation (PNV) and soils using proxy indicators such as existing vegetation, morphometry, surficial geology, local climate, and landforms. In any case, the interrelationships between these indicators must be thought out and defensible.

To consistently delineate ecologic map units, the criteria for delineations must be easily observable at the level of mapping. For instance, at the LTA level it would be unfeasible to use individual soil bodies and PNV as delineation criteria because these elements are not observable at that scale. Instead, more readily available landscape elements such as bedrock geology and vegetation cover types reflecting regional climate would be more appropriate.

LTAs are delineated primarily on the boundaries between broad geomorphic units. Use a combination of tools (bedrock and surficial geology maps, raised relief maps, remote sensing imagery) to discern boundaries between mountains, glacial features, or other geomorphology. A team with geologic, ecological, and soils expertise can quickly draft lines on U.S. Geological Survey (USGS) 1:100,000 topographic maps. Another option is to use the Terrestrial Ecological Unit Inventory (TEUI) Toolkit—a computer package of GIS and other analysis tools—to build the draft LTAs.

Following the initial draft, subsequent review teams from other national forests, other agencies, and academia can improve the maps and make them more consistent with the delineation factors. Avoid splitting out inclusions and small areas of special interest. These should only be delineated at LT or landtype phase (LTP) level.

Observable delineation criteria enable land managers and users of the TEUI to more readily recognize ecological units during land management activities. If the user is unable to distinguish where ecological units diverge, a misinterpretation of the landscape capabilities and management may occur.

Actual line placement criteria (or delineation criteria) are often along areas that show significant change within a single landscape element, such as the change in the slope gradient in a mountain base or footslope position. These delineation criteria will often change, as the landscapes they differentiate change.

The specific delineation criteria must be selected with the goal of creating consistently repeating map units that have distinct capability ratings or management interpretations.

2.3 Mapping Landtype Associations

The following procedures are guidelines that apply to mapping LTAs. Usually, LTA delineation is based on broad geology and/or geomorphology, with climatic, soils, and vegetation effects in a supporting role. For example, a mountain may be used to define the boundary of an LTA, but its highest elevations split out as another LTA because of a distinct change in temperatures and a related striking change in vegetation. A distinct band of different geology/soils would be another reason for splitting out a different LTA on the mountain.

Design criteria should include construction of ecological types in accordance with this document. Ecological types at the landscape scale will of course be broader in nature than at land unit-scale and associated landscape elements are classified at higher (broader) levels (see table 2.1 for recommended levels of classification).

2.3.1 LTA Mapping Process

1. Conduct preliminary field reconnaissance.
 - a. Use field visits and overflights of the area to gain a better understanding of the landscape and distribution of ecological types within the inventory area.
 - b. Use the TEUI Geospatial Toolkit (USDA Forest Service 2005) to review “virtual flybys,” shaded relief models, distribution of vegetation, landforms, aspect, slope, and elevation gradients to better understand the landscape.
2. Create preliminary polygons.
 - a. Use 1:100,000 aerial photography, topographic maps, digital elevation models, digital orthophoto quadrangles (DOQs), satellite imagery, and other resource maps as appropriate to delineate preliminary polygons. Employ an interdisciplinary team with geology, ecology, and soils expertise. At this stage, geologic input will probably be the most important.
 - b. Use the TEUI Geospatial Toolkit or similar technology to delineate preliminary map polygons. Use the DOQ image as a base while using multiple windows to compare delineations to other resource maps such as satellite imagery, shaded relief, and 3-D views with appropriate themes draped over the base (USDA Forest Service 2005).

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- c. Base delineation on sound photo interpretive principles using all observable features, as well as the specific criteria and class limits defined in the classification and/or descriptive legends for each of the landscape elements.
 - d. Develop map-unit concepts by organizing and grouping LT map units with similar combinations of map-unit characteristics such as landforms, vegetation, geology, slope, and elevation ranges. Geomorphology is likely to be the primary driving factor in delineating LTA map units. Describe what makes a map unit different than those surrounding it or the map unit significance.
 - e. Use observable properties on aerial photography or other imagery when delineating map units.
 - f. Use caution when relying on visible existing vegetation from aerial photographs or as satellite imagery, as it may not represent PNV. Knowing the disturbance history will help locate areas where potential vegetation and existing vegetation may differ.
3. Develop preliminary map unit legend.
 - a. Develop a connotative legend using the procedures described in section 3.2.2, “Connotative Legends.”
 - b. Label polygons on photos, Mylars, and/or the coverage being created using the digitizing method in the TEUI Geospatial Toolkit.
 4. Review or develop new classifications as appropriate.
 - a. If PNV and geologic information are lacking in some areas, perform limited fieldwork to develop preliminary landscape element classifications and legends.
 - b. Use summaries of existing LT to develop ecological classifications or identify LT and their associated patterns using a field sampling process. See 2.3.1 Part 6.
 5. Incorporate existing information.
 - a. If existing LTs are available, aggregate these to form LTAs. This can be done with GIS, if available, or used to guide delineation of the LTA boundaries, if done by hand.
 - b. Use other maps such as geology maps, State Soil Geographic Database soil maps, vegetation maps, shaded-relief maps, and other mapped data to visualize and delineate LTAs.

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6. Conduct field sampling.
 - a. If existing LTs are not available, verify LTA maps by sampling field data. A systematic sampling method employing transects across the landscape will be most efficient. A lower sample density than for corresponding land-unit mapping should be used for this step. For LTA verification purposes, intensive data are not critical. Transects to document changes in slope, landform, geology, soil subgroups, and vegetation series will typically be adequate.
 - b. Ensure data is adequate for correlation of LTA within subregions, and correlation of ET within LTA if a bottom-up process is used.
 7. Perform quality control.
 - a. Perform quality control checks on mapping, documentation, sampling procedures, and the accuracy and precision of estimates. Design the checks into the work plan development process, and perform them progressively during the mapping and classification process. Quality control checks range from scheduled field reviews to daily assists. The mapping team's primary responsibility is to ensure the application of quality control.
 - b. Ensure that LTA meet minimum documentation standards. Correlate LTA within subregions and patterns of LT within LTA.
 8. Enter Data.
 - a. Progressively enter data into the Natural Resource Information System (NRIS) Terra database. Additional regional tables may be needed to ensure more localized interpretations needs are satisfied.
 - b. Minimum data include GISDD requirements and those in table 2.2.
 9. Document map units.
 - a. Develop block diagrams depicting pattern or associate of map units concepts.
 - b. Collect photographs to catalog and document landscapes, vegetations, soils, and geology.
 - c. Provide statements of significance (i.e., those characteristics that distinguish the observed LTA from surrounding LTAs).

10. Finalize mapping and classifications.

- a. Finalize legend.
- b. Finalize mapping.
 - i. Match adjacent LTA mapping. The completed LTA maps should be joined to adjacent survey areas. A quality join must be maintained along the inventory boundary. Accomplishing a quality join requires that the map-unit delineations, attributes, and interpretations match across the boundary.
 - ii. Compile mapping to a stable base. Compilation methods will vary according to specific mapping techniques used on an inventory. Typically, lines are transferred and registered to a stable-based Mylar, and scanned or digitized into the GIS environment. Alternatively, if onscreen digitizing is used to develop, maintain, or adjust mapping products, this step may not be required.
 - iii. Scan or digitize mapping. All mapping layers should be prepared for scanning or digitizing according to national cartographic standards. It is also useful to code LTs with LTA identifiers so LTA maps can also displayed at 1:24,000 scale. This step will greatly facilitate analysis for planning purposes.
- c. Finalize any taxonomic classification developments including PNV and ecological type classifications.

11. Finalize descriptions for map units and ecological types.

- a. Distribute draft map and documentation for peer review. Peer review among national forests and partners within your region or subregion is particularly valuable.
- b. Map unit descriptions must meet standards outlined in table 2.1 and table 2.2, GIDD standards, and contain a statement of significance.

12. Develop interpretations.

- a. Develop interpretations for the map unit component and/or landtype association.
- b. Management implications are an important part of this work, and indeed, are the end objective of all ecological unit mapping. Implications are tailored to the needs of the local area, and can include the following information:

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- Relative value of biodiversity, as measured by plant or animal species richness, diversity of plant community and patch types (beta diversity), etc.
 - Suitability for silvicultural prescriptions, reforestation, methods, etc.
 - Prescribed and wildfire implications.
 - Habitat for species of management interest.
 - Ecosystem productivity, both terrestrial and aquatic.
 - Historic range of variation, and what the LTA will likely look like in the future without treatment.
 - Susceptibility to acid rain, ozone, etc.
 - Susceptibility to insects and diseases.
 - Soil erosion and compaction.
 - Mass wasting and other geologic hazards.

13. Prepare manuscript.

Written documentation for LTAs should be organized by national forest, subregion (group of forests), or by region. Document should include objectives, definition of an LTA and explanation of the hierarchy of ecological units, methods used to delineate and attribute LTAs, description for each LTA using table 2.1 as a guide, management implications, and literature cited. See 11.b. for additional instruction on map unit descriptions.

2.3.2 Logistics

Facility and Equipment Needs

Base Maps

USGS topographic maps at 1:100,000 scale are considered the desired publication scale map for LTAs. This map is usually used for forestwide planning efforts.

Aerial Photography

Aerial photography may be used as a base map as well as for field reference. For LTAs, using photography at scales ranging from 1:60,000 to 1:100,000 is generally recommended.

Common types of aerial photography include natural color, infrared, and large format. Using stereo pairs to view landscapes in three dimensions can aid in interpreting landscape elements.

The Aerial Photography Field Office (APFO), Farm Service Agency, is the primary source of aerial imagery for the U.S. Department of Agriculture. More than 10 million images are stored in the APFO library, dating from 1955 through the present. For more information, visit <http://www.apfo.usda.gov>.

The National High Altitude Photography program, initiated in 1980, was coordinated by the USGS to acquire aerial photography of the 48 conterminous States every 5 years. Visit <http://edc.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/napp>.

Digital Orthophoto Quadrangles

A DOQ is a digital representation of an aerial photograph with ground features located in their true positions. Displacements in imagery caused by camera tilt, sensor orientation, and terrain relief are removed. DOQs combine the image characteristics of a photograph with the accuracy and scale associated with a map. Though they cannot be used for stereo interpretation, they are an excellent digital base map for onscreen digitizing or review of registration. For more information about DOQs, visit <http://fsweb.gsc.wo.fs.fed.us/>.

Digital Elevation Models

A digital elevation model is a digital data file containing an array of elevation information over a portion of the Earth's surface. This array is developed using information extracted from digitized elevation contours from primary base series maps. For more information, visit <http://fsweb.gsc.wo.fs.fed.us/>.

Satellite Imagery

The USGS National Center for Earth Resources Observation and Science at <http://edcwww.cr.usgs.gov/> provides a variety of satellite imagery.

The Remote Sensing Application Center (RSAC) at <http://fsweb.rsac.fs.fed.us/> is a detached Washington Office Engineering Staff unit located in Salt Lake City, UT. The mission of RSAC is to provide technical support to U.S. Department of Agriculture (USDA) Forest Service resource specialists and managers in the use of remote sensing, image processing, GIS, and related geospatial technologies for all resource applications. RSAC is collocated with the USDA Forest Service Geospatial Service and Technology Center and the USDA APFO.

Hardware and Software Requirements

Field offices should have the most recent corporate hardware and software upgrades, including requirements for NRIS Terra and the TEUI Geospatial Toolkit.

Field Equipment

Appendix H provides a complete list of equipment and sources.

2.3.3 Personnel Requirements

TEUI Team Expertise and Makeup

The LTA development core team should consist of personnel with expertise in geology, soils, and ecology. The core team should be kept small, with no more than three or four personnel. Other personnel have an important role in reviewing and refining the products. Typically, ad hoc USDA Forest Service review teams, as well as interagency and academic reviewers, are involved.

Training and Qualifications

Competent geologists, soil scientists, and ecologists should already have the basic skills to build LTA map units and descriptions. Training in the TEUI Geospatial Toolkit is certainly called for. The core team should make themselves fully familiar with existing relevant literature, data, and maps.

Job Descriptions

Examples of job descriptions are available in appendix I.

2.4 Data Collection

LTA data collection is much less intensive than for development of LTs or LTPs. LTAs can be described by a panel of experts, drawing on existing maps, imagery, publications, experience, and appropriate landscape data or existing LT data can be summarized or reclassified for use at the landscape scale.

Data collection can also be used to predict or identify LTs and their occurrence within potential LTA. Landscape transects are commonly used for this purpose.

2.5 Data Storage

LTA data will typically take the form of attribute tables (such as table 2.2), GIS coverages, and written documentation. Quantitative data are typically summarized from finer scale field data. All LTA data will be stored in the NRIS Terra database. See 2.3.11 part 11b. for additional instructions.

2.6 Analysis

Analysis takes the form of expert teams working with existing maps, data, and publications. Rigorous classification of vegetation or soils usually takes place at finer (LT) scale, and then taxonomic units are aggregated (appropriately) to form units appropriate for LTA scale. For example, for potential vegetation, plant associations can be classified from field plot data, and then these taxa are aggregated and reclassified into new taxa appropriate for use at LTA scale.

2.7 Reporting

See section 2.31, item 13 above. Documentation should at a minimum have rigorous peer review, and ideally be published as a research station general technical report.

Chapter 3. Landtype Protocol

3.1 Objective

The objective of this protocol is to identify the standards and guidelines for developing terrestrial ecological units (TEUs) at the landtype (LT) level of the National Hierarchy. TEUs are areas of relatively stable environments that depict the inherent properties of their ecosystem elements. TEUs are not static, however, and may be refined and updated as knowledge about the ecosystems they capture is accrued. When used in conjunction with information on existing conditions, historical conditions, and ecological processes, TEUs provide a foundation for making sustainable land management decisions.

Ecological units represent consistently repeating portions of landscapes with similar combinations of ecological types. These ecological types represent the distinguishing characteristics of a particular geographic area. Ecological units identify interrelationships among ecological types and establish a tie between observed ecological condition and predicted environmental response. Table 1.1 provides a summary of the Terrestrial Ecological Unit Inventory (TEUI) elements. Detailed descriptions of each element are provided in chapter 1.

3.1.1 Business Requirements

LT and landtype phase (LTP) maps are used for comprehensive forest plan revisions, watershed assessments, burned area emergency rehabilitation efforts, wildlife habitat analysis, and project level implementation and analysis. Interpretations developed from the data are valuable for depicting land capability and potentials.

3.1.2 Products

The LT product is a Geographic Information System (GIS) map layer, developed at a 1:24,000 map scale, which meets all U.S. Department of Agriculture (USDA) Forest Service guidelines for TEUs and is registered to the primary base series maps. TEUI core attribute data are available in the corporate Natural Resource Information System (NRIS) Terra database, and map unit descriptions and ecological type descriptions are documented to the standards described in this technical guide.

3.2 Planning and Design

3.2.1 Ecological Type Classification and Characterization

An ecological type is a category of land with a unique combination of landscape elements. The elements making up an ecological type are climate, geology, geomorphology, soils,

and potential natural community. Ecological types differ from other ecological types in the ability to produce vegetation and respond to management and natural disturbances. Classification of ecological types is used to validate landscape stratifications, assist in map unit design and delineation, and describe map unit components.

Classification of Ecological Types

The classification process organizes and describes relationships between the inherent landscape elements. Preliminary or established ecological types are used to design and assist in the delineation of ecological units. Table 3.1 shows the suggested levels of detail for each element.

Table 3.1. *Suggested level of detail used for classification and mapping at the landscape and land-unit scales.*

Planning and analysis scale	Ecological unit levels	Geology	Geomorphology	Soil	Potential natural vegetation
Landscape	Landtype association (LTA)	Primary lithology or groups of secondary	Geomorphic process and subprocess types	Great group and subgroup	Series and subseries
Land unit	Landtype (LT)	Secondary lithology	Landforms, element landforms, and morphometry	Subgroups, families, and series	Subseries and plant associations
	Landtype phase (LTP)	Secondary lithology	Landforms, element landforms, and morphometry	Series and phases of series	Plant associations and plant association phases

Differentiation Between Ecological Types

At the landtype association (LTA) level, ecological types are driven by geomorphology, but strongly influenced by bedrock geology, parent material, soil subgroups, vegetation series, and climatic effects induced by elevation, growing degree days, or precipitation. Synthesis of data will rely more on existing information and expert panels than at the land-unit scale.

At the LT and LTP levels, ecological types are classified based on differences in potential natural vegetation (PNV), soils, local climate or microclimate, geomorphology, surficial geology, bedrock geology, and/or hydrology. Ecological type classification requires analysis and description of relationships among these elements. This work requires simultaneous analysis of these elements based on integrated plots, transect observation sites, and bedrock geology data.

Statistical analysis is appropriate where sampling is conducted in a random or systematic manner and a large enough sample of the population is present to capture the variability

in the landscape elements. Pattern analysis is suitable for all sampling designs. Pattern analysis methods include gradient analysis, ordination, and classification. Gradient analysis is used to determine the distribution of plant species and soil properties along easily recognized environmental gradients such as elevation and topographic moisture status. Ordination methods are used to detect less obvious relationships among landscape elements.

Naming Ecological Types

Ecological types are named using a minimum of a two-part soil and plant community name. Use soil series name, family name, or classes of soil taxonomy with or without accompanying terms to name the soil portion. Incorporate geologic, geomorphic, and/or landform names, if changes in them constitute differentia among the ecological types. Use the level of soil taxonomy (series, family, or higher category) that is needed to meet the objectives of the survey. Name the plant community portion according to potential natural community (USDA NRCS 2003). Some examples of names are displayed in table 3.2.

Table 3.2. *Examples of ecological type names.*

Code	Short Name (optional)	Long Name (required)
ET022	ABLA/VASC, Guiser family	Subalpine fir/grouse whortleberry, Guiser family
554.1		Lithic Haplustalfs, shallow LSM Pisos/ Loamy-skeletal, very cobbly 5 Quar mixed, mesic, sandy loam 0 ----
ET3001	Prime Giant Sequoia	Giant Sequoia, Holland soils, Granitic, gently sloped, fluvial process dominated
5	Dry Pine	Pinus/Vaccinium, excessively drained sands

Classes of soil taxonomy with or without accompanying phase terms are used to name the soil portion. Incorporation of geologic, geomorphic, and/or landform names is generally encouraged. Use the categorical level of soil taxonomy (series, family, or higher category) that is intended to meet the objectives of the survey. The vegetation portion is also named at the appropriate level for the objectives of the survey and level of documentation. Examples of map unit codes and names are shown in table 3.4.

Ecological Map Unit Design Criteria

Ecological map units are designed to represent the naturally repeating patterns of ecological types across the landscape. The map unit organizes these patterns and describes the interrelationships between the components that occur together in a continuum across the landscape. Be aware that map unit concepts often grade into one another and are not always distinct.

Map Unit Composition

Map units are typically composed of one or more ecological types or components. Ecological types are the taxonomic unit for which the map unit component is named. Ecological types may occur in one or more map units and their properties are derived from wherever that type occurs. The map unit component may also represent a narrower range of characteristics or properties of an ecological type because they are based on that part of the ecological type that occurs spatially within a specific map unit.

Map Unit Kind

TEUI incorporates the concept of “map unit kind” from traditional soil survey methods to help describe the relationships between map unit components. Map units are divided into four categories: (1) consociations, (2) complexes, (3) associations, and (4) undifferentiated groups (USDA NRCS 2003).

Consociations are map units in which one named component is predominant. These units are typical of uniform areas where one ecological type is dominant and can be delineated separately at the LT and LTP level of mapping.

Complexes and associations are map units in which two or more major components occur in regularly repeating patterns. In a complex, the major components cannot be separated at the scale of mapping. In an association, the major components can be separated (USDA NRCS 2003b).

Undifferentiated groups are used when the components are not consistently associated geographically and, therefore, do not always occur together in the same map delineation. These components are included in the same named map unit because their use and management are the same or very similar for common uses.

Major and Minor Components

Map units are composed of one or more major and minor components. Major components typically comprise 15 percent or more of the map unit. Minor components (inclusions) typically comprise less than 15 percent of the map unit. A minor component in one map unit may be a major component in another. Both major and minor components are used to develop the range in characteristics for the ecological type for which a component is named.

3.2.2 Standards

Mapping Standards

- Mapping scale for LTs is 1:24,000 and LTPs at 1:12,000. Use top-down, bottom-up interdisciplinary team approach (Cleland et al. 1997).

- Recommended minimum size delineations are 2 acres for LTPs and 6 acres for LTs.
- Minimum width is 2 mm or 160 feet on the ground at a 1:24,000 mapping scale.
- Linear features such as riparian or wetland areas less than 2 mm wide or less than 6 acres that encompass a stream may be mapped at the 1:24,000 scale as a TEU line segment or mapped as point features and indicated with the appropriate spot symbol.
- LT and LTP are correlated within LTA.

Documentation Standards

Document reliability of map unit characteristics through a systematic data collection process using transects, traverses, and observations. Determine documentation needs based on sampling intensity, level of taxonomic classification, standards requirements, and ecological type variability. Table 3.3 describes minimum levels of documentation. Design of the map units should be consistent with order of sampling intensity as described in the work plan. Table 3.5 describes sampling intensity levels.

Refer to NSSH Part 627.08 for documentation standards for soils in order to meet NCSS statements. A soil map is not required. However, a TEUI map is required in place of a soil map.

Table 3.3. *Minimum levels of documentation for landtypes.*

Landtypes		
Ecological type	Components	Map units
A minimum of three complete integrated plots that represent the concept of the ecological type in the survey area are recorded before an ecological type is added to the descriptive legend. Completed documentation must reflect the geographic and environmental range across which the ecological type is mapped. Representative sites for each ecological type are identified.	A minimum of three complete integrated plots that represent the concept of the component in the map unit are needed. Completed documentation must reflect the geographic and environmental range of the map unit. Integrated plots may be used from transects or traverses within the named map units.	A minimum of three transects with a minimum of 30 sample sites (integrated plots and/or observations) across geographic and environmental range of each map unit are recorded. Completed documentation must reflect the geographic and environmental range of the map unit. Each map unit component must have a complete ecological type description.

Naming Ecological Units

Name ecological units for one or more ecological types or for something that distinguishes and provides a brief description of that unit. Numbers or other brief descriptors may be used for complex units that prove difficult to name. Map unit descriptions must include the full technical names for each element used to characterize the ecological unit. Table 3.4 gives examples of ecological unit names.

Table 3.4. *Examples of ecological unit names for landtypes.*

Map symbol	Map unit name
2641	ABLA-PIEN/VASC, Ivywild Family—ABLA/VASC, Hensen Family—complex, 10–30-percent slopes
554	Lithic Haplustalfs, LSM, 5, 0, loamy-skeletal, mixed, mesic, shallow, very cobbly sandy loam, Pisos/Quar— Lithic Eutroboralfs, LSC, 5, 0, loamy-skeletal, mixed, shallow, very cobbly sandy loam, Pisos/Quga association: 15- to 40-percent slopes
3001	Giant Sequoia, Holland soils, Granitic, gently sloped, fluvial process dominated
5	Fire-dependent, multiple-aged, somewhat brushy, jack/red pine forests of somewhat excessively or well drained sandy/gravelly soils, flat to strongly rolling habitats
30SH123	PIPO/QUGA-Burnac—FETH-Acree complex on lower montane shale hills, 15- to 30-percent slopes
3622	Sedimentary Sideslopes, Big Sagebrush—Tall Forb Complex

Table 3.5. *Sampling intensity levels.*

Level of national hierarchy	Sampling intensity	Field procedures	Kinds of map units	Scales for field mapping
Landtype Phase	Sampling intensity 1—Intensive (i.e., watershed and landscape analysis, burned area rehabilitation analysis, forest and grassland project planning, species habitat modeling).	Collect data and document (integrated plots and/or observation sample sites) 90 percent of polygons for each map unit.	Consociations	1:12,000
Landtype	Sampling intensity 2—Intensive (i.e., watershed and landscape analysis, burned area rehabilitation analysis, forest and some broad scale project planning).	Collect data and document (integrated plots and/or observation sample sites) 75 percent of polygons for each map unit.	Mostly consociations and some complexes	1:24,000
Landtype	Sampling intensity 3—Extensive (i.e., forest planning and broad scale assessment, watershed and landscape assessment).	Collect data and document (integrated plots and/or observation sample sites) 50 percent of polygons for each map unit. LTs are delineated by observation and interpretation of remotely sensed data.	Mostly associations or complexes, and some consociations	1:24,000

Table 3.5. *Sampling intensity levels (continued).*

Level of national hierarchy	Sampling intensity	Field procedures	Kinds of map units	Scales for field mapping
Landtype	Sampling intensity 4—Extensive (i.e., general ecological type information for broad statements concerning land-use potential and general land management).	Collect data and document (integrated plots and/or observation sample sites) 25 percent of polygons for each map unit. LTs are delineated by interpretation of remotely sensed data.	Mostly associations; some complexes and consociations	1:24,000
Landtype association	Use existing information and expert panel.	Verify through existing landtypes or transects with intensity similar to sampling intensity 4 above.	Varies but must be at landscape scale	1:100,000

TEU Map Unit Legend

The TEU map unit legend consists of a map unit symbol and a map unit name.

Connotative Legends

Connotative legends may be used to display differentiating information in the map unit symbol. Connotative legends may be used at any level in the National Hierarchy. In this example of a connotative legend, the map unit symbol is connotative of climate zones and lithology in the survey's ecological section. For this survey area, eight distinct climate zones are defined by soil moisture and temperature; broad vegetation type (e.g., pinyon juniper, ponderosa pine, mixed conifer, spruce fir, and alpine); and associated environmental conditions such as precipitation, snowfall, and elevation. Lithology is denoted using either the primary or secondary lithology classes. Figure 3.1 provides an example of a connotative legend.

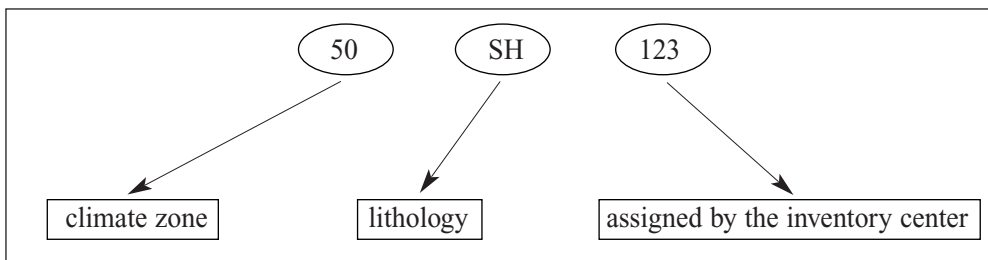


Figure 3.1. *Example of connotative legend.*

The map unit code is the final code applied to a TEU map unit. It is the key field between the database and the TEU GIS map coverage, provides a shorthand reference for map units, and can be used as a tool to query particular information about map units. It also allows the mapper easy recognition and recall of map unit concepts. The map unit code is used in the mapping process to designate polygons on aerial photographs or

quad sheets. Other landscape elements may be substituted in the above example as appropriate.

The TEU map unit code should be connotative (where possible), simple, and meaningful for grouping and sorting TEUs by the main differentiating criteria for the survey area. Following these objectives has proved useful for developing LTAs.

Lists of Valid Values and Codes for TEUI Elements

It is useful to develop a list of valid values and codes for each inventory area, reflecting the range available for each of the TEUI elements for that area. These lists are developed based on the best available information and knowledge of the inventory area. Update them throughout the life of the inventory based on additional knowledge gained through the inventory process. All lists use national definitions and codes. Use appropriate levels of classification listed in table 2.1 as guidelines for each element.

Description of TEUI Map Units

The TEUI map unit description is a summary of information about a map unit throughout its area of occurrence. A map unit description contains information about the composition, distribution, and extent of ecological types as well as the relationships between components. Additional map unit descriptors such as elevation, aspect, slope, mean annual precipitation, frost-free days, and average annual snowfall are also included.

The data necessary to develop a map unit description are generated from information gathered in the field (see appendixes C, D, and E), information gathered electronically (e.g., range in elevation for a map unit using a digital elevation model [DEM]), and information from existing data sources such as soil surveys. Examples of ecological map unit descriptions can be found in appendix F.

Mapping Ecological Units

Mapping begins after the development of preliminary map unit concepts. The landscape is stratified into map units according to established ecological type criteria. The objective is to minimize and characterize the variability within an ecological unit while placing the boundaries where significant changes occur within one or more elements.

Delineation Criteria

Delineation of ecological map units is not always a straightforward process. The delineation process attempts to create meaningful ecological units, and break these units where changes occur on the landscape. Fortunately, dependency among landscape elements

allows the mapper to delineate significant changes in unseen elements such as PNV and soils through proxy indicators such as morphometry, surficial geology, local climate, and landforms.

To consistently delineate ecologic map units, the criteria for delineations must be easily observable at the scale of mapping. For instance, at the LTA scale (1:100,000) it would be unfeasible to use individual soil bodies and PNV as delineation criteria because these elements are not observable at that scale. Instead, more readily available landscape elements such as bedrock geology and vegetation cover types reflecting regional climate would be more appropriate.

Unless all areas of a TEUI are to be field checked, the use of unseen elements such as soils and PNV as delineation criteria will introduce error into the mapping process. Even at sampling intensity 1, in which 90 percent of the polygons are visited, errors will be introduced if these criteria are used to delineate polygons. Instead, the use of readily observable features such as landform, slope morphometry, and local climate would be more appropriate.

The use of observable delineation criteria allows land managers and users of TEUI to more readily recognize ecological units during land management activities. If the user is unable to distinguish where ecological units diverge, then a misinterpretation of the landscape capabilities and management may occur.

Actual line placement criteria (or delineation criteria) are often along areas that show significant change within a single landscape element, such as the change in the slope gradient in a mountain base or footslope position. These delineation criteria will often change as the landscape that they are differentiating changes.

For example, while delineating a polygon of pure quaking aspen, the boundary may be delineated along the vegetative cover change (aspen to sagebrush) segments, along landform positions (backslope to footslope) for other segments, or along aspect changes in yet other segments.

The specific delineation criteria must be selected with the goal of creating consistently repeating map units with one or more components that have distinct capability ratings or management interpretations.

TEUI Attributes Linked to Aquatic Ecological Unit Line Segments, Valley Segments, or Polygons

Map units and components may be linked to a buffered stream line segment or polygon rather than a TEU polygon. This method may be desirable in describing riparian areas that are significant, but either too narrow (i.e., less than 2 mm) or too small (i.e., less than 6 acres) to map as a TEU. In this case, TEU attributes are assigned to the line segment or polygon (in the case of water bodies) associated with the riparian area being described. This attribution of line segments should be coordinated with the existing aquatic inventory if applicable. For example, a small riparian area along a valley segment may coincide with an aquatic ecological unit inventory line segment. In this case, a quality join should be completed with the aquatic inventory, or map units shared between the inventories.

Mapping Landtypes and Landtype Phases

The following procedures are guidelines that apply to mapping the LT or LTP regardless of whether development of the LT or LTP involves new polygon delineation or modification of existing soil survey polygons. The mapping process is more involved than for LTAs and generally takes 2 to 5 years to complete depending on the size, complexity, mapping intensity, and management objectives of the inventory area.

LT and LTP Mapping Process

1. Conduct preliminary field reconnaissance.
 - a. Take field trips and/or overflights of the area to gain a better understanding of the landscape and distribution of ecological types within the survey area.
 - b. Use the TEUI Geospatial Toolkit (USDA Forest Service 2005) to review “virtual flybys,” shaded relief models, distribution of vegetation, landforms, aspect, slope, and elevation gradients to better understand the landscape.
2. Create preliminary polygons.
 - a. Use existing or newly created LTA mapping as a starting point.
 - b. Use stereo pairs of 1:24,000 aerial photography, topographic maps, DEMs, digital orthophoto quadrangles (DOQs), satellite imagery, and other resource maps as appropriate to assist in delineating preliminary polygons.
 - c. Use the TEUI Geospatial Toolkit (USDA Forest Service 2005) to further help define and delineate preliminary map polygons. Use the DOQ image as a base

while using multiple windows to compare delineations as they appear on other resource maps such as satellite imagery, shaded relief, and 3-D-thematic views.

- d. Base delineation on photo interpretive principles using all observable features, and specific criteria and class limits defined in the classification and/or descriptive legends for each of the LT elements.
 - e. Develop a map unit concepts by organizing and grouping polygons with similar combinations of map unit characteristics such as landforms, vegetation, geology, slope, and elevation ranges.
 - f. Use delineation criteria to capture the location of spatial changes in the LT elements, such as landforms, vegetation, geologic structures, and weak and resistant materials whose properties are most observable on aerial photographs.
 - g. Clearly indicate which information is speculative and which is evaluated or derived from premap tools (e.g., slope, elevation, aspect).
 - h. Use caution when relying on visible existing vegetation from aerial photographs or satellite imagery, as it may not represent PNV. Knowing the disturbance history of an area will help locate possible areas where PNV and existing vegetation differ.
3. Develop preliminary map unit legend.
- a. Develop a connotative legend using combinations of the valid values and codes. Indicate if the map unit is provisional, additional, or accepted (USDA NRCS 2003).
 - b. Label polygons on photos, Mylars, and/or in the coverage being created using appropriate digitizing methods.
4. Review or develop new classifications as appropriate.
- a. Ensure soil classification is up-to-date (USDA NRCS 2003b). In some areas, a lack of PNV and geologic information may require limited fieldwork to develop preliminary classifications and legends.
5. Incorporate existing soil survey polygons.
- a. Develop a thorough understanding of the existing information to make decisions regarding the modification of polygon delineations. The purpose should be to retain the design of the existing map units where they meet all LT criteria. In this case, a simple crosswalk from the old map unit code to the new may suffice.

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- b. Because not all existing soil survey map units meet TEUI criteria, understand the difference between modifications that affect the intent of the original map unit design, and those that do not. Many modifications to polygon delineations will not change the intent or design of the original soil survey map units. These modifications will not require additional documentation.
 - c. If necessary, include some modifications that change the central concepts of the original soil survey map units. In this case, additional documentation and field inventory will be necessary to meet NCSS requirements for soils. See 1.5 Soil Survey Program.
 - d. Apply the same standards for mapping the LT regardless of whether new or existing polygon delineation is considered. A number of variables are involved with using existing information, making it difficult to describe an exact process for developing the LT legend. Some of these variables include quality and availability of base maps, availability of aerial photos with original delineation, quality of original delineation, quality and availability of supporting documentation, and personal knowledge of the development of existing information.
 6. Incorporate water bodies.
 - a. Do not delineate water bodies and streams that appear as double lines on the primary base series maps as polygons during LT mapping. These features are incorporated from the core water layer during the map compilation process. Where a water body is completely enclosed by a LT polygon, the water body can be ignored during TEU mapping. Delineate any polygons adjacent to a water body by extending the polygon boundaries to an imaginary intersection in the center of the water body. This boundary will be a temporary misrepresentation of the TEU on the hard copy of the TEU map. The electronic overlaying process will place water boundaries from the water layer onto the TEU map. Water bodies may be delineated on the TEU map with a nonscanable color, if desired. Typically, the water bodies may be imported from cartographic feature files or DOQs.
 7. Conduct field sampling.
 - a. Select a sampling design commensurate with the inventory objectives and standards requirements. Consider the location of the plots on the landscape. In terms of efficiency, a stratified sampling design is best. Other considerations, however, such as time and cost, must be evaluated. Several sampling methods are summarized below. These may include one or a combination of the following methods:

-
- i. *Representative sampling.* Select representative premap polygons and sample typical locations for modal components. Traversing, a method of collecting representative samples, can verify the occurrence of ecological types within map units, develop additional ecological types, and meet documentation standards. Integrated plots should be located in areas of uniform vegetation and environment (i.e., landform, slope characteristics, soils, surficial geology). This technique is not statistically valid, but is suitable for pattern analysis.

Note: This method is biased toward the mapper's professional interpretation of what components to sample. It requires experience and local knowledge of what is being mapped. Sites are selected to capture the modal or dominant properties of each ecological unit component. This method is often the most time-effective and cost-efficient sampling design for ecological units.

- ii. *Random sampling.* Use random-number table or other method to obtain Universal Transverse Mercator coordinates. Establish rule base for handling access problems, disturbance areas, and other situations requiring design alterations.

Note: In practice this method will not be used often because of its inefficiency and high cost in time and funding. A random sample could result in samples clustered in one area, particularly if the sample size is low. One drawback of random sampling is the possibility that the sample will not represent the population (Barber 1988).

- iii. *Systematic sampling.* Select appropriate grid for size and variability of premapped polygons. Establish rule base for handling access problems, disturbance areas, and other situations that require design alterations.

Note: This method has the strength of avoiding bias but may have logistical weaknesses (possibly many plots in remote areas) or be biased by the spatial distribution of the landscape where regularly repeating patterns are not adequately sampled. To eliminate bias, check for randomness in the sampling frame (Barber 1988).

- iv. *Transect sampling.* Generate transect methods to minimize mapping bias. Establish rule base for handling access problems, disturbance areas, and other situations that alter transect layout. Located randomly within each stratification unit, transects should be oriented to capture the maximum variation in key environmental gradients, usually elevation, soil climate,

climate, soil taxa, or site productivity. Transect observation sample sites may include notes and partial descriptions, but must be done consistently.

Note: Transects offer several benefits. They can be used efficiently to incorporate both observation sample sites and intensive plots, thus accomplishing mapping, inventory, and classification objectives in a single field effort. They can be oriented to capture the maximum variation in environmental gradients (usually elevation, but others such as soil drainage or moisture are possible). They are an efficient way to deploy field crews to capture the maximum amount of useful data per hour expended. Their methodology tests the map unit composition for the identified components. If well organized, they eliminate a field crew's need to look for representative sites (or temptation to avoid undesirable types, such as bramble thickets).

- v. *Stratified random design.* A stratified random sample is obtained by forming classes, or strata, from within the inventory area and then selecting a simple sample from each (Barber 1988). Select stratification criteria and apply to the study area. The most common stratification is the ecological map unit component. Within a designated stratification, randomly generate the spatial coordinates for sample location sites. Navigate to the assigned coordinates using Global Positioning System (GPS) technology. Establish a rule base for handling access problems, disturbance areas, and other situations that alter sample design layout.

Note: This design is best suited for inventory areas with less variance or heterogeneity in ecological map unit components. At broader scales, or in highly complex landscapes, the randomness of this procedure may introduce error when the sample size is inadequate to capture the diversity of the landscape. This sample design is most statistically defensible and advantageous when an adequate number of sites are sampled to capture the variation within a given stratification.

- 8. Select sampling location.
 - a. For representative sampling design, select a sampling site that reflects the central concept (i.e., typical condition observed) of the map unit and its components. Care should be taken to avoid micro features or ecotones.
 - b. For random sample designs and transects, do not avoid micro features or ecotones.

-
9. Select an area to test the legends, verify initial delineations, and map unit concepts.
 - a. Perform site characterization by collecting data at integrated plot sites and other observations according to established protocols.
 - b. Complete mapping of the selected area based on information collected during the field sampling, verification, correlation, and quality control processes.
 - c. The steps above are iterative. Extrapolate map unit delineations to areas of high confidence.

Note: The mapping process and field sampling process may be interactive or may occur independently in stages. Important influencing factors include the time of year of mapping, the experience and training of delineators, and the adequacy and completeness of existing TEUI information. In the beginning, the process is generally more interactive with a small amount of delineation followed by field sampling. This process continues until the mappers are comfortable with their ability to accurately photo interpret and extrapolate map unit concept and component concepts of the TEU. As mapping continues, less field verification will be necessary.

10. Track, refine, and correlate ecological units, components, and type characteristics.
 - a. Track documentation amounts by type of observation, update preliminary legend in a timely manner, revise any taxonomic changes, and track all correlation decisions.
 - b. Update map units to approved status when all documentation requirements have been met.
 - c. Check map unit composition through visual inspection and supplemental transects to verify and refine map unit composition estimates.
 - d. Merge or correlate ecological units, components, and ecological types that have similar characteristics, composition, and management interpretations. For example, as new mapping areas are visited in the field, the number of ecological units increases. As they are added, each new unit is progressively checked for significant differences with similar established units. As more map units are added, their properties overlap those of competing units. Correlation maintains significantly different ecological units, while reducing the number of units that have similar management implications, capabilities, and composition.

11. Perform quality control.

- a. Perform quality control checks on mapping, documentation, sampling procedures, and the accuracy and precision of estimates. Ensure TEUI and NCSS standards are met. Design the checks to be carried out during the work plan development process, and progressively during the mapping and classification process. Quality control checks range from scheduled field reviews to daily assists. The mapping team has the primary responsibility of ensuring the application of quality control.
- b. For additional instruction see 3.5.5 Correlation of Ecological Types and Units, 3.5.3 Quality Control and Assurance, and 3.5.4 Quality Control/Assurance Roles and Responsibilities.

12. Enter Data.

- a. Progressively enter data into the NRIS Terra database. Additional regional tables may be needed to ensure more localized interpretations needs are satisfied.

13. Document map units.

- a. Develop block diagrams depicting map unit concepts.
- b. Collect photographs to catalog and document landscapes, vegetations, soils, and geologies.
- c. Assign appropriate classifications.

14. Finalize mapping and classifications.

- a. Finalize legend.
 - i. The legend is considered finalized when all mapping is complete, no new map units are to be added, and no changes are going to be made to ecological types or ecological unit components.
- b. Finalize mapping.
 - i. Match adjacent LT mapping. The completed LT maps should be joined to adjacent survey areas. A quality join must be maintained along the survey boundary. Accomplishing a quality join requires that the map unit delineations, attributes, and interpretations match across the boundary.

-
- ii. Compile mapping onto a stable base. Compilation methods will vary according to specific mapping techniques used on an inventory. Typically, lines are transferred to stable-based Mylar and scanned or digitized into the GIS environment. Alternatively, if onscreen digitizing and/or digitizing tablets are used to maintain or adjust mapping products, this step may not be required.
 - iii. Scan or digitize mapping. All mapping layers should be prepared for scanning or digitizing according to national cartographic standards.
 - c. Finalize any taxonomic classification developments including PNV and ecological type classifications.
15. Finalize descriptions for ecological units and ecological types.
- a. The descriptions of all mapping products are considered final when no subsequent changes are to be made during the current mapping effort.
 - b. Examples of ecological unit and ecological type descriptions are provided in appendix F.
16. Develop interpretations.
- a. Interpretations are to be developed for the ecological types, ecological unit components, and the ecological unit as determined during the work plan development process. The most common interpretation is made on the ecological unit component, as it has the least variability, the easiest field recognition, and most meaningful management implications at the given mapping scale.
 - b. Standard interpretations for soils are provided in the *National Forestry Manual* (USDA NRCS 2000) and the *National Soil Survey Handbook* (USDA NRCS 2003b).
17. Prepare manuscript.
- a. An example of a manuscript format is provided in appendix F.

Mapping Alternatives

The following alternatives are suggested approaches for mapping the TEU. Choose an appropriate method following the evaluation of individual survey areas described in table 1.5.

Because each situation will be unique, the following list is a guideline. The best alternative may be one or a combination of the following alternatives and should be selected after discussion with the regional TEUI specialist.

Crosswalk Existing Mapping

Develop a list of soil survey map units and the new ecological map units to which they correspond, taking care that all ecosystem elements are adequately incorporated and described. Begin with existing delineations. Retain those delineations that meet TEUI criteria. Document those delineations that do not meet TEUI criteria or NCSS standards and propose changes to the original mapping, and/or develop a plan to gather supplemental data to meet TEUI documentation requirements.

It may be possible to make the majority of drafting changes onscreen using DEMs, DOQs, a Landsat Thematic Mapper, and other TEUI tools to help identify where changes are obvious on the original soil survey.

Update Existing Mapping

Use photos or remote sensing as a background with the original soil survey or other ecological unit inventory mapping to evaluate delineations for TEUI landscape elements. Make changes to the original mapping as needed on overlays or onscreen. New polygons must be documented and correlated to existing or new map units, ensuring that all data standards are met.

Conduct New Mapping

Follow the procedures outlined in sections 2.3.1 and 3.2.2 to delineate TEUs.

The cost effectiveness and timeliness of these alternatives should be compared against starting over with a new legend. One recommended method is to randomly select a small area or subset of the inventory area and revise the mapping as needed to meet TEU objectives. Compare the new map to the existing map and evaluate the cost of the revision with the gain of additional information and increase in interpretation accuracy. Determine the cost-benefit relationships of proceeding with the given alternative, and develop the work plan according to the selected alternative.

3.2.3 Existing Information Sources

Base Maps

Primary Base Series Maps

Primary base series maps are large-scale USDA Forest Service maps constructed from U.S. Geological Survey (USGS) topographic quadrangle maps. In addition to the information carried on USGS maps, primary base series maps contain additional USDA Forest Service information such as protracted Public Land Survey System landlines, ownership, USDA

Forest Service route numbers, administrative boundaries, and facilities. For more information, visit <http://fsweb.gsc.wo.fs.fed.us/>.

Aerial Photography

Aerial photography may be used as a base map as well as for field reference. Common types of aerial photography include natural color, infrared, and large format. Using stereo pairs to view landscapes in three dimensions can help interpret landscape elements.

The Aerial Photography Field Office (APFO), Farm Service Agency, is the primary source of aerial imagery for the U.S. Department of Agriculture. More than 10 million images are stored by the APFO, dating from 1955 through the present. For more information, visit <http://www.apfo.usda.gov>.

The National High Altitude Photography program, initiated in 1980, is coordinated by the USGS to acquire aerial photography of the 48 conterminous States every 5 years. Visit <http://edc.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/napp>.

Digital Orthophoto Quadrangles

A DOQ is a digital representation of an aerial photograph with ground features located in their true positions. Displacements in imagery caused by camera tilt, sensor orientation, and terrain relief are removed. DOQs combine the image characteristics of a photograph with the accuracy and scale associated with a map. Though they cannot be used for stereo interpretation, they are an excellent digital base map for onscreen digitizing or review of registration. For more information about DOQs, visit <http://fsweb.gsc.wo.fs.fed.us/>.

Digital Elevation Models

A DEM is a digital data file containing an array of elevation information over a portion of the Earth's surface. This array is developed using information extracted from digitized elevation contours from primary base series maps. For more information, visit <http://fsweb.gsc.wo.fs.fed.us/>.

Satellite Imagery

A variety of satellite imagery is available through the USGS National Center for Earth Resources Observation and Science at <http://edcwww.cr.usgs.gov/>.

The Remote Sensing Application Center (RSAC) at <http://fsweb.rsac.fs.fed.us/> is a detached Washington Office Engineering Staff unit located in Salt Lake City, UT. The mission of RSAC is to provide technical support to USDA Forest Service resource specialists and managers in the use of remote sensing, image processing, GIS, and related geospatial

technologies for all resource applications. RSAC is collocated with the USDA Forest Service Geospatial Service and Technology Center and the USDA APFO.

Use of Existing Inventories

TEUI Evaluation Criteria

An existing inventory meets the basic requirements of TEUI at the land unit scale if it meets the following criteria:

- Soils and ecological types have been correlated within subregion and/or major land resource areas.
- The inventory must use integrated plots as the basis for ecological types. Integrated plots are defined in section 3.3.1.
- Plots must be geospatially located on aerial photos or on a GIS point layer documentation of map units.
- Plot data must be available either as hard copy or electronically.
- An ecological type classification must have been developed according to the methods described in “Use of Soil Surveys” below.
- Ecological type and TEU LT documentation must meet standards as defined in table 3.3.
- Sampling intensity needs must be determined according to table 2.5, with intensity levels that meet the needs of the users.
- Map unit components are described as ecological types.
- Soil classification, description, and documentation meet NCSS standards. See 1.5 Soil Survey Program.

Updating Existing Inventories

Additional fieldwork and analysis are often necessary to meet the above requirements. For example, vegetation, geologic, and geomorphic information should be collected to the standards described in this technical guide to supplement soil descriptions and create ecological types. When soil sample site data cannot be spatially located, collection of additional soil data is required. Every effort should be made to supplement existing data at the exact location where they were originally collected.

Use of Soil Surveys

One of the first decisions to be made in mapping the TEUI is the extent to which existing or ongoing soil surveys will be used. Soil surveys must be evaluated according to the following criteria:

1. Do they meet current NCSS standards as described in this technical guide?
2. Do they meet additional TEUI criteria and standards for geology, landform, and PNV as described in this document?
3. Can ecological type classifications be created using the data available to the soil survey?

The evaluation of a soil survey includes an evaluation in two categories: written documentation (map unit and taxonomic unit descriptions) and maps or delineations. A primary consideration is an acceptable correlation between the map unit descriptions and the actual polygon delineations and their supporting data.

The evaluation process requires knowledge of local conditions (or access to someone who can provide this knowledge), a familiarity with photo interpretation and mapping, and an understanding of soil survey maps and information and how they were developed. As a minimum, the regional TEUI coordinator, TEUI project leader, and forest soil scientist should be involved in this review. The regional ecologist and forest ecologist should also be consulted.

Additional Evaluation Criteria

Evaluate each soil survey map unit description to determine the extent to which geology, landform, and PNV elements have been incorporated and described. Select a representative sample of delineations from the soil survey area for comparison with map unit descriptions. Aerial photographs must be used to evaluate delineations for the landform component. Aerial photos with the original mapping are most desirable.

From this observation, establish the adequacy of the map unit description for geology, landform, and PNV, compared to the standards described in this technical guide. Evaluate the accuracy of map unit boundaries and the concept of each mapping unit.

Evaluate polygon size. Polygon size should be appropriate to the guidelines for the TEUI. Polygons that are larger than the size recommended should be evaluated to determine if more detail is needed. Polygons that are smaller than the size recommended, particularly

less than 6 acres, should be evaluated to determine if they are already recognized as “included,” “other,” or “similar” in another map unit, and for consistency and accuracy of delineation.

Consider the following questions:

- Does the map unit description include all TEUI elements? Does enough data exist to create ecological types from the map unit descriptions? Are inclusions adequately described for each map unit? Does the map unit description include the interrelationships among components where they can be determined? Are the scale of mapping and size of polygons consistent with the TEUI? Are riparian areas and wetlands delineated according to the TEUI size criteria?
- For geology: What is the source of the geology information used in the soil survey? Is more detailed or updated information available that was not used in the soil survey? Do the soil survey map units and components adequately describe lithology and/or parent/surficial materials? Are the interrelationships between geology and other landscape elements described?
- For landform: Does the soil survey map unit describe landforms? Can the landforms described be crosswalked to the valid values listed in this technical guide? Do soil survey polygon delineations correlate well with descriptions of landform in the map unit? Do delineations of the same map unit consistently identify the same landforms? Are the landforms listed consistent with their related parent material descriptions? Can landforms be combined or aggregated to meet the inventory’s purpose?
- For PNV: Do soil survey map units describe PNV? Are relationships to soils and microsite established where possible? Are the variability and level of description acceptable for TEUI mapping (i.e., information appropriate to scale)? Do polygon delineations correlate well with descriptions of PNV in the map unit? Are there species lists and indications of species composition at site locations?

Use of Riparian Inventories

Evaluate existing riparian inventories to determine whether they meet TEUI polygon delineation criteria. Transfer existing riparian delineations that meet TEUI criteria to either aerial photos or the prepunched, matte Mylar. Either riparian polygons should be correlated with existing TEUs or new map units should be proposed and documented.

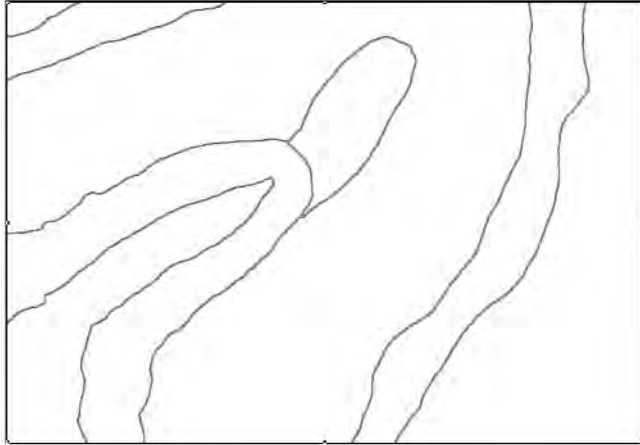


Figure 3.2. *Original soil survey mapping.*



Figure 3.3. *Original soil survey mapping with image in background.*



Figure 3.4. *Black lines represent new delineations meeting TEUI criteria.*



Figure 3.5. *Final TEUI map.*

Incorporation of Valley Segments

Where valley segments have been identified as part of the Aquatic Ecological Inventory, they should be incorporated into TEU mapping.

3.2.4 Work Plans

For LTs and LTAs, execute the following major planning steps:

- Establish memorandum of understanding (MOU) to specify the conduct of TEUI with cooperating agencies. As a minimum, the MOU must address the management and administration of the soils portion of the TEUI and address NCSS standards for classification, description, and documentation.
- Identify primary users of the inventory data. The needs of users affect the design of map units and guide the style of reports.
- Collect and evaluate existing information pertinent to the inventory area, such as previous soil resource inventories, plant community classifications, landform descriptions, and geology legends.
- Determine inventory leadership responsibilities. Verify assignments and clarify understandings between soil scientists, ecologists, and others on the size, purpose, procedures, and products of the inventory. Identify the what, where, who, when, and how to do the job. Document the assignments in the TEUI work plan or the memorandum of understanding.
- Ensure that data collection plans are consistent with the objectives and required standards of the inventory.

-
- Evaluate adequacy of personnel (time and expertise), equipment, and funding to accomplish the work. Analyze methods (detailers, helicopters, contracting). Clarify management needs for successfully accomplishing the inventory.
 - Schedule periodic quality control and assurance reviews.

Work Plans for Inventory Areas

Prepare work plans for all TEUIs. Submit work plans to the regional office for approval/review and incorporation into the region's Inventory and Monitoring Program Plan. In addition to serving as a record of purpose, the work plan provides specifications, participant responsibilities, report plans, and a general work schedule. The work plan also provides the participants with a common understanding of the product to be produced, and guides ecologists, geologists, and soil scientists in organizing and conducting the inventory. The content of a work plan should include the elements described below.

Purpose for Doing the Work

Specify inventory objectives with sufficient detail to support recommended inventory intensity and map unit design. The main objective is to produce a product for current and future resource management and forest planning needs. It must be cost efficient and maintain technical integrity of mapping procedures. Determine specific information requirements by consulting potential users and other specialists, and by reviewing pertinent documents such as the forest plan. Coordinate with other resource specialists to design the inventory to meet multiple needs for information. When survey areas contain large areas of land with different management direction, develop objectives for each area. For example, an area that contains classified wilderness and intensively managed forest will generally require an inventory with two different sampling intensities, map scales, and mapping techniques. The mapping detail should be identified. Use inventory sampling intensity levels as defined in table 2.5.

Description of the Work Area

Describe location, physiography, climate, and vegetation of the inventory area. State the ownership and acreages of lands to be inventoried. Supply a general location map.

Cooperating Agencies and Their Responsibilities

List responsibilities of, and expected contributions from, cooperating agencies, if applicable.

Specifications and Plans

Develop specifications consistent with the objectives of the inventory. Accomplish ecological map unit design and interpretations in an interdisciplinary manner. Identify disciplines and expertise necessary to assist in this effort. Include scientifically defensible methods for data collection needed to describe potential and existing vegetation, soil, topographic features, geology, landform, hydrologic function, and climate information significant for management. Describe classification systems and data analyses to be used for these elements, and procedures for integrating these data into ecological type classifications.

Describe additional needs including map compilation and finishing, word and data processing, and contracting specifications. Identify the final products. Describe manuscript format and content. Identify map scale. Establish timeframes and assign responsibility for manuscript preparation, review, and distribution. Specify plans to consolidate and/or incorporate mapping from other inventory areas to meet management needs.

Special Studies

Work plans should include specifics of special studies conducted to supplement needed survey information. Some examples of special studies may include soil temperature and moisture, management responses, geomorphic studies, botanical sampling, and soil chemical analysis.

Signature Blocks

Include appropriate signature blocks for approving officials.

Memorandum of Understanding

Develop MOUs as appropriate to document the relationships and expectations of agencies involved in TEUI.

Annual Plan of Operation

The annual plan of operation serves as the guide for inventory progress measurements during quality control reviews. It is developed annually as progress brings inventory into new stages of the work plan. Include the amount of work completed and an appraisal of the remaining work. Estimate time required to complete inventory and schedule work for the current fiscal year. Include targeted acres, amount, and kind of supporting data, sampling for lab analysis, interpretation development, a schedule of reviews, plans for report writing and map finishing, and training of personnel and resource managers.

Inventory and Monitoring Program Plan

TEUIs should be incorporated into the region's Inventory and Monitoring Program Plan. The Inventory and Monitoring Program Plan is developed to support assessments, forest plan revisions, and determine program needs. The plan also is used to develop a realistic forecast of national needs and provides a basis for program accountability and funding of inventories.

Note: See section 3.6.2 for further description of the Inventory and Monitoring Program Plan.

3.2.5 Logistics

Schedule

Consider local weather patterns, timing of snowmelt, runoff, and greenup of vegetation when scheduling field activities.

Facility and Equipment Needs

Office Space

Office space for the TEUI crew should be located as close to the survey area as possible and include sufficient room for light tables, desks, and access to Government computers and networks for data acquisition. Ideally the crews will share the same work area to facilitate communication of classification and mapping concepts.

Field Camps

Field camps may need to be located at facilities closer to the sampling areas, including ranger stations, work centers, guard stations, campgrounds, or other government facilities. Sometimes it may be necessary to set up spike camps to access very remote areas. Accessing such areas may include travel by all-terrain vehicle, by four-wheel-drive vehicle, by boat, on foot, on horseback, or by helicopter. Planning of such trips requires that all crew members have a thorough knowledge of the area including access points, landmarks, trails, and landing zones, and must also take into account safety concerns of backcountry travel. These concerns may include, but are not limited to, steep and rugged topography; weather-related hazards such as lightning, flooding, extreme heat or cold; and the potential for incidents with dangerous animals.

Field Equipment

A complete list of equipment and sources can be found in appendix H.

Hardware and Software Requirements

Field offices should have the most recent corporate hardware and software upgrades including requirements for the NRIS Terra database and the TEUI Geospatial Toolkit.

Personnel Requirements

TEUI Team Expertise and Makeup

TEUI field crews must have expertise in geology, soils, climate, plant taxonomy, and ecology. The TEUI requires expertise in conducting a systematic (cause/effect) evaluation of the relationships among the elements that make up the ecological types. Team members must be able to conduct analyses that integrate those landscape elements into ecological types.

The TEUI team is typically composed of a project leader and crew members with the skills described above. The project leader should have adequate experience conducting TEUI, supervision, and program management. Crewmembers should be specialists in at least one of the above disciplines, but a crew will not always have a specialist representing each field. The TEUI team should also have expertise in GIS and database analysis.

Training and Qualifications

Each team member will have a training and development plan. Suggested training plans and courses are listed in appendix I.

Job Descriptions

Examples of job descriptions are available in appendix I.

3.3 Data Collection

3.3.1 Field Data Collection—Standards and Methods

Integrated Plots

Data must be collected in an integrated manner. Vegetation, soils, landform, surficial geology, and bedrock, where available, must be fully described for every sample site used to establish an ecological type and document a map unit.

At a sample site, a plot should be uniform in environment and vegetation, and large enough to include the normal species composition of the stand. The vegetation must be homogeneous over a large enough area to completely include the sample plot. Obvious ecotones, or sites lacking environmental uniformity, are not suitable for sampling.

The sample site should exhibit minimal effects of historical land use or recent disturbance. Some sites initially targeted for sampling will prove to be unsuitable when examined in the field. Acceptable sample sites include the following criteria:

- Minimum age for the overstory.
- Minimum canopy closure for forested types.
- No evidence of old homesteads, roads, fields, etc.
- Absence of exotics and low abundance of early successional species in the understory.
- Minimal evidence of recent cutting, thinning, underplanting, grazing, or other management-related disturbance.

Required and Optional Fields (Attributes)

Core attributes represent the minimum plot level data required to meet the national TEUI protocol. See 3.3.2 Field Forms and 3.3.3 Integrated Plot Standards for required core attributes or data standards.

Optional attributes are those identified as commonly desired by many regions to facilitate classification and characterization, or to develop interpretations. Optional attributes recognized by the TEUI protocol are included to lend credibility, database support, and standardization of these attributes. Regional TEUI program managers may choose to upgrade certain optional attributes to required attributes (core) for their region.

All core attributes in the national TEUI protocol will be supported in the NRIS Terra database and follow national standards. Support means that data entry and edit forms are provided and applications and reports will be developed to use this information. All optional attributes recognized in the national TEUI protocol can be accommodated in the NRIS Terra database. Data entry screens and database fields can hold this information. Corporate tools, however, will be driven largely by corporate or core data. Data collected at a region's discretion beyond the core and optional attributes listed in this document may not necessarily be accommodated in the NRIS Terra database and might not follow a national standard. Coordinate with regional and national stewards on such matters.

3.3.2 Field Forms

The following TEUI forms organize the elements of TEUI based on theme:

- **General Site Data Form.** Data recorded on this form describe basic information about the site such as location, examiners, slope, elevation, ground cover, etc. This information is collected for both integrated plots and observation sites.
- **Ocular Macroplot Form.** This form contains a basic set of field attributes that characterize vegetation composition and structure at integrated plots to support ecological classification.
- **Tree Measurement Form.** This form is used to record data for individual tree measurements. This type of data should be collected where appropriate to derive productivity, stand structure, and related interpretations.
- **Geologic and Geomorphic Forms.** These forms contain attributes on geologic and geomorphic data that characterize the site.
- **Soil Pedon Description Forms.** These forms contain a detailed set of soil pedon data that characterize the site.

The NRIS Terra database houses the data from the above field forms. Data is entered through the NRIS Terra module using ORACLE forms. Instructions are found in the <http://fsweb.sandy.wo.fs.fed.us/terra/>.

Use of Other Forms

The TEUI field forms in this document were developed in conjunction with TEUI and NRIS personnel. All data items on all forms can be entered into the NRIS Terra database unless otherwise noted. Regions may choose to use an alternate form, condense the TEUI forms, or alter form layout as long as core data fields are maintained. For example, a region may choose to print forms that show only the fields required for that region (national core plus optional fields determined by region). The data entry forms in the NRIS Terra database, however, closely emulate the field form layout and column order as presented in this document.

3.3.3 Integrated Plot Standards

Standard methods of data collection for soil, geology, geomorphology, and vegetation are referenced or described below.

Sample Site/Plot Locations

Sample site data should be located on air photos by a pinprick identifying the location of the integrated plot and the sample site ID should be clearly labeled in permanent ink on the back. A point layer should then be created. The point layer may be developed by using DOQs as a background for onscreen digitizing, transferring the point from the photo to a Mylar overlay and digitizing, or by building the layer electronically using GPS coordinates recorded in the field. The sample site ID is then entered into the database along with the plot information.

Care should be taken to compare GPS-derived sample site locations with points on the photos or base maps. Because of poor GPS satellite configurations or GPS reception, accuracy of GPS-derived locations may be lower than the location as determined manually in the field. These areas are readily discovered when the GIS point coverage from the GPS coordinates is crosschecked with the locations on the photos or base maps.

Soil Data

Soil pedon data is collected according to NCSS standards. Use codes and procedures in the NRCS publication *Field Book for Describing and Sampling Soils* (Schoeneberger et al. 2002). A soil pedon data form, instructions, and codes are also included in appendix E. For landforms and parent materials, use terms in appendix D. Soil and map unit data are entered into corporate systems.

Geologic Data

Geologic information should be collected according to the standards in the Forest Service Manual 2881. Describe surficial geology origin and kind using the terms and definitions listed in the NRIS Terra data dictionary. Also note depth to bedrock where observed.

Geomorphology

Geomorphic information is collected to the standards in *A Geomorphic Classification System* (Haskins et al. 1998). That volume also describes how to collect the morphometric characteristics listed in table 2.8. Data types and valid values are listed in appendix D. At a minimum, plot locations will be assigned a classification from the list of hierarchy geomorphology classes in appendix E to describe the dominant, active landform-process relationship.

Vegetation Data

Several general methods have been identified as acceptable for collecting vegetation cover data at the scale appropriate for classification of ecological types. These methods include ocular macroplots; multiple small plots or frames; and variable-radius plots (used for determining density and basal area of live trees and snags).

Presampling tests should be conducted to determine minimum plot size and number of replications needed to capture the variability of the site. Plot size must equal or exceed the minimal area of the plant community in the stand. The required minimum plot size varies within wide limits, depending on vegetation formation and stratum. The actual size needed can be determined from a minimum area curve (i.e., by plotting number of species against plot size). As a rule of thumb, a single representative plot meets the minimal area requirements when enlarging the plot adds no or very few new species. Plots larger than the minimal area provide acceptable data but are less efficient in terms of resources required to accomplish the sampling. If plots are too small, floristic data will not be adequate for developing a vegetation classification. Distinct advantages often exist to using different plot layouts depending on site conditions, types and amounts of vegetation, and variability of vegetation.

3.4 Data Storage

Natural Resource Information System Terra

Map unit, component, and ecological type data are entered in the NRIS Terra database. Specific instructions and help are available in the NRIS Terra data entry guide and online in the database application at <http://fsweb.sandy.wo.fs.fed.us/terra/>.

Geographic Information System Data Dictionary

GIS layers for the LT and LTP levels meet the requirements in the GIS data dictionary. Visit <http://fsweb.wo.fs.fed.us/im/standards/gis/coredata/> for more information. GIS layers include the following elements:

- Polygon coverage composed of map units.
- Line coverage.
- Point coverage containing point locations of integrated plots.

National Soil Information System

Data to be entered in NASIS will be governed by the MOU and work plan. As a minimum, field units must provide soils documentation (USDA NRCS 2003b, part 627.08) to NRCS for correlation purposes, with the exception of a soil map.

3.5 Analysis

3.5.1 Data Summaries

Typical data summaries for map units include acres, slope, elevation, aspect, curvature, number of plots, etc. Typical summaries for components include location of integrated plots and type location, ranges in characteristics and properties for soils, vegetation, geology, geomorphology, and slope shape.

3.5.2 Synthesis and Interpretation

Data Analysis to Develop Vegetation Classifications

The entire vegetation classification process, from initial literature review to final published classification, is outlined in section 2.21 of the *Existing Vegetation Classification and Mapping Technical Guide* (Brohman et al. 2005). We focus here on the data analysis step of their process. Discussion is limited to potential vegetation, and assumes familiarity with basic concepts of statistics such as whether data are normally distributed or non-parametric, measures of variance and central tendency, etc. We will further assume that the objective of analysis is to identify patterns in vegetation community data to classify those communities, and then use environmental data (slope, aspect, soil depth, etc.) to relate those communities to environmental gradients. (For examples, see Spies and Barnes 1985, Shumar and Anderson 1986, or McCay et al. 1997). Cleland and Ramm provide a useful, concise literature review of multivariate analysis techniques used in ecological classification (<http://www.ncrs.fs.fed.us/gla/reports/ecs-methods.pdf>). The reader is also strongly advised to obtain and study *Analysis of Ecological Communities* (McCune et al. 2002) as a guide to the analysis of vegetation community data.

Such analysis goes beyond basic statistical analysis in that it involves many variables (hence multivariate analysis), and we often look for consistent patterns in vegetation abundance rather than compare means. The work, therefore, takes on a descriptive as well as analytic nature. Furthermore, one concise answer does not generally arise from this iterative process that classifies the data with more and more confidence as successive analysis shapes a clearer picture of how the data should be grouped—and how consistently it relates to realities on the ground. Classification is a skill that develops over months.

Figures 3.6 and 3.7 provide useful flowcharts to outline the data analysis process. Figure 3.6 shows that the data are first entered, checked, and cleaned. Ensure that data are entered in a format consistent with the data analysis software package. This time-consuming process can be greatly simplified by using field data recorders.

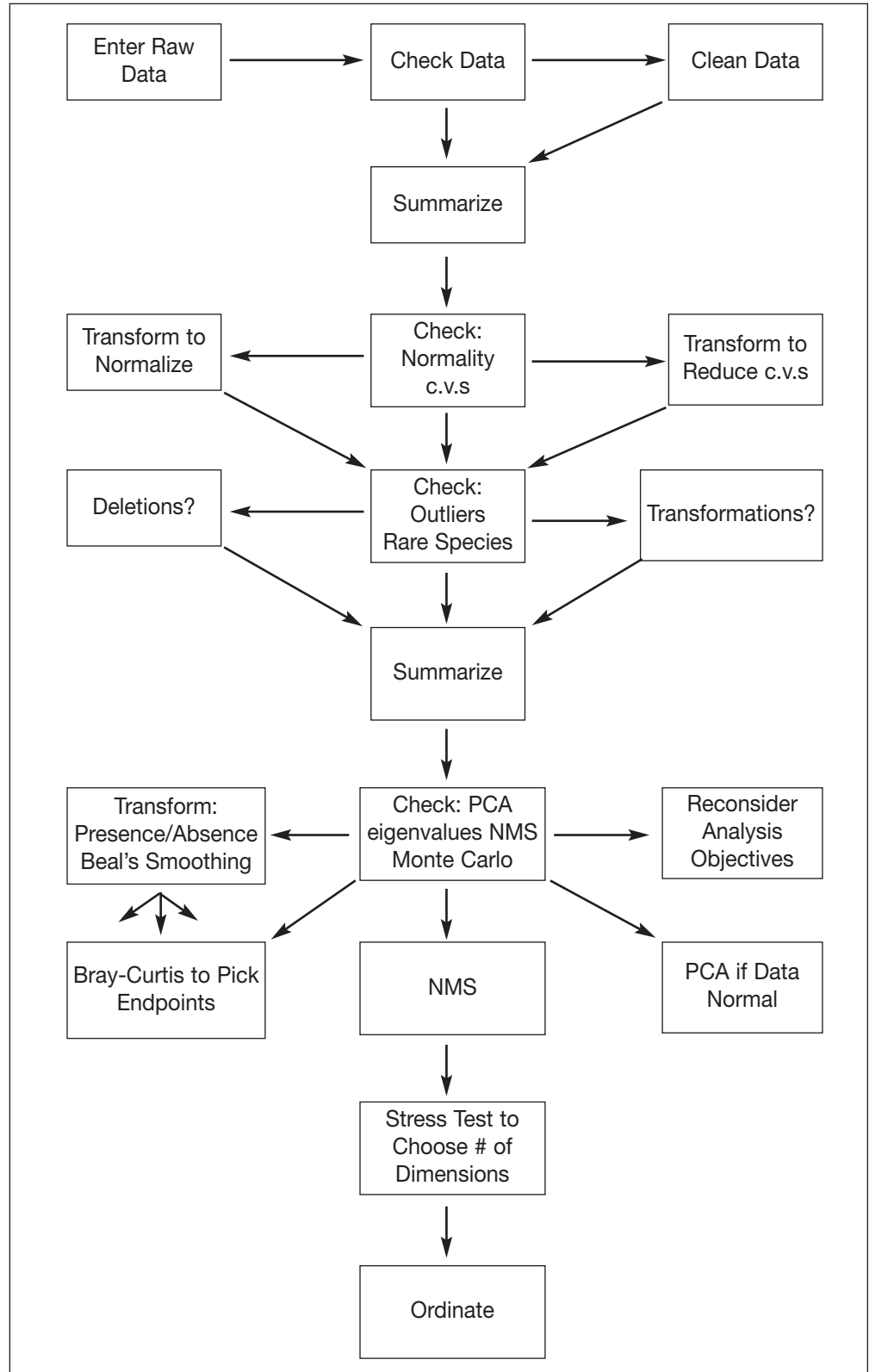


Figure 3.6. Typical analysis flow for community data. Figure courtesy of Jeri Peck, *Ecostats*.

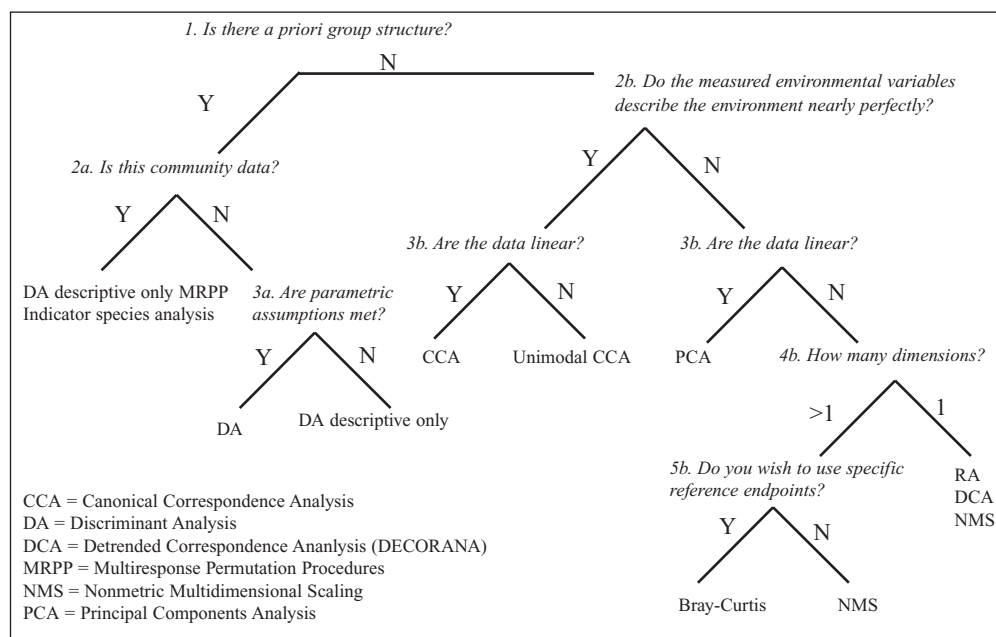


Figure 3.7. *Selecting an analysis technique. Figure courtesy of Jeri Peck, Ecostats, and Bruce McCune, Oregon State University.*

Data are then summarized to get some basic ideas about the data set. Data used to develop vegetation sets typically consists of a species abundance by plots matrix. The plot numbers can identify the rows of species abundance data, with one column for each species. (Alternately, the columns can be plot numbers with one row for each species, known as a transposed matrix.) The count of species, the number of times a species occurs, its average cover, and the range in its cover values are all data summaries typically generated for a data set. Another value of generating a summary is that rare species (those occurring only a few times or less) can be identified. Excluding rare plant data from an analysis often will improve the results because rare occurrences of a species can distort the patterns generated in clustering and ordination routines.

Identifying outliers is related to identifying rare species. Outliers are data points with values far outside the normal range of data variation (more than two standard deviations from the mean is a common rule of thumb). Outliers can greatly skew results and distort plant community data patterns. Software programs can identify outliers. When analysis seeks to identify vegetation patterns, removing outliers from a data set is desirable and is not cheating. We are not looking for significant differences between means, but instead discerning the significance of patterns.

Transformations are also useful during the data preparation process, particularly with environmental data such as slopes, elevations, aspects, tree basal area, etc. If we are comparing tree basal areas ranging from 20 to 160 square feet per acre with elevations that run from 900 to 4,600 feet above sea level, the difference in units and the difference in scales can distort results. In these cases, it is desirable to normalize the data by converting all variables to the same scale but using each value as a percent of the total possible value in its range.

Another common transformation is the arcsin transformation, where percent data is converted to a decimal number to approximate a normal distribution. Aspect data are transformed using the formula in Beers et al. (1966). Other transformations are possible. We aim to standardize and normalize data when necessary, not change it so we get a more desirable answer.

After the completion of these data preparation steps, we are ready to begin analysis. Summaries are a good first step. Species in a species-plot matrix can be summarized by how often they occur, their average occurrence, and their range of values. Sort them by lifeform, listing the overstory tree species first, then the understory trees, followed by shrubs, and then the herbaceous layer. Another value of summarization is that species that seldom occur in the data set can be excluded from future analyses. As with excluding outliers, excluding these uncommon species can avoid distortions.

Analyses now fall into two groups: clustering and ordination. A variety of analysis programs can perform these routines, and are detailed in McCune et al. (2002). Figure 3.7 provides some guidelines on selecting analysis techniques. Note that each method has its strengths and weaknesses. A variety of analysis methods should be used, and if they generate roughly the same result, a correct picture of the ecological reality is probably being developed. In contrast, a method that gives starkly different results from most other methods would be strongly suspect and could be discarded.

Clustering, in which samples are grouped by similarity, is generally performed first. In the more sophisticated ordination analysis, samples are arranged (or ordinated) along axes of ecological space based on the multiple relationships of the plant species and their abundances to each other. The strength of these relationships is measured with eigenvalues. High eigenvalues mean a good deal of variation is being explained by the ordination. The axes of the ordination generally correspond to environmental gradients. Elevation and available moisture are two common gradients explaining most of the variation in a data set. Canonical correlation can be used to formally relate these axes to environmental attributes; with other ordination programs (such as correspondence analysis and multidimensional scaling), these relationships are only inferred.

Interpretations

Interpretations can be developed by selecting appropriate attributes for analysis and display and/or combining TEU attributes/interpretations with other sources. The following tables are a subset of typical attributes and interpretations commonly derived from the TEU information. Documentation of new interpretations should include what data are used, how they are developed, and what assumptions are made.

Attributes Used for Analysis and Characterization

Table 3.6 provides a list of commonly used LT component data attributes used in analysis, display, and interpretation.

Soil Interpretations

Standard soil interpretations are generated from the NRCS NASIS database and the criteria are documented in the *National Forestry Manual* (NFM), the *National Soil Survey Handbook* (NSSH), and *National Range and Pasture Handbook*. Generally, the criteria may be supplemented for local or regional use. Table 3.7 provides a list of recommended soil interpretations for LTs. All interpretations are based on the soil component and care should be taken when aggregating ratings to the map unit level. When map units have multiple components, percent composition should be used to adjust ratings depicted on GIS map displays and in analysis procedures. Adjustments may include dominant soil component, dominant interpretive condition, most limiting component, least limiting component, or others as appropriate for the interpretive use being considered.

Table 3.6. *Data attributes used in analysis, display, and interpretation.*

Planning and analysis scale	Interpretation/ attribute	Description	Reference
Land unit	Runoff potential	Surface runoff refers to the loss of water from an area by flow over the land surface. The estimation of the amount of runoff is important to hydrologic models in assessing the streamflow and water storage.	NSSH 2002
Land unit	Available water holding capacity	Available water capacity is the volume of water that should be available to plants if the soil, inclusive of fragments, were at field capacity. It is commonly estimated as the amount of water held between field capacity and wilting point, with corrections for salinity, fragments, and rooting depth.	NSSH 2002
Land unit	Drainage class	Drainage class identifies the natural drainage condition of the soil. It refers to the frequency and duration of wet periods.	NSSH 2002
Land unit	Hydrologic group	Hydrologic group is a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to a seasonally high water table, intake rate and permeability after prolonged wetting, and depth to a very slowly permeable layer. The influence of ground cover is treated independently.	NSSH 2002
Land unit	Erosion hazard	Erosion hazard is the hazard of soil erosion	Defined locally
Land unit	K-factors	Soil erodibility factors (Kw) and (Kf) are erodibility factors that quantify the susceptibility of soil detachment by water. These erodibility factors predict the long-term average soil loss, which results from sheet and rill erosion under various alternative combinations of crop systems and conservation techniques. Factor Kw considers the whole soil, and factor Kf considers only the fine-earth fraction, which is the material less than 2.0 mm in diameter.	NSSH 2002
Land unit	Hydric soil rating	A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. Hydric soils along with hydrophytic vegetation and wetland hydrology are used to define wetlands.	NSSH 2002
Land unit	Flooding frequency and duration	Flooding is the temporary covering of the soil surface by flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources. Shallow water standing or flowing that is not concentrated as local runoff during or shortly after rain or snowmelt is excluded from the definition of flooding.	NSSH 2002
Land unit	Organic matter percent	Organic matter percent is the weight of decomposed plant and animal residue and expressed as a weight percentage of the soil material less than 2 mm in diameter.	NSSH 2002
Land unit	Slope stability	Defined locally	

Table 3.7. *Recommended soil interpretations for landtypes.*

Planning and analysis scale	Interpretation name	Description	Reference
Land unit	Potential erosion hazard (road trail)	Potential erosion hazard is the hazard or risk of soil loss from unsurfaced roads/trails.	NFM (1998)
Land unit	Potential erosion hazard (off-road/off-trail)	Ratings indicate the hazard or risk of soil loss from off-road and off-trail areas after disturbance activities that expose the soil surface.	NFM (1998)
Land unit	Soil rutting hazard	Ratings indicate the hazard or risk of ruts in the uppermost soil surface layers by operation of forest equipment. Soil displacement and puddling (soil deformation and compaction) may occur simultaneously with rutting.	NFM (1998)
Land unit	Road suitability (natural surface)	Road suitability is the suitability for using the natural surface of the soil component for roads by trucks for the transport of logs and other wood products from the site.	NFM (1998)
Land unit	Log landing suitability	Log landing suitability is the suitability of the soil at the forest site to serve as a log landing.	NFM (1998)
Land unit	Construction limitations for haul roads and log landings	Ratings reflect limitations for constructing haul roads and log landings.	NFM (1998)
Land unit	Harvest equipment operability	Harvest equipment operability is the suitability for operating harvesting equipment.	NFM (1998)
Land unit	Mechanical site preparation (surface)	Ratings indicate the suitability of using surface-altering soil tillage equipment.	NFM (1998)
Land unit	Mechanical site preparation (deep)	Ratings indicate the suitability of using deep soil tillage equipment.	NFM (1998)
Land unit	Hand planting suitability	Ratings indicate the expected difficulty of hand planting.	NFM (1998)
Land unit	Mechanical planting suitability	Mechanical planting suitability is the difficulty of planting tree or shrub seedlings using a mechanical planter.	NFM (1998)
Land unit	Shallow excavations 620-1	Shallow excavations are trenches or holes dug in the soil to a maximum depth of 5 or 6 feet. They are used for pipelines, sewer, and telephone, and power lines. Trenching machines or backhoes are used to make shallow excavations.	NSSH Interpretive Guide (1993)

Table 3.7. *Recommended soil interpretations for landtypes (continued).*

Planning and analysis scale	Interpretation name	Description	Reference
Land unit	Local roads and streets 620-5	Local roads and streets are those roads and streets that have all-weather surfacing (commonly of asphalt or concrete) and that are expected to carry automobile traffic year-round. The roads and streets consist of (1) the underlying local soil material, either cut or fill, which is called “the sub-grade”; (2) the base material, which may be lime-stabilized soil, cement-stabilized soil, gravel, or crushed rock; and (3) the actual road surface or street pavement, which is either flexible (asphalt), rigid (concrete), or gravel with binder in it. They are graded to shed water, and conventional drainage measures are provided. With the probable exception of the hard surface, roads and streets are built mainly from the soil at hand.	NSSH Interpretive Guide (1993)
Land unit	Roadfill 620-7	Roadfill consists of soil material that is excavated from its original position and used in road embankments elsewhere. The evaluations for roadfill are for low embankments that generally are less than 6 feet in height and are less exacting in design than high embankments, such as those along superhighways. The rating is given for the whole soil, from the surface to a depth of about 5 feet, based on the assumption that soil horizons will be mixed in loading, dumping, and spreading. Criteria, limits, and restrictive features for rating soils for local roads and streets are provided in the NSSH (1993). Soils are rated as to the amount of material available for excavation, the ease of excavation, and how well the material performs after it is in place.	NSSH Interpretive Guide (1993)
Land unit	Sand source 620-8	Sand as a construction material is usually defined as particles ranging in size from 0.074 mm (sieve #200) to 4.75 mm (sieve #4) in diameter. Sand is used in great quantities in many kinds of construction. Specifications for each purpose vary widely. The intent of this rating is to show only the probability of finding material in suitable quantity. The suitability of the sand for specific purposes is not evaluated.	NSSH Interpretive Guide (1993)
Land unit	Gravel source 620-9	Gravel as a construction material is defined as particles ranging in size from 4.76 mm (sieve #4) to 76 mm (3 inches) in diameter. Gravel is used in great quantities in many kinds of construction. Specifications for each purpose vary widely. The intent of this rating is to show only the probability of finding material in suitable quantity. The suitability of the gravel for specific purposes is not evaluated.	NSSH Interpretive Guide (1993)
Land unit	Topsoil 620-10	The term “topsoil” has several meanings. As used here, the term describes soil material used to cover an area so as to improve soil conditions for the establishment and maintenance of adapted vegetation.	NSSH Interpretive Guide (1993)
Land unit	Soil reconstruction material for drastically disturbed areas 620-11	Soil reconstruction of areas drastically disturbed, as in surface mining, is the process of replacing layers of soil material or unconsolidated geologic material, or both, in a vertical sequence of such quality and thickness that a favorable medium for plant growth is provided.	NSSH Interpretive Guide (1993)

Table 3.7. *Recommended soil interpretations for landtypes (continued).*

Planning and analysis scale	Interpretation name	Description	Reference
Land unit	Camp areas 620-12	Camp areas are tracts of land used intensively as sites for tents, trailers, campers, and the accompanying activities of outdoor living. Camp areas require such site preparation as shaping and leveling in the areas used for tents and parking areas, stabilizing roads and intensively used areas, and installing sanitary facilities and utility lines. Camp areas are subject to heavy foot traffic and some vehicular traffic.	NSSH Interpretive Guide (1993)
Land unit	Picnic areas 620-13	Picnic areas are natural or landscaped tracts used primarily for preparing meals and eating outdoors. These areas are subject to heavy foot traffic. Most vehicular traffic is confined to access roads and parking lots. Soils are rated on the basis of properties that influence the development costs of shaping the site, trafficability, and the growth of vegetation after development.	NSSH Interpretive Guide (1993)
Land unit	Paths and trails 620-15	Paths and trails are used for walking, horseback riding, and similar uses and require little or no cutting or filling. The soils are rated based on the properties and qualities that influence trafficability and erodibility.	NSSH Interpretive Guide (1993)
Land unit	Off-road motorcycle trails	Off-road motorcycle trails are primarily for recreational use. Trails for other off-road vehicles may have similar criteria. Little or no preparation is done to the trail, and the surface is not vegetated or surfaced. Considerable compaction of the soil on the trail is expected.	NSSH Interpretive Guide (1993)
Land unit	Pond reservoir area 620-28	A pond reservoir area is an area that holds water behind a dam or embankment.	NSSH Interpretive Guide (1993)
Land unit	Excavated ponds (aquifer-fed) 620-30	An aquifer-fed excavated pond is a body of water created by excavating a pit or dugout into a ground-water aquifer. Excluded are ponds that are fed by surface runoff and embankment ponds that impound water 3 feet or more above the original surface.	NSSH Interpretive Guide (1993)
Land unit	Pesticide loss potential—leaching 620-35	“Pesticide loss potential—leaching” is the potential for pesticides to be transported by percolating water below the plant root zone. Pesticides in ground-water solution are leached from the soil surface layer and transported vertically or horizontally through the soil and vadose zone by percolating water. Leaching pesticides have the potential to contaminate shallow and deep aquifers, springs, and local water tables.	NSSH Interpretive Guide (1993)

Table 3.7.—*Recommended soil interpretations for landtypes (continued).*

Planning and analysis scale	Interpretation name	Description	Reference
Land unit	Pesticide loss potential—soil surface runoff 620-36	“Pesticide loss potential—soil surface runoff” is the potential for pesticides to be transported by surface runoff beyond the field boundary where the pesticide was applied. Pesticides are transported by surface runoff as either pesticides in solution or pesticides adsorbed to sediments suspended in runoff. Pesticides that are surface transported have a potential to contaminate surface waters, such as lakes, ponds, streams, and rivers	NSSH Interpretive Guide (1993)
Land unit	Equipment operability for logging areas 620-37	Equipment operability for logging areas applies to the use of rubber-tired skidders in the general logging area, including the yarding area for felled or bunched trees or logs and that extends to a designated skid trail.	NSSH Interpretive Guide (1993)
Land unit	Total tree harvesting 620-40	Total tree harvesting consists of yarding the entire tree to the landing area. Factors considered in rating soils for this practice are the nutrient status of the soil and the effects of removing the tops of trees, which would otherwise be incorporated back into the soil. Also considered is the erosion potential of the soil and the effects of removing slash, which would be a protective factor for the soil.	NSSH Interpretive Guide (1993)
Land unit	Prescribed burning 620-43	Prescribed burning is the deliberate ignition of a combustible material. Foresters use fire to perform three basic functions: consume dead organic material, alter living vegetation, and produce a desired ecological effect. The three functions are not mutually exclusive. Burning dead material inevitably affects the vegetation. The ecological function is, to some extent, a synthesis of other functions. Soil properties are considered in prescriptions for burning not from the standpoint of the actual ignition but from the standpoint of the management objectives of the desired ecological effect.	NSSH Interpretive Guide (1993)
Land unit	Seedling mortality 620-44	Seedling mortality refers to the probability of the death of naturally occurring or planted tree seedlings, as influenced by kinds of soil or topographic conditions.	NSSH Interpretive Guide (1993)
Land unit	Plant competition 620-45	Plant competition is the likelihood that plants other than the desired species will become established during revegetation efforts and that their presence will affect seedling establishment and the growth of desired species.	NSSH Interpretive Guide (1993)

3.5.3 Quality Control and Assurance

Quality control and quality assurance are important at all levels of the TEUI process to ensure that TEUI products are accurate, consistent, and meet the objectives outlined in the memorandum of understanding, work plan, and this technical guide. NCSS standards are required elements of TEUI at the LT and LTP level.

NCSS standards include those for soil classification as found in *Keys to Soil Taxonomy*; those for soil description as found in *The Field Book for Describing and Sampling Soils*; and those for documentation as found in the *National Soil Survey Handbook Part 627.08*, with exception that the TEUI map is substituted for the soil map.

Quality Control

Quality control is the process of providing direction, inspection, and coordination of TEUI activities to ensure that all products meet the defined standards in this guide. The TEUI project leader and crew must ensure that day-to-day activities meet TEUI and NCSS standards.

Quality Assurance

Quality assurance is the process of providing technical standards, review, and training to support TEUI quality control. Quality assurance is the primary responsibility of the regional and national TEUI and NCSS staff.

3.5.4 Quality Control/Quality Assurance Roles and Responsibilities

National

The national TEUI coordinators are responsible for the formulation, coordination, and updates of technical guides and procedural manuals, including the development of national work plans and training courses. Additional responsibilities include setting national policy and ensuring mapping consistency and data quality between regions.

Regional

Regional offices are responsible for the coordination and quality assurance for all TEUI activities including data collection, documentation, interpretation, and correlation. Regional offices will ensure that TEUI meet standards, including NCSS standards, and that documentation is completed and available for correlation. They must ensure the consistency of mapping and data quality between inventory areas, including quality assurance of the data entered into the NRIS Terra database, such as ecological unit, component, site, and geospatial data. In addition, regional offices should compile mapping and complete map unit descriptions at the section and subsection levels of the National Hierarchy.

TEUI Project

The TEUI project staff is responsible for meeting TEUI standards at the LTA, LT, and LTP levels of the National Hierarchy. The TEUI project leader ensures that the proper quality control measures are being conducted by crewmembers. Crewmembers are responsible for ensuring that all data and mapping standards are applied consistently.

3.5.5 Correlation of Ecological Types and Units

Correlation is a process for ensuring consistency in naming, classifying, and interpreting ecological types. The correlation process also provides quality control for consistent description and documentation of the landscape elements.

Field Reviews

Field reviews of TEUIs are scheduled to critically examine design of ecological types and mapped ecological units in the field. The field review serves as a quality assurance procedure to ensure that the database, mapping, classification, and associated documentation of the inventory area meets standards.

The review team leader will give particular attention to the review of soils documentation to ensure NCSS standards are met as outlined in Section 1.5, Soil Survey Program. Field units are encouraged to use progressive correlation for the soils portion of the TEUI, and are required to meet NCSS standards, including documentation necessary for final correlation. TEUI are certified as meeting NCSS standards by NRCS only through a final correlation memorandum (USDA NRCS 2003b).

The TEUI project staff organizes the field review to examine representative map units and sites of major ecological types and units in the area. The field review should also be used to address and correct problems encountered with classification, mapping concepts, and specific needs of the inventory. During this process, the work plan is reviewed and the annual plan of operations is updated. Field review reports are developed by the regional staff and submitted to the regional forester for signature. Any items identified during this process are submitted to the forest supervisor and/or TEUI project office for action.

Review Participants

The field review should include national and regional specialists who have responsibility for each of the landscape elements. Resource specialists and managers familiar with the area, scientists working on nearby ecological unit inventory projects, and representatives of cooperating agencies are encouraged to participate. All field review

participants should be encouraged to state their observations and opinions relative to each ecological type and unit observed, and all discussion should be noted for consideration in making correlation decisions.

Scheduling Field Reviews

Field reviews are to be scheduled as part of the annual plan of operations for each survey area. There should be at least an initial field review at the end of the beginning of the project, one or more progress field reviews during the life of the project, and a final field review at the end of the project.

3.5.6 Mapping and Interpretative Reliability

Accuracy Assessment

The following procedure is a suggested method for performing accuracy assessment of ecological units:

1. Conduct office assessment.
 - a. Assess distributions and ranges of each map unit for environmental variables such as elevation, slope, aspect, and spectral reflectance values.
 - b. Review frequency distribution curves produced from the analysis to determine ranges and variability in the environmental variables.
 - c. Review existing documentation to determine if representative values are within the ranges for these variables.
 - d. Where discrepancies are apparent, refine polygons and use procedures below to conduct field assessment.
2. Conduct field-accuracy assessment for mapping, classification, and description.
 - a. Randomly select 10 percent of the total number of map units for the survey area.
 - b. From the above sample, randomly select individual delineations (polygons) to assess.
 - c. Develop a transect design commensurate with polygon shape and ecological patterns.
 - d. Sample at predetermined intervals according to established intensity levels. At higher intensity levels, more sampling is required to meet the desired interpretative reliability.
 - e. Compare results of sampling to ecological unit and type descriptions.

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- f. Document results and compare to established standards in the work plan.
 - g. Adjust line work and correlate mapping and taxonomic units as necessary to meet established standards.

3.6 Reporting

3.6.1 Format and Content

NCSS Publications

Publications must meet the minimum requirements as described in part 644 of the *National Soil Survey Handbook* (USDA NRCS 2003b).

3.6.2 Accomplishment Reporting and Scheduling

Report accomplishments by appropriate budget line item and associated activity code.

Appendix A. Glossary

abiotic. Pertaining to the nonliving parts of an ecosystem, such as soil particles, bedrock, air, water (Helms 1998).

abundance. The total number of individuals of a taxon or taxa in an area, volume, population, or community. Often measured as cover in plants (Lincoln et al. 1998).

accuracy. The degree to which a measured quantity approaches the true value of what is being measured (Lincoln et al. 1998).

accuracy assessment. The process by which the accuracy or correctness of an image (or map) is evaluated.

alliance. (1) A grouping of associations with a characteristic physiognomy, and sharing one or more diagnostic species, which, as a rule, are found in the uppermost or dominant stratum of the vegetation (Jennings et al. 2004). (2) A physiognomically uniform group of associations sharing one or more diagnostic (dominant, differential, indicator, or character) species that, as a rule, are found in the uppermost stratum of the vegetation (FGDC 1997).

arc. In GIS, within a spatial context, a locus of points that forms a curve that is defined by a mathematical expression (FGDC 1998).

attribute. One of a set of descriptive terms; a characteristic (Lincoln et al. 1998).

bedrock geology. Characteristics of the consolidated material at the Earth's surface or that immediately underlies soil or other unconsolidated, surficial deposits, specifically lithology (rock type), weathering, structure (e.g., fracturing or bedding), and stratigraphy (the rock-unit age and designation).

business needs. Ongoing tasks related to a particular business or project and the information and other support contributing to the completion of these tasks.

canopy closure. The proportion of ground, usually expressed as a percentage, that is occupied by the perpendicular projection downward of the aerial parts of the vegetation of one or more species. It usually refers to the tree life form of the uppermost canopy, as seen from above, and cannot exceed 100 percent. It is similar in concept to absolute canopy.

canopy cover. (1) The proportion of ground, usually expressed as a percentage, that is occupied by the perpendicular projection downward of the aerial parts of the vegetation or the species under consideration. The additive cover of multiple strata or species may exceed 100 percent (FGDC 1997). (2) The percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings within the canopy are included (SRM 1998, USDA NRCS 1997). Canopy cover is synonymous with canopy closure (Helms 1998). For woody plants, canopy cover is synonymous with crown cover (USDA NRCS 1997, Helms 1998).

canopy cover, absolute. The canopy cover of a species in a plant community, regardless of the presence of other species.

canopy cover, relative. The canopy cover of a species in a plant community, expressed as a percentage of the total cover of all species.

canopy structure. The arrangement of vegetation layers in a plant community.

class. A group of individuals or other units similar in selected properties and distinguished from all other classes of the same population by differences in these properties (Buol et al. 1973).

classification. (1) The process of grouping similar entities together into named types or classes based on shared characteristics. (2) The grouping of similar types according to criteria that are considered significant for this purpose. The rules for classification must be clarified before identifying the types within the classification standard. The classification methods should be clear, precise, quantitative (where possible), and based on objective criteria so that the outcome would be the same whoever performs the definition (or description). Classification necessarily involves definition of class boundaries (FGDC 1997, citing UNEP/FAO 1995).

climax. A self-replacing plant community or species with no evidence of replacement by other plants.

climax plant community. The stable community in an ecological succession that is able to reproduce itself indefinitely under existing environmental conditions in the absence of disturbance. Viewed as the final stage or end-point in plant succession for a site. The climax community develops and maintains itself in steady state conditions.

community. (1) A general term for an assemblage of plants living together and interacting among themselves in a specific location; no particular ecological status is implied. (2) Any group of organisms interacting among themselves (Daubenmire 1978).

community composition. The kinds, absolute amounts, or relative proportions of plant species present in a given area or stand. It can be described qualitatively or quantitatively. The latter may use either absolute amounts or relative proportions of the plant taxa present. The amount of each plant taxon should be expressed as percent cover (FGDC 1997, Jennings et al. 2004).

community type. An aggregation of all plant communities with similar structure and floristic composition. A unit of vegetation within a classification with no particular successional status implied.

component. A subset of an ecological type used to describe the spatial arrangement of an ecological type within the map unit. A component may represent a narrower range of characteristics than the ecological type for which it is named.

composition. (1) The amount or proportion of the plant species on a given area (SRM 1989). (2) A list of the species that comprise a community or any other ecological unit (Lincoln et al. 1998).

constancy. The number of occurrences of a species in a group of plots divided by the total number of plots, expressed as a percentage. All plots must be the same size. For example, if a particular community has 10 plots and a species is found in 8 of the 10, the constancy of that species is 80 percent.

coordinates. In mapping, coordinates are pairs of numbers expressing horizontal distances along orthogonal axes; alternatively, triplets of numbers measuring horizontal and vertical distances (FGDC 1998).

cover. Usually meant as canopy cover that is the gross outline of the foliage of an individual plant or group of plants within a stand or plot. Expressed as a percent of the total area of the plot and may exceed 100 percent if more than one layer is considered. See **canopy cover** and **vegetation cover**.

cover type. A designation based on the plant species forming a plurality of composition within a given area (e.g., oak-hickory) (FGDC 1997). The Society of American Foresters Forest Cover Types (Eyre 1980) and the Society for Range Management Rangeland Cover Types (Shiflet 1994) are examples of cover types.

data element. A logically primitive item of data (FGDC 1998).

delineation. The process of separating map units (repeating sets of polygons) using a consistent set of criteria.

diagnostic species. Any species or group of species whose relative constancy or abundance clearly differentiates one type from another (Jennings et al. 2004). This definition implies that diagnostic species must be determined empirically through analysis of plot data (Mueller-Dombois and Ellenberg 1974).

differential species. A plant species that, because of its greater fidelity in one kind of community than in others, can be used to distinguish vegetation units (Gabriel and Talbot 1984 as cited in Jennings et al. 2004).

differentiating characteristics. Properties selected as the basis for grouping individuals into classes (Buol et al. 1973).

digital elevation model. Digital data file containing an array of elevation information over a portion of the Earth's surface (USDA Forest Service 1999).

digital orthophoto quadrangle. Digital representation of an aerial photo with ground features located in their "true" positions (Clarke 1999).

division. (1) In terrestrial ecological unit inventory, an ecological unit in the ecoregion planning and analysis scale of the National Hierarchy Framework corresponding to subdivisions of a domain that have the same regional climate (ECOMAP 1993). (2) In the Federal Geographic Data Committee (FGDC) physiognomic hierarchy, the level separating Earth cover into either vegetated or nonvegetated categories (Grossman et al. 1998).

dominance. The extent to which a given species has a strong influence in a community because of its size, abundance, or coverage. Strong dominance affects the fitness of associated species (Lincoln et al. 1998).

dominant. An organism exerting considerable influence on a community by its size, abundance, or coverage (Lincoln et al. 1998).

dominant species. The species with the highest percentage of cover, usually in the uppermost layer (Kimmins 1997, as cited in Jennings et al. 2004).

ecological units. Map units designed to identify land and water areas at different levels of resolution based on similar capabilities and potentials for response to management and natural disturbance. These capabilities and potentials derive from multiple elements: climate, geomorphology, geology, soils, water, and potential natural vegetation. Ecological units should, by design, be rather stable. They may, however, be refined or updated as better information becomes available.

ecological type. A category of land with a distinctive (i.e., mappable) combination of landscape elements. The elements making up an ecological type are climate, geology, geomorphology, soils, and potential natural vegetation. Ecological types differ from each other in their ability to produce vegetation and respond to management and natural disturbances.

ecosystem. A functional system of interacting organisms and their environment (Whittaker 1962). Ecosystems have six major attributes: structure, function, complexity, interaction/interdependency, scale, and change over time (Kimmins 1997).

ecotone. The boundary or transitional zone between adjacent communities or biomes. A tension zone (Lincoln et al. 1998).

elements. In this document, the attributes of a landscape that describe its environmental characteristics. Examples include climate, bedrock geology, surficial geology, soils, and potential vegetation.

evaluation. The comparison of dynamic sampling results to management objectives consisting of predetermined standards, expected norms, threshold values, and/or trigger points.

existing vegetation. (1) The plant cover, or floristic composition and vegetation structure, occurring at a given location at the current time. (2) The plant species existing at a location at the present time. Contrast with potential natural vegetation.

Federal Geographic Data Committee (FGDC). An interagency committee, organized in 1990 under the Office of Management and Budget Circular A-16, that promotes the coordinated use, sharing, and dissemination of geospatial data on a national basis. The FGDC is composed of representatives from 17 Cabinet level and independent Federal Agencies (FGDC 1998).

fidelity. The degree of restriction of a plant species to a particular situation, community, or association (Lincoln et al. 1998).

flora. (1) All the plant species that make up the vegetation of a given area (Allaby 1994). (2) The plant life of a given region, habitat, or geological stratum (Lincoln et al. 1998).

floristic composition. A list of plant species of a given area, habitat, or association (Lincoln et al. 1998).

forbs. Broad-leaved herbaceous plants (FGDC 1997).

fuzzy logic. A type of reasoning designed to accommodate ambiguity. Using fuzzy sets in accuracy assessment permits explicit recognition of the possibility of ambiguity regarding appropriate map labels for some locations on a map/classification. This recognition can help the user determine the relative (not absolute) accuracy of a particular classification, and thus the usefulness of that classification for applications requiring varying levels of accuracy (Wirth et al. 1996).

Geographic Information System (GIS). A set of computer tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world for a particular set of purposes. Spatial data in GIS are characterized by their position, attributes, and spatial interrelationships (topology) (Burrough 1986).

geomorphology. The classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

geospatial data. Information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the Earth. This information may be derived from, among other things, remote sensing, mapping, and surveying technologies (FGDC 1998).

Global Positioning System (GPS). An array of space satellites and ground receivers that use geometry to provide information about the precise latitude, longitude, and elevation of a particular point (Wirth et al. 1996).

grid. A rectilinear arrangement. Examples include the Public Land Survey, raster GIS, and systematic field sampling schemes.

group. An aggregation of similar items. The word can also have specific meanings that vary with discipline (e.g., soil Great Groups and National Vegetation Classification System vegetation groups are very different entities).

image processing. A general term referring to manipulation of digital image data. Processing includes image enhancement, image classification, and image preprocessing (or rectification) operations (Wirth et al. 1996).

indicator species. (1) A species whose presence, abundance, or vigor is considered to indicate certain environmental conditions (Gabriel and Talbot 1984, as cited in Jennings et al. 2004). (2) A species that is sensitive to important environmental features of a site such that its constancy or abundance reflects significant changes in environmental factors. (3) A plant whose presence indicates specific site conditions or a type.

inventory. The systematic acquisition, analysis, and organization of resource information needed for planning and implementing land management (USDA NRCS 1997).

Landsat. Name for the series of Earth-observing satellites first launched in 1972 by National Aeronautics and Space Administration (originally named ERTS, for Earth Resource Technology Satellite). Landsat satellites serve as platforms for several sensors, including the return beam vidicon, Landsat Multispectral Scanner, and Landsat Thematic Mapper (Wirth et al. 1996).

landtype association (LTA). Landscape scale map units defined by a dominant geomorphic process type, similar landforms, surficial and near-surface geologic formations, and associations of soil families and potential natural vegetation at the series level (Forman and Godron 1986, ECOMAP 1993, Cleland et al. 1997).

layer (GIS). A digital information storage unit, also known as a theme. Different kinds of information (e.g., roads, boundaries, lakes, and vegetation) can be grouped and stored as separate digital layers or themes in GIS (Wirth et al. 1996).

layer or stratum. (1) A structural component of a community consisting of plants of approximately the same height structure (e.g., tree, shrub, and herbaceous layers). (2) The definition and measurement of these structural components in their vertical and height relationships to each other (e.g., tree subcanopy layer, shrub understory layer) (Grossman et al. 1998).

life form. (1) The characteristic structural features and method of perennation of a plant species; the result of the interaction of all life processes, both genetic and environmental (Lincoln et al. 1998). Life form is related to growth form, physiognomy, and habit, but also includes consideration of the type and position of renewal (perennating) buds that the other terms typically do not include. (2) Includes gross morphology (size, woodiness, etc.), leaf morphology, life span, and phenological (or life cycle) phenomena (Barbour et al. 1980).

map. (1) A spatial representation, usually graphic on a flat surface, of spatial phenomena (FGDC 1998). (2) A representation, usually on a plane surface, of a region of the Earth or heavens (Robinson et al. 1978).

mapping. In its most generic sense, the process of using points, lines, polygons, or pixels to represent geographic features spatially.

map scale. The extent of reduction required to display a portion of the Earth's surface on a map and is defined as a ratio of distances between corresponding points on the map and on the ground (Robinson et al. 1978). Scale indirectly determines the information content and size of the area being represented. The mapping scale is determined by the agency's business needs and the characteristics of the data obtained for the project area. Maps generated from digital imagery can appropriately be displayed at a range of scales.

map unit. A collection of features defined and named the same in terms of a unifying theme (USDA NRCS 1993). Each map unit differs in some respect from all others within a geographic extent. Map units are differentiated in map unit design and defined in a map unit description. Design of map units generalizes the taxonomic units present to the smallest set that meets the objectives of the map at that scale, and that are feasible to delineate with available resources and technology.

map unit characterization. The description of the elements in a map unit. In regard to ecological units, includes the “primary five” (geomorphology, geology, climate, soils, and potential vegetation), but also often includes supporting elements, such as hydrology, disturbance regimes, etc.

map unit delineation. The criteria used to spatially differentiate between map units. For ecological units, the relative importance of these criteria varies with scale. For example, at landtype association scale, differences in geomorphology and geology are normally the primary delineation criteria between map units, whereas at land unit scale, soils and potential vegetation become more important.

map unit description (MUD). Describes the composition of ecological types (or components) as they occur in a map unit. These descriptions form the primary reference document for identifying the ecological types that occur within a map unit.

map unit design. The process establishing the relationship between classifications and map products depicting them. In this document, design considerations include the interrelationships between elements, component relationships within the map unit, and how the map unit relates to other scales.

map unit legend. A list of the map units that occur in a specific inventory area, including the map unit code and map unit name, and is developed using national coding and naming procedures.

map unit validation. In this paper, the process of verifying the accuracy of ecological unit differentiation, delineation, and characterization.

metadata. Data about the data: the content, quality, condition, and other characteristics of a given set of data. Metadata is intended to provide a capability for organizing and maintaining an institution’s investment in data as well as to provide information for the application and interpretation of data received through a transfer from an external source (Jennings, et al. 2004, as modified from FGDC 1997). Metadata often includes details on the methodologies used in data collection, relevant literature references, purpose of data collection, etc.

modeling. In reference to geospatial data, the process of creating a new GIS layer by combining or operating on existing layers. Modeling creates an image (or images) that contains several types of information comprised of several GIS variables (e.g., a scene could be considered in terms of its vegetation, elevation, water, and climate at the same time) (Wirth et al. 1996).

monitoring. (1) The systematic collection, analysis, and interpretation of resource data to evaluate progress toward meeting management objectives (SRM 1998). (2) The collection and analysis of resource data to measure changes in the amounts, spatial distribution, or condition of resource types or parameters over time.

morphometry. The measurement and mathematical analysis of the configuration of the Earth’s surface and of the shape and dimensions of its landforms (i.e., relief, elevation range, slope aspect, gradient, shape, and position, dissection frequency and depth, and drainage pattern and density).

National Hierarchy of Ecological Units. The Forest Service's multiple-scale, multiple-element system of map units used to characterize the natural world and provide a framework for national forest planning and management (Cleland et al. 1997). Other State and Federal agencies also use the National Hierarchy, particularly at broader scales.

outlier. Referring to data, a sample or datum that has low similarity to all the other samples in the dataset.

overstory. The canopy layer of a forest.

patch. A relatively homogenous nonlinear area that differs from its surroundings (Forman 1995). It can specifically describe forested patches, nonforest vegetation patches, rock/barren patches, or water patches.

patterns. Repeating coordinated species abundances and groups of samples with similar species composition.

physiognomy. (1) The characteristic feature or appearance of a plant community or vegetation (Lincoln et al. 1998). (2) The overall appearance of a kind of vegetation (Daubenmire 1968, Barbour et al. 1980). (3) The expression of the life forms of the dominant plants and vegetation structure (Mueller-Dombois and Ellenberg 1974, Barbour et al. 1980).

pixel. Two-dimensional picture element that is the smallest nondivisible element of a digital (raster) image (FGDC 1998). Common pixel resolutions are 30 m and 90 m (i.e., each pixel represents a square of the Earth's surface 30 m or 90 m on a side).

plant association. A recurring potential natural plant community with a characteristic range in species composition, specific diagnostic species, and a defined range in habitat conditions and physiognomy or structure (Jennings et al. 2004). These occur as repeatable patterns across the landscape (FGDC 1997).

plot. (1) A circumscribed sampling area for vegetation (Lincoln et al. 1998). (2) Any two-dimensional sample area of any size, including quadrates, rectangular plots, circular plots, and belt-transects (which are merely very long rectangular plots). Belt-transects are often simply called strips or transects (Mueller-Dombois and Ellenburg 1974).

point. In reference to geospatial data, a dimensional-dimensional object that specifies geometric location. One coordinate pair or triplet specifies the location. Area point, entity point, and label point are special implementations of the general case (FGDC 1998).

polygon. An areal feature that occupies a unique spatial location.

potential natural vegetation (PNV). The plant community that would become established if all successional sequences were completed without human interference under the present environmental and floristic conditions, including those created by man (Tüxen 1956, as cited in Mueller-Dombois and Ellenberg 1974).

reflectance. The total solar energy incident on a given feature minus the energy that is either absorbed or transmitted by the feature. Reflectance is dependent on the material type and condition, and allows different features in a visual image to be distinguished (Wirth et al. 1996).

representative sampling. Employs systematic or random location of plots within strata, but rejection criteria may be necessary to avoid sampling obvious ecotones, which are of limited use for classifying vegetation. The gradsect technique or gradient-directed sampling is one example of this approach (Austin and Heylingers 1991, as cited in Jennings et al. 2004). It is a form of stratified random sampling that may be cost effective for sampling vegetation patterns along environmental gradients (Gillison and Brewer 1985).

resolution. The minimum difference between two independently measured or computed values that can be distinguished by the measurement or analytical method being considered or used (FGDC 1998).

remote sensing. (1) The gathering of data regarding an object or phenomenon by a recording device (sensor) that is not in physical contact with the object or phenomenon under observation (Wirth et al. 1996). (2) The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer 1994).

scale. (1) The relationship between a distance on a map and the corresponding distance on the Earth. (2) In general, the degree of resolution at which ecological processes, structures, and changes across space and time are observed and measured (ECOMAP 1993). (3) Describes the proportion that defines the relationship of a map, image, or photograph to that which it represents, such as distance on the ground (Burrough 1986).

sensor. A device that records electromagnetic radiation or other data about an object and presents it in a form suitable for obtaining information about the environment (Wirth et al. 1996).

series. (1) In vegetation classification, an aggregation of taxonomically related plant associations that takes the name of climax species that dominate the principle layer. It is a group of associations or habitat types with the same dominant climax species. Conceptually it is analogous to an alliance, with the series being a potential natural vegetation concept (Driscoll et al. 1984). (2) In soil science, a group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile, except for texture of the surface horizon (USDA NRCS 1993).

shrubs. Woody plants that generally exhibit several erect, spreading, or prostrate stems, and have a bushy appearance. In instances where life form cannot be determined, woody plants less than 5 meters in height will be considered shrubs (FGDC 1997).

site. An area delimited by fairly uniform climatic and soil conditions (similar to habitat).

spatial data. Data that record the geographic location and shape of geographic features and their spatial relationships to other features (FGDC 1998).

spatial resolution. The measure of sharpness or fineness in spatial detail. It determines the smallest object that can be resolved by a given sensor, or the area on the ground represented by each pixel. For digital imagery, spatial resolution corresponds to pixel size and may be understood as roughly analogous to “grain” in photographic images (Helms 1998).

species. In biological classification, the category below genus and above the level of subspecies and variety. It is the basic unit of biological classification (Lincoln et al. 1998).

stand. A community, particularly of trees, possessing sufficient uniformity as regards to composition, age, spatial arrangement, or condition, to be distinguishable from adjacent communities, so forming a silvicultural or management entity (Ford-Robertson 1971).

stratum. In general, one of a series of layers, levels, or gradations in an ordered system. In the natural environment, the term is used in the sense of (1) a region of sea, atmosphere, or geology that is distinguished by natural or arbitrary limits or (2) a layer of vegetation, usually of the same or similar height (FGDC 1998).

structure. (1) The spatial arrangement of the components of vegetation (Lincoln et al. 1998). (2) A function of plant size and height, vertical stratification into layers, and horizontal spacing of plants. Physiognomy refers to the general appearance of the vegetation, while structure describes the spatial arrangement of plants in more detail. Physiognomy should not be confused with structure (Mueller-Dombois and Ellenberg 1974).

succession. Partial or complete replacement of one community by another (Daubenmire 1978).

surficial geology. The mode of deposition of unconsolidated deposits lying on bedrock or occurring on the Earth’s surface, and the rock type(s) from which those deposits are derived, known as “kind” and “origin,” respectively.

taxa. The plural form of taxon, which is a classification entity.

taxonomic unit. The basic set of classes or types that comprise a classification; in this document, a classification of environmental elements or integrated environmental elements (ecological types). Taxonomic units represent a conceptual description of ranges and/or modal conditions in environmental characteristics. A taxonomic unit (or taxon) is a class developed through the scientific classification process, or a class that is part of a taxonomy (USDA NRCS 1993). A taxonomic unit is the physical representation of a taxon, or the physical representation of a unit of a classification.

theme. (1) A group of data that represent a place or thing such as soils, vegetation, or roads. A theme could be less concrete such as population density, school districts, or administrative boundaries (FGDC 1998). (2) For a GIS context, see **layer**.

trees. Woody plants that generally have a single main stem and have more or less definite crowns. In instances where life form cannot be determined, woody plants equal to or greater than 5 meters in height will be considered trees (FGDC 1997).

user's accuracy. In reference to accuracy assessment, an accuracy measure based on a commission error as shown in the error matrix. Also known as reliability, user's accuracy is the probability that pixels classified on the map actually represent the category on the ground. User's accuracy is calculated by dividing the total number of correctly classified sites of a certain category by the total number of the certain category classified by the map (Wirth et al. 1996).

vascular plant. Plant with water and fluid conductive tissue (xylem and phloem), including seed plants, ferns, and fern allies (FGDC 1997).

vegetation cover. Vegetation that covers or is visible at or above the land or water surface. It is a subcategory of Earth cover. The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants (FGDC 1997).

vegetation data. The attributes of the vegetation that are used to classify and characterize the vegetation type and to map vegetation stand. These data come from the interpretation of remotely sensed imagery, fieldwork, and other thematic data sources (FGDC 1997).

vegetation mapping. The process of delineating the geographic distribution, extent, and landscape patterns of vegetation types based on composition, physiognomy, and structure.

vegetation type. A named class of plant community or vegetation defined on the basis of selected shared floristic, physiognomic, and/or structural characteristics, which distinguish it from other classes of plant communities or vegetation (Jennings et al. 2004).

Appendix B. Literature Cited

- Abrams, M.D.; Ruffner, C.M. 1995. Physiographic analysis of witness-tree distribution (1765–1798) and present forest cover through north central Pennsylvania. *Canadian Journal of Forest Research*. 25: 659-668.
- Allaby, M. 1994. *The concise Oxford dictionary of ecology*. Oxford, England: Oxford University Press.
- Almendinger, J.C.; Hanson, D.S.; Jordan, J.K. 2000. Landtype associations of the Lake States. St. Paul, MN: Minnesota Department of Natural Resources. 21 p.
- Attwill, P.M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. *Forest Ecology and Management*. 63: 247-300.
- Austin, M.P.; Heyligers, P.C. 1991. New approach to vegetation survey design: gradsect sampling. In: Margules, C.R.; Austin, M.P., eds. *Nature conservation: cost-effective biological surveys and data analysis*. Melbourne, Australia: Commonwealth Scientific and Industrial Research Organization. 31-336.
- Baker, R.G.; Bettis III, E.A.; Schwert, D.P.; et al. 1996. Holocene paleoenvironments of northeast Iowa. *Ecological Monographs*. 66: 203-234.
- Balee, W., ed. 1998. *Advances in historical ecology*. New York: Columbia University Press.
- Banks, J.C.G. 1991. A review of the use of tree rings for the quantification of forest disturbances. *Dendrochronologia*. 9: 51-70.
- Barber, G.M. 1988. *Elementary statistics for geographers*. New York: Guildford Press. 507 p.
- Barbour, M.G.; Burk, J.H.; Pitts, W.D. 1980. *Terrestrial plant ecology*. Menlo Park, CA: Benjamin/Cummings.
- Bates, R.L.; Jackson, J.A., eds. 1980 and 1987. *Glossary of geology*. 2nd and 3rd eds. Alexandria, VA: American Geological Institute. 788 p.
- Beers, T.W.; Dress, P.E.; Wensel, L.C. 1966. Aspect transformation in site productivity research. *Journal of Forestry*. 64: 691-692.
- Bergeron, Y.; Leduc, A.; Harvey, B.D.; et al. 2002. Natural fire regime: a guide for sustainable management of the Canadian boreal forest. *Silva Fennica*. 36(1): 81-95.
- Birkeland, P.W. 1974. *Pedology, weathering, and geomorphological research*. New York: Oxford University Press. 285 p.

-
- Black, B.A.; Abrams, M.D. 2001a. Analysis of temporal variation and species-site relationships of witness tree data in southeastern Pennsylvania. *Canadian Journal of Forest Research*. 31: 419-429.
- Black, B.A.; Abrams, M.D. 2001b. Influences of Native Americans and surveyor biases on metes and bounds witness-tree distribution. *Ecology*. 82: 2574-2586.
- Blasing, T.J.; Duvick, D.N.; Cook, E.R. 1983. Filtering the effects of competition from ring-width series. *Tree-ring Bulletin*. 43: 19-30.
- Bourdo, Jr., E.A. 1956. A review of the General Land Office Survey and of its use in quantitative studies of former forests. *Ecology*. 37: 754-768.
- Brender, E.V. 1974. Impact of past land-use on the lower Piedmont forest. *Journal of Forestry*. 72: 34-36.
- Brender, E.V.; Merrick, E. 1950. Early settlement and land use in the present Toccoa Experimental Forest. *Scientific Monthly*. 71: 318-325.
- Brohman, R.; Bryant, L., eds. 2005. Existing vegetation classification and mapping technical guide. Gen. Tech. Rep. WO-67. Washington, DC: USDA Forest Service Ecosystem Management Coordination Staff. 305 p.
- Bromley, S.W. 1935. The original forest types of southern New England. *Ecological Monographs*. 5: 61-89.
- Brown, D.G. 1998. Mapping historical forest types in Baraga County Michigan, U.S.A., as fuzzy sets. *Plant Ecology*. 134: 97-111.
- Brubaker, L.B. 1987. Forest disturbance and tree-ring analysis. In: Jacoby, G.C.; Hornbeck, J.W., comps. *Proceedings of the international symposium on ecological aspects of tree-ring analysis*. 17-21 August 1986. Tarrytown, NY. Washington, DC: U.S. Department of Energy. 101-118.
- Buell, M.F.; Buell, H.F.; Small, J.A. 1954. Fire in the history of Mettler's Woods. *Bulletin of the Torrey Botanical Club*. 81: 253-255.
- Buol, S.W.; Hole, F.D.; McCracken, R.J. 1973. *Soil genesis and classification*. Ames, IA: The Iowa State University Press. 527 p.
- Burgi, M.; Russell, E.W.B. 2000. Evaluating accuracy of two types of early land survey records in the northeastern United States. *Journal of the Torrey Botanical Society*. 127: 94-98.
- Burrough, P.A. 1986. *Principles of geographical information systems for land resource assessment*. New York: Oxford University Press. 194 p.
- Canham, C.D.; Loucks, O.L. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. *Ecology*. 65: 803-809.

-
- Carvell, K.L. 1986. Effect of past history on present stand composition and condition.
In: Proceedings, guidelines for managing immature Appalachian hardwood stands.
Morgantown, WV: West Virginia University Books, Office of Publications. SAF
Publication 86-03: 1-7.
- Christensen, N.L. 1989. Landscape history and ecological change. *Journal of Forest History*.
33: 116-124.
- Cissel, J.H.; Swanson, F.J.; Weisburg, P.J. 1999. Landscape management using historical fire
regimes. *Ecological Applications*. 9: 1217-1231.
- Clark, J.S. 1990. Fire and climate change during the last 750 years in northwestern Minnesota.
Ecological Monographs. 60: 135-159.
- Clark, J.S.; Royall, P.D. 1996. Local and regional sediment charcoal evidence for fire regimes in
presettlement north-eastern North America. *Journal of Ecology*. 84: 365-382.
- Clarke, K.C. 1999. Getting started with geographic information systems. 2nd ed. Upper Saddle
River, NJ: Prentice Hall.
- Cleland, D.T.; Avers, P.E.; McNab, H.W.; et al. 1997. National hierarchy framework of ecological
units. In: Broyce, M.S., Haney, A. 1997. *Ecosystem management: applications for sustainable
forest and wildlife resources*. New Haven, CT; London: Yale University Press. 384 p.
- Cleland, D.T.; Ramm, C.W. A synopsis of ecological classification numerical methods.
Rhineland, WI: USDA Forest Service North Central Research Station. 13 p.
- Collinson, A.S. 1988. Introduction to world vegetation. 2nd ed. London: Unwin Hyman. 325 p.
- Compton, R. 1985. *Geology in the field*. New York: John Wiley & Sons. 398 p.
- Connolly, M. 2001 (March 29). Letter to the record. Resource inventory direction. File code
1110. Washington, DC: USDA Forest Service Ecosystem Management Staff.
- Cook, E.R.; Kairiukstis, L.A., eds. 1990. *Methods of dendrochronology: applications in the
environmental science*. Dordrecht, The Netherlands: Kluwer Academic Publishers,
International Institute for Applied Systems Analysis.
- Cook, J.E. 1996. Implications of modern successional theory for habitat typing: a review.
Forest Science. 42: 67-75.
- Crankshaw, W.B.; Qadir, S.A.; Lindsey, A.A. 1965. Edaphic controls of tree species in
presettlement Indiana. *Ecology*. 46: 688-698.
- Creber, G.T. 1977. Tree rings: a natural data storage system. *Biological Reviews*. 52: 349-383.

-
- Daubenmire, R. 1968. Soil moisture in relation to vegetation distribution in the mountains of northern Idaho. *Ecology*. 49: 431–438.
- Daubenmire, R. 1978. *Plant geography with special reference to North America*. New York: Academic Press. 338 p.
- Day, G.M. 1953. The Indian as an ecological factor in the northeastern forest. *Ecology*. 34: 329-346.
- Delcourt, H.R.; Delcourt, P.A. 1974. Primeval magnolia-holly-beech climax in Louisiana. *Ecology*. 55: 638-644.
- Delcourt, H.R.; Delcourt, P.A. 1996. Presettlement landscape heterogeneity: evaluating grain of resolution using General Land Office Survey data. *Landscape Ecology*. 11: 363-381.
- Delcourt, P.A.; Delcourt, H.R.; Ison, C.R.; et al. 1998. Prehistoric human use of fire, the Eastern Agricultural Complex, and Appalachian oak-chestnut forests: paleoecology of Cliff Palace Pond, Kentucky. *American Antiquity*. 63: 263-278.
- DeMeo, T. 2002. Use of landtype associations as a coarse filter for ranking quality of Indiana bat habitat on the Monongahela National Forest, West Virginia. In: Smith, M.L., ed. 2002. *Proceedings, landtype associations conference: development and use in natural resources management, planning and research*. Gen. Tech. Rep. NE-294. Newton Square, PA: USDA Forest Service Northeastern Research Station. 71-80.
- DeMeo, T.; Cleland, D.T.; Howes, S.; et al. 2002. Towards national landtype association data standards. In: Smith, M.L., ed. 2002. *Proceedings, landtype associations conference: development and use in natural resources management, planning and research*. GTR-NE-294. Newton Square, PA: USDA Forest Service Northeastern Research Station. 117 p.
- Dieterich, J.H. 1980. Chimney Spring Forest Fire history. Res. Pap. RM-220. Ft. Collins, CO: USDA Forest Service Rocky Mountain Forest and Range Experiment Station. 8 p.
- Dinsdale, E.M. 1965. Spatial patterns of technological change: the lumber industry of northern New York. *Economic Geography*. 41: 252-274.
- Driscoll, R.S.; Merkel, D.L.; Radlof, R.L.; et al. 1984. An ecological land classification framework for the United States. Misc. Pub. 1439. Washington, DC: USDA Forest Service.
- Dunn, C.P.; Guntenspergen, G.R.; Dorney, J.R. 1983. Catastrophic wind disturbance in an old-growth hemlock-hardwood forest, Wisconsin. *Canadian Journal of Botany*. 61: 211-217.
- Ecological Application. 2000. *Ecological Applications*. 10(5).
- ECOMAP. 1993. National hierarchy framework of ecological units. Washington, DC: USDA Forest Service. 20 p.

-
- Egan, D.; Howell, E.A., eds. 2001. The historical ecology handbook: a restorationist's guide to reference ecosystems. Washington, DC: Island Press. 469 p.
- Engstrom, R.T.; Gilbert, S.; Hunter, M.L.; et al. 1999. Practical applications of disturbance ecology to natural resource management. In: Szaro, R.C.; Johnson, N.C.; Sexton, W.T.; et al., eds. Ecological stewardship: a common reference for ecosystem management. Vol. 2. Oxford, England: Elsevier Science. 313-330.
- Ernst, J.W. 1979. With compass and chain: Federal land surveyors in the Old Northwest, 1785–1816. New York: Arno Press. 319 p.
- Eyre, F.H. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p.
- Federal Geographic Data Committee (FGDC). 1997. Vegetation classification standard. FGDC-STD-005. Reston, VA: Vegetation Subcommittee, FGDC Secretariat, U.S. Geological Survey. 58 p.
- Federal Geographic Data Committee (FGDC). 1998. Content standard for digital geospatial metadata. Rev. FGDC-STD-001-1998. Washington, DC: FGDC. http://www.fgdc.gov/standards/documents/standards/metadata/v2_0698.pdf.
- Finley, R.W. 1976. Original vegetation cover of Wisconsin: compiled from U.S. General Land Office notes. [1:500,000]. St. Paul, MN: USDA Forest Service North Central Forest Experiment Station.
- Ford, J.; Martinez, D. 2000. Traditional ecological knowledge, ecosystem science, and environmental management. Ecological Applications. 10: 1249.
- Ford-Robertson, F.C. 1971. Terminology of forest science, technology practice, and products. The multilingual forestry terminology series. Vol. 1. Washington, DC: Society of American Foresters. 349 p.
- Forman, R.T.T. 1995. Land mosaics: the ecology of landscapes and regions. New York: Cambridge University Press. 632 p.
- Forman, R.T.T.; Godron, M. 1986. Landscape ecology. New York: John Wiley & Sons. 619 p.
- Foster, C.H.W., ed. 1998. Stepping back to look forward: a history of the Massachusetts forest. Cambridge, MA: Harvard University Press. 352 p.
- Foster, D.R.; Zebryk, T.M. 1993. Long-term vegetation dynamics and disturbance history of a *Tsuga*-dominated forest in New England. Ecology. 74: 982-998.
- Fredlund, G.G. 2001. Inferring vegetation history from phytoliths. In: Egan, D.; Howell, E.A. The historical ecology handbook: a restorationist's guide to reference ecosystems. Washington, DC: Island Press. 335-365.

-
- Frelich, L.E.; Lorimer, C.G. 1991. Natural disturbance regimes in hemlock-hardwoods forests of the Upper Great Lakes Region. *Ecological Monographs*. 61: 145-164.
- FSVEG. 2005. Common stand exam user guide. Ft. Collins, CO: USDA Forest Service NRIS FSVEG Team. Available on the Web at <http://fsweb.nris.fs.fed.us/products/FSVeg/documentation/index.shtml>.
- Fulé, P.Z.; Covington, W.W.; More, M.M. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. *Ecological Applications*. 7(3): 895-908.
- Gabriel, H.W.; Talbot, S.S. 1984. Glossary of landscape and vegetation ecology for Alaska. Alaska Tech. Rep. 10. Washington, DC: USDI Bureau of Land Management. 137 p.
- Gary, H.L.; Currie, P.O. 1977. The Front Range pine type: a 40-year photographic record of plant recovery on an abused watershed. Gen. Tech. Rep. RM-46. Ft. Collins, CO: USDA Forest Service Rocky Mountain Research Station. 17 p.
- Gates, P.W. 1976. Problems of agricultural history. *Agricultural History*. 46: 33-58.
- Gauch, H.G. 1982. Multivariate analysis in community ecology. New York: Cambridge University Press. 298 p.
- Gillison, A.N.; Brewer, K.R.W. 1985. The use of gradient-directed transects or gradsects in natural resource survey. *Journal of Environmental Management*. 20: 103-127.
- Glitzenstein, J.S.; Canham, C.D.; McDonnell, M.J.; et al. 1990. Effects of environment and land-use history on upland forests of the Cary Arboretum, Hudson Valley, New York. *Bulletin of the Torrey Botanical Club*. 117: 106-122.
- Gordon, R.B. 1969. The natural vegetation of Ohio in pioneer days. *Bulletin of the Ohio Biological Survey (New Series)*. 3: 1-113.
- Grimm, E.C. 1984. Fire and other factors controlling the Big Woods vegetation of Minnesota in the mid-nineteenth century. *Ecological Monographs*. 54: 291-311.
- Grossman, D.H.; Faber-Langendoen, D.; Weakley, A.S.; et al. 1998. International classification of ecological communities: terrestrial guidelines for describing associations and alliances of the U.S. NVC, Ver. 3.0, vegetation of the United States. Vol. 1. The national vegetation classification system: development, status, and applications. Arlington, VA: The Nature Conservancy. 75 p.
- Gruell, G.E. 1983. Fire and vegetation trends in the northern Rockies: interpretations from 1871-1982 photographs. Gen. Tech. Rep. INT-158. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station. 113 p.
- Gutsell, S.L.; Johnson, E.A. 1996. How fire scars are formed: coupling a disturbance process to its ecological effect. *Canadian Journal of Forest Research*. 26: 166-174.

-
- Guyette, R.; McGinnes, Jr., E.A. 1982. Fire history of an Ozark Glade in Missouri. Transactions of the Missouri Academy of Science. 16: 85-93.
- Hall, F.C. 2003. Growth basal area handbook. Portland, OR: USDA Forest Service Pacific Northwest Region. 104 p.
- Haskins, D.M.; Correll, C.S.; Foster, R.A.; et al. 1998. A geomorphic classification system. Ver. 1.4. Washington, DC: USDA Forest Service. 110 p.
- Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area. Quaternary Research. 3: 329-382.
- Helms, J.A., ed. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 210 p.
- Henry, J.D.; Swan, J.M.A. 1974. Reconstructing forest history from live and dead plant material: an approach to the study of forest succession in southwest New Hampshire. Ecology. 55: 772-783.
- Hutchinson, M. 1988. A guide to understanding, interpreting, and using the Public Land Survey field notes in Illinois. Natural Areas Journal. 8: 245-255.
- Jennings, M.; Faber-Langendoen, D.; Peet, R.; et al. 2004. Guidelines for describing associations and alliances of the U.S. national vegetation classification. Ver. 4.0. Washington, DC: Vegetation Classification Panel, Ecological Society of America. 165 p.
- Johnson, E.A. 1979. Fire recurrence in the subarctic and its implications for vegetation composition. Canadian Journal of Botany. 57: 1374-1379.
- Johnson, E.A.; Larsen, C.P.S. 1991. Climatically induced change in fire frequency in the southern Canadian Rockies. Ecology. 72: 194-201.
- Johnson, M.C.; Gerland, J.K. 1996. Tapping "green gold": the steam rail and logging tram roads of East Texas. Environmental History. 1: 46-65.
- Johnston, B.C. 1989. Woodland classification: the pinyon-juniper formation. In: Ferguson, D.E.; Morgan, P.; Johnson, F.D., eds. Proceedings, land classifications based on vegetation: applications for resource management. Gen. Tech. Rep. INT-257. Ogden, UT: USDA Forest Service Intermountain Research Station. 160-166.
- Kearsley, J.B.; Jackson, S.T. 1997. History of a *Pinus strobus*-dominated stand in northern New York. Journal of Vegetation Science. 8: 425-436.
- Kimball, A.J.; Witham, J.W.; Rudnický, J.L.; et al. 1995. Harvest-created and natural canopy gaps in an oak-pine forest in Maine. Bulletin of the Torrey Botanical Club. 122: 115-123.

-
- Kimmerer, R.W. 2000. Native knowledge for native ecosystems. *Journal of Forestry*. 98: 4-9.
- Kimmins, J.P. 1997. *Forest ecology: a foundation for sustainable management*. 2nd ed. Upper Saddle River, NJ: Prentice Hall. 596 p.
- Kimmins, J.P. 1987. *Forest ecology*. New York: Macmillan. 531 p.
- Krebs, C.J. 1972. *Ecology: the experimental analysis of distribution and abundance*. New York: Harper & Row. 694 p.
- Larsen, C.P.S.; MacDonald, G.M. 1998. An 840-year record of fire and vegetation in a boreal white spruce forest. *Ecology*. 79: 1-13.
- Lillesand, T.M.; Kiefer, R.W. 1994. *Remote sensing and image interpretation*. New York: John Wiley & Sons. 750 p.
- Lincoln, R.J.; Boxshall, G.A.; Clark, P.F. 1998. *A dictionary of ecology, evolution, and systematics*. New York: Cambridge University Press. 361 p.
- Lindsey, A.A.; Crankshaw, W.B.; Qadir, S.A. 1965. Soil relations and distribution map of the vegetation of presettlement Indiana. *Botanical Gazette*. 126: 155-163.
- Loope, W.L.; Anderson, J.B. 1998. Human vs. lightning ignition of presettlement surface fires in coastal pine forests of the Upper Great Lakes. *American Midland Naturalist*. 140: 206-218.
- Lorimer, C.G. 1977. The presettlement forest and natural disturbance cycle of northeastern Maine. *Ecology*. 58: 139-148.
- Lorimer, C.G. 1980. The use of land survey records in estimating presettlement fire frequency. In: Stokes, M.A.; Dieterich, J.H., tech. coord. *Proceedings, fire history workshop*. Gen. Tech. Rep. RM-81. Ft. Collins, CO: USDA Forest Service Rocky Mountain Forest and Range Experiment Station. 57-62.
- Lorimer, C.G. 1985. Methodological considerations in the analysis of forest disturbance history. *Canadian Journal of Forest Research*. 15: 200-213.
- Lorimer, C.G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. *Wildlife Society Bulletin*. 29: 425-439.
- Lorimer, C.G.; Frelich, L.E. 1989. A methodology for estimating canopy disturbance frequency and intensity in dense temperate forests. *Canadian Journal of Forest Research*. 19: 651-663.
- Manies, K.L.; Mladenoff, D.J. 2000. Testing methods to produce landscape-scale presettlement vegetation maps from the U.S. public land survey records. *Landscape Ecology*. 15: 741-754.

-
- Manies, K.L.; Mladenoff, D.J.; Nordheim, E.V. 2001. Assessing large-scale surveyor variability in the historic forest data of the original U.S. Public Land Survey. *Canadian Journal of Forest Research*. 31: 1719-1730.
- Marks, J.B. 1942. Land use and plant succession in Coon Valley, Wisconsin. *Ecological Monographs*. 12: 121-133.
- Marschner, F.J. 1974. Map of the original vegetation of Minnesota. [1:500,000 scale map]. St. Paul, MN: USDA Forest Service North Central Forest Experiment Station.
- McBride, J.R. 1983. Analysis of tree rings and fire scars to establish fire history. *Tree-ring Bulletin*. 43: 51-67.
- McCay, D.H.; Abrams, M.D.; DeMeo, T.E. 1997. Gradient analysis of secondary forests of eastern West Virginia. *Journal of the Torrey Botanical Society*. 124(2): 160-173.
- McCune, B.; Grace, J.; Urban, D.L. 2002. Analysis of ecological communities. Gleneden Beach, OR: MjM Software Design. 304 p.
- McWilliams, W.H.; Reese, G.C.; Conner, R.C.; et al. 1997. Today's eastern forests: what have 350 years of European settlement wrought? *Transactions of the North American Wildlife and Natural Resource Conference*. 62: 220-235.
- Mitchell, R.J.; Palik, B.J.; Hunter, Jr., M.L. 2002. Natural disturbance as a guide to silviculture. *Forest Ecology and Management*. 155: 315-317.
- Moore, E.H.; Witham, J.W. 1996. From forest to farm and back again: land use history as a dimension of ecological research in coastal Maine. *Environmental History*. 1: 50-69.
- Motzkin, G.; Patterson III, W.A.; Drake, N.E.R. 1993. Fire history and vegetation dynamics of a *Chamaecyparis thyoides* wetland on Cape Cod, Massachusetts. *Journal of Ecology*. 81: 391-402.
- Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. New York: John Wiley & Sons. 547 p.
- Nelson, T.C. 1957. The original forests of the Georgia piedmont. *Ecology*. 38(3): 340-397.
- Noss, R.F. 1985. On characterizing presettlement vegetation: how and why. *Natural Areas Journal*. 5: 5-19.
- Nowacki, G.J. 2003. Twins from separate mothers—soil scientists and ecologists. In: Davis, R.; Talbot, C., co-chairs. National cooperative soil survey conference proceedings, committee 2: ecological interpretations and principles. USDA Natural Resources Conservation Service Supplemental Report. Plymouth, MA. 1-2 p.

-
- Nowacki, G.J.; Abrams, M.D. 1992. Community, edaphic, and historical analysis of mixed oak forests of the Ridge and Valley Province in central Pennsylvania. *Canadian Journal of Forest Research*. 22: 790-800.
- Nowacki G.J.; Abrams, M.D. 1997. Radial-growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. *Ecological Monographs*. 67: 225-249.
- Nowacki, G.J.; Abrams, M.D.; Lorimer, C.G. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. *Forest Science*. 36: 276-292.
- Nowacki, G.J.; Kramer, M.G. 1998. The effects of wind disturbance on temperate rain forest structure and dynamics of southeast Alaska. Gen. Tech. Rep. PNW-GTR-421. Portland, OR: USDA Forest Service Pacific Northwest Research Station. 32 p.
- Nowacki, G.J.; Trianosky, P.A. 1993. Literature on old-growth forests of eastern North America. *Natural Areas Journal*. 13: 87-107.
- Oliver, C.D.; Stephens, E.P. 1977. Reconstruction of a mixed-species forest in central New England. *Ecology*. 58: 562-572.
- Orwig, D.A.; Abrams, M.D. 1994. Land-use history (1720–1992), composition, and dynamics of oak-pine forests within the piedmont and coastal plain of northern Virginia. *Canadian Journal of Forest Research*. 24: 1216-1225.
- Patch, J.R. 1998. Proceed with caution. Solving the biodiversity conundrum using the natural disturbance paradigm. *Canadian Forest Industries*. Jan./Feb.: 48-52.
- Payette, S.; Filion, L.; Delwaide, A. 1990. Disturbance regime of a cold temperate forest as deduced from tree-ring patterns: the Tautare Ecological Reserve, Quebec. *Canadian Journal of Forest Research*. 20: 1228-1241.
- Payette, S.; Moreau, C.; Sirois, L.; et al. 1989. Recent fire history of the northern Quebec biomes. *Ecology*. 70: 656-673.
- Phipps, R.L. 1982. Comments on interpretation of climatic information from tree rings, eastern North America. *Tree-ring Bulletin*. 42: 11-22.
- Pickett, S.T.A.; White, P.S., eds. 1985. *The ecology of natural disturbance and patch dynamics*. San Diego, CA: Academic Press.
- Pielou, E.C. 1984. *The interpretation of ecological data*. New York: John Wiley & Sons. 263 p.
- Pielou, E.C. 1991. *After the ice age: the return of life to glaciated North America*. Chicago: University of Chicago Press. 366 p.

-
- Pitkanen, A. 2000. Fire frequency and forest structure at a dry site between AD 440 and 1110 based on charcoal and pollen records from a laminated lake sediment in eastern Finland. *The Holocene*. 10: 221-228.
- Pregitzer, K.S.; Reed, D.D.; Bornhorst, T.J.; et al. 2000. A buried spruce forest provides evidence at the stand and landscape scale for the effects of environment on vegetation at the Pleistocene/Holocene boundary. *Journal of Ecology*. 88: 45-53.
- Progulske, D.R. 1974. Yellow ore, yellow hair, yellow pine: a photographic study of a century of forest ecology. South Dakota State University Agricultural Experiment Station Bulletin. Brookings, SD: South Dakota State University. 616 p.
- Province of British Columbia. 1998. Standard for terrestrial ecosystem mapping in British Columbia. Ecosystems Working Group, Terrestrial Ecosystems Task Force, Resources Inventory Committee. <http://srmwww.gov.bc.ca/risc/pubs/teecolo/tem/catalog.htm>.
- Province of British Columbia. 2001. <http://srmwww.gov.bc.ca/rib/wis/tem/index.htm>.
- Reed, W.J.; Larsen, C.P.S.; Johnson, E.A.; et al. 1998. Estimation of temporal variations in historical fire frequency from time-since-fire map data. *Forest Science*. 44: 465-475.
- Reice, S.R. 2001. *The silver lining: the benefits of natural disasters*. Princeton, NJ: Princeton University Press. 218 p.
- Reid, E.H.; Strickler, G.S.; Hall, W.B. 1980. Green fescue grassland: 40 years of secondary succession. Res. Pap. PNW-274. Portland, OR: USDA Forest Service Pacific Northwest Forest and Range Experiment Station. 39 p.
- Rentch, J.S.; Desta, F.; Miller, G.W. 2002. Climate, canopy disturbance, and radial growth averaging in a second-growth mixed-oak forest in West Virginia, U.S.A. *Canadian Journal of Forest Research*. 32: 915-927.
- Reynolds, R.V.; Pierson, A.H. 1942. Fuel wood use in the United States: 1630–1930. Circular 641. Washington, DC: U.S. Department of Agriculture.
- Rhodes, T.E.; Davis, R.B. 1995. Effects of late Holocene forest disturbance and vegetation change on acidic Mud Pond, Maine, U.S.A. *Ecology*. 76: 734-746.
- Robinson, A.H.; Sale, R.; Morrison, J.L. 1978. *Elements of cartography*. 4th ed. New York: John Wiley & Sons. 415 p.
- Russell, E.W.B.; Davis, R.B.; Anderson, R.S.; et al. 1993. Recent centuries of vegetational change in the glaciated northeastern United States. *Journal of Ecology*. 81: 647-664.

-
- Salvador, A., ed. 1994. International stratigraphic guide. 2nd ed. Boulder, CO: Geological Society of America. 214 p.
- Schoeneberger, P.J.; Wysocki, D.A.; Benham, E.C.; et al., eds. 2002. Field book for describing and sampling soils. Ver. 2.0. Lincoln, NE: USDA Natural Resources Conservation Service, National Soil Survey Center. 220 p.
- Schulte, L.A.; Mladenoff, D.J. 2001. The original U.S. Public Land Survey records: their use and limitations in reconstructing presettlement vegetation. *Journal of Forestry*. 99: 5-10.
- Sears, P.B. 1925. The natural vegetation of Ohio. *Ohio Journal of Science*. 25: 139-149.
- Seischab, F.K.; Orwig, D. 1991. Catastrophic disturbances in the presettlement forests of western New York. *Bulletin of the Torrey Botanical Club*. 118: 117-122.
- Seymour, R.S.; White, A.S.; deMaynadier, P.G. 2002. Natural disturbance regimes in northeastern North America: evaluating silvicultural systems using natural scales and frequencies. *Forest Ecology and Management*. 155: 357-367.
- Shanks, R.E. 1953. Forest composition and species association in the beech-maple forest region of western Ohio. *Ecology*. 34: 455-466.
- Shiflet, T.N., ed. 1994. Rangeland cover types of the United States. Denver, CO: Society for Range Management. 152 p.
- Shumar, M.L.; Anderson, J.E. 1986. Gradient analysis of vegetation dominated by two sub-species of big sagebrush. *Journal of Range Management*. 39(2): 156-160.
- Siccama, T.G. 1971. Presettlement and present forest vegetation in northern Vermont with special reference to Chittenden County. *American Midland Naturalist*. 85: 153-172.
- Silbernagel, J.; Chen, J.; Gale, M.R.; et al. 1997. An interpretation of landscape structure from historic and present land cover data in the eastern Upper Peninsula of Michigan. Gen. Tech. Rep. NC-192. St. Paul, MN: USDA Forest Service North Central Station.
- Silbernagel, J.; Martin, S.R.; Gale, M.R.; et al. 1997. Prehistoric, historic, and present settlement patterns related to ecological hierarchy in the eastern Upper Peninsula of Michigan, U.S.A. *Landscape Ecology*. 12: 223-240.
- Simard, H.; Bouchard, A. 1996. The precolonial 19th century forest of the Upper St. Lawrence Region of Quebec: a record of its exploitation and transformation through notary deeds of wood sales. *Canadian Journal of Forest Research*. 26: 1670-1676.
- Skovlin, J.M.; Thomas, J.W. 1995. Interpreting long-term trends in Blue Mountain ecosystems from repeat photography. PNW-GTR-315. Portland, OR: USDA Forest Service Pacific Northwest Research Station.

-
- Smith, M.L., ed. 2002. Proceedings, landtype associations conference: development and use in natural resources management, planning and research. Gen. Tech. Rep. NE-294. Newton Square, PA: USDA Forest Service Northeastern Research Station. 117 p.
- Society for Range Management (SRM). 1998. Revised. A glossary of terms used in range management. Denver, CO: Society for Range Management. 32 p.
- Society for Range Management (SRM) Task Group on Unity in Concepts and Terminology. 1995. Evaluating rangeland suitability: the evolving technology. *Rangelands*. 17: 85-92.
- Spies, T.A.; Barnes, B.V. 1985. A multifactor ecological classification of the northern hardwood and conifer ecosystems of Sylvania Recreation Area, Upper Peninsula, Michigan. *Canadian Journal of Forestry Research*. 15: 949-960.
- Spurr, S.H. 1951. George Washington, surveyor and ecological observer. *Ecology*. 32: 544-549.
- St. George, S.; Nielsen, E. 2000. Signatures of high magnitude 19th century floods in *Quercus macrocarpa* tree rings along the Red River, Manitoba, Quebec. *Geology*. 28: 899-902.
- Steele, R.; Cooper, S.V.; Ondov, D.M.; et al. 1983. Forest habitat types of eastern Idaho-western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: USDA Forest Service Intermountain Forest and Range Experiment Station. 122 p.
- Stewart, L.O. 1935. Public Land Surveys: history, instructions, methods. Ames, IA: Collegiate Press.
- Strickler, G.S.; Hall, W.B. 1980. The Standley Allotment: a history of range recovery. USDA Forest Service Research Paper PNW-278. Portland, OR: USDA Forest Service Pacific Northwest Research Station. 35 p.
- Stringham, T.K.; Shaver, P.L.; Mieman, P.J. 2001. States, transitions, and thresholds: further refinement for rangeland applications. Oregon Agr. Exp. Sta. Special Report 1024. Corvallis, OR: Oregon State University. 15 p.
- Svalberg, T; Tart, D.; Fallon, D.; et al. 1997. Bridger-East ecological unit inventory. Pinedale, WY: USDA Forest Service Bridger-Teton National Forest.
- Swetnam, T.W. 1993. Fire history and climate change in giant sequoia groves. *Science*. 262: 885-889.
- Swetnam, T.W.; Allen, C.D.; Betancourt, J.L. 1999. Applied historical ecology: using the past to manage for the future. *Ecological Applications*. 9: 1189-1206.
- Tankersley, K.B.; Holland, J.D.; Kilmer, R.L. 1996. Geoarchaeology of the Kilmer Site: a paleoindian habitation in the Appalachian Uplands. *North American Archaeologist*. 17: 93-111.

-
- Tansley, A.G. 1935. The use and abuse of vegetational concepts and terms. *Ecology*. 16: 284-307.
- Travis, R.B. 1955. Classification of rocks. *Quarterly of the Colorado School of Mines*. 50(1): 98.
- Tüxen, R. 1956. Die heutige natürliche potentielle Vegetation als Gegenstand der vegetationskartierung. Remagen. *Berichte zur Deutschen Landeskunde*. 19: 200-246.
- UNEP/FAO (United Nations Environment Programme/Food and Agriculture Organization of the United Nations). 1995. Background note on ongoing activities relating to land use and land cover classification. Nairobi, Kenya: United Nations.
- USDA Forest Service. 1990. Minerals and Geology. FSM 2800.
- USDA Forest Service. 1991a. Ecological classification and inventory handbook. FSH 2090.11.
- USDA Forest Service. 1991b. Ecosystem classification, interpretation, and application. FSM 2060.
- USDA Forest Service. 1991c. Soil management handbook. FSH 2509.18.
- USDA Forest Service. 1999. Implementation of remote sensing for ecosystem management. EM-7140-28. Washington, DC: USDA Forest Service Remote Sensing Advisory Team and Remote Sensing Applications Center. 17 p.
- USDA Forest Service. 2002. Rio Grande National Forest land use management plan. Monte Vista, CO: U.S. Department of Agriculture, Region 2, Rio Grande National Forest.
- USDA Forest Service. 2003a. Methodology technical guide: cover-frequency transect protocol. Available at http://fsweb.ftcol.wo.fs.fed.us/ftp/pub/staff/rangelands/docs/protocols/transects/cover_frequency/Cover_Frequency_Methodology_Tech_Guide.doc. 32 p.
- USDA Forest Service. 2003b. Methodology technical guide: line intercept transect protocol. Available at http://fsweb.ftcol.wo.fs.fed.us/ftp/pub/staff/rangelands/docs/protocols/transects/line_intercept/Line_Intercept_Methodology_Tech_Guide.doc. 18 p.
- USDA Forest Service. 2003c. National range protocols. Ft. Collins, CO: USDA Forest Service Washington Office, Detached Rangelands Staff. <http://fsweb.ftcol.wo.fs.fed.us/frs/rangelands/inventory/index.shtml>.
- USDA Forest Service. 2005. TEUI geospatial toolkit. <http://fsweb.rsac.fs.fed.us/geospatialtoolkit>. Salt Lake City, UT: USDA Forest Service Remote Sensing Application Center.
- USDA Forest Service. [In Press.] Resource Inventories and Monitoring and Ecosystem Assessment. FSM 1940.
- USDA Forest Service. [In Press.] Resource Inventories and Monitoring and Ecosystem Assessment. FSH 1909.xx.

-
- USDA Natural Resources Conservation Service (NRCS). Revised 1993. Soil survey manual. Agricultural Handbook 18. Washington, DC: USDA NRCS Soil Survey Staff. 437 p.
- USDA Natural Resources Conservation Service (NRCS). 1997. National range and pasture handbook. Washington, DC: USDA NRCS Grazing Lands Technology Institute. 125 p.
- USDA Natural Resources Conservation Service (NRCS). 2000. National forestry manual, title 190.
- USDA Natural Resources Conservation Service (NRCS). 2003a. Keys to soil taxonomy. 9th ed. Agriculture Handbook 436. Washington, DC: USDA NRCS Soil Survey Staff. 869 p. Available at http://soils.usda.gov/technical/classification/tax_keys/keysweb.pdf.
- USDA Natural Resources Conservation Service (NRCS). 2003b. National soil survey handbook (NSSH). Title 430-VI. Washington, DC: USDA NRCS Soil Survey Staff. <http://soils.usda.gov/technical/handbook/>.
- USDA Natural Resources Conservation Service (NRCS). 2004. National forestry handbook, title 190.
- USDA Soil Conservation Service. 1994. Soil climate regimes of the United States. Lincoln, NE: National Soil Survey Center. 22 p.
- Van Wagner, C.E. 1988. The historical pattern of annual area burned in Canada. Forest Chronicles. 64: 182-185, 319.
- Veatch, J.O. 1959. Presettlement forest map of Michigan. East Lansing, MI: Michigan Department of Resource Development, Michigan State University.
- Walker, D.; Stelfox, J.B.; Wasel, W; et al. 1996. Natural disturbance regimes as templates for boreal forest harvest. In: Barclay, R.M.R; Brigham, R.M., eds. Proceedings, bats and forests symposium. British Columbia Ministry of Forests Research Program Working Paper 23/1996.
- Webster, R.; Oliver, M.A. 1990. Statistical methods in soil and land resource survey: spatial information systems. New York: Oxford University Press. 307 p.
- Wertz, W.A.; Arnold, J.A. 1972. Land systems inventory. Ogden, UT: USDA Forest Service, Intermountain Region. 12 p.
- Westoby, M.; Walker, B.H.; Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management. 42: 266-274.
- White, C.A. 1991. A history of the Rectangular Survey System. 2nd printing. Washington, DC: USDI Bureau of Land Management.
- White, M.A.; Mladenoff, D.J. 1994. Old-growth forest landscape transitions from pre-European settlement to present. Landscape Ecology. 9: 191-205.

-
- Whitney, G.G. 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. *Ecology*. 67: 1548-1559.
- Whitney, G.G. 1987. An ecological history of the Great Lakes Forest of Michigan. *Journal of Ecology*. 75: 667-684.
- Whitney, G.G. 1990. The history and status of the hemlock-hardwood forests of the Allegheny Plateau. *Journal of Ecology*. 78: 443-458.
- Whitney, G.G. 1994. From coastal wilderness to fruited plain: a history of environmental change in temperate North America from 1500 to the present. Cambridge, England: Cambridge University Press.
- Whitney, G.G.; DeCant, J.P. 2001. Government Land Office surveys and other early land surveys. In: Egan, D.; Howell, E.A. *The historical ecology handbook: a restorationist's guide to reference ecosystems*. Washington, DC: Island Press. 147-172.
- Whitney, G.G.; Somerlot, W.J. 1985. A case of woodland continuity and change in the American Midwest. *Biological Conservation*. 31: 265-287.
- Whittaker, R.H. 1962. Net production relations of shrubs in the Great Smoky Mountains. *Ecology*. 43: 357-377.
- Wirth, T.; Maus, P.; Powell, J.; et al. 1996. Monitoring aspen decline using remote sensing and GIS. In: Greer, J.D., ed. *Proceedings of the 6th Forest Service remote sensing applications conference*. Bethesda, MD: American Society for Photogrammetry and Remote Sensing. 174-183.
- Wright, Jr., H.E. 1974. Landscape development, forest fires, and wilderness management. *Science*. 186: 487-495.

Additional Reading

- Avery, T.E.; Berlin, G.L. 1992. *Fundamentals of remote sensing and airphoto interpretation*. 5th ed. New York: Macmillan. 472 p.
- Bailey, R.G. 1980. Description of the ecoregions of the United States. Misc. Pub. 1391. Washington, DC: USDA Forest Service. 77 p.
- Bayer, Kenneth C. 1983. Generalized structural, lithologic, and physiographic provinces in the fold and thrust belts of the United States. [1:2,500,000]. U.S. Geological Survey.
- Bernknopf, R.L.; et al. 1993. Societal value of geologic maps. U.S. Geological Survey Circular 1111. 53 p.
- Bloom, A.L. 1978. *Geomorphology*. New York: Prentice Hall. 482 p.

-
- Breshears, D.D.; Herrick, J. 2002. State and transition models: response to thresholds and nonlinear responses in ecosystems. *Ecological Society of America Bulletin*. 83: 3.
- Dietrich, R.V.; Duto, Jr., J.T.; Foote, R.M., comps. 1982. AGI data sheets for geology in the field, laboratory, and office. Alexandria, VA: American Geological Institute.
- Easterbrook, D.J. 1993. Surface processes and landforms. New York: Macmillan. 520 p.
- Fennemen, N.M. 1931. Physiography of the western United States. New York: McGraw-Hill. 534 p.
- Fennemen, N.M.; Johnson, D.W. 1946. Physical divisions of the United States. [1:7,000,000]. In: Thelin, G.P.; Pike, R.J. 1991. Landforms of the conterminous U.S.: a digital shaded-relief portrayal. [1:3,500,000]. I-2206. U.S. Geological Survey. 16 p.
- FS/BLM/NRCS Interagency Task Team. 1989. Proposed service-wide data standards for soil, water, air/climate, and geology information. Working paper. USDA Forest Service.
- Graf, W.L., ed. 1987. Geomorphic systems of North America: Geological Society of America DNAG centennial special. Vol. 2.
- Hammond, Edwin H. 1970. Classes of land-surface form: U.S. Geological Survey National Atlas Sheet No. 62. [1:7,500,000]. From: Hammond, E.H. 1964. Classes of land surface form in the 48 States, U.S.A. [1:5,000,000]. *Annals of the Association of American Geographers* 54(1): map supplement no. 4.
- Haskins, D.M.; Chatoian, J.M. 1993. Geology data standards for ecological unit inventories for the Pacific Southwest Region. Tech. Pap. 05-008. San Francisco: USDA Forest Service Pacific Southwest Region. 152 p.
- Holdorf, H.; Donahue, J. 1990. Landforms for soil surveys in the northern Rockies. Misc. Pub. 51. Missoula, MT: University of Montana, Montana Forest and Conservation Experiment Station. 26 p.
- Hunt, C.B. 1979. Surficial geology. [1:7,500,000]. U.S. Geological Survey National Atlas Sheet.
- King, P.B. 1967. Tectonic features. [1:7,500,000]. U.S. Geological Survey National Atlas Sheet No. 70.
- King, P.B.; Beikman, H.M. 1974a. Explanatory text to accompany the geologic map of the United States. U.S. Geological Survey Prof. Paper 901. Reston, VA: U.S. Geological Survey.
- King, P.B.; Beikman, H.M. 1974b. Geologic map of the United States. [1:2,500,000]. U.S. Geological Survey Map. Reston, VA: U.S. Geological Survey.
- Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. *American Geographic Society Special Publication* 36. 116 p.

-
- Kuchler, A.W. 1966. Potential natural vegetation. Rev. [1:7,500,000]. U.S. Geological Survey National Atlas Sheet. New York: American Geographical Society.
- Olson, C.G. 1994. Draft geomorphic description system for the Soil Conservation Service. Working paper. USDA Soil Conservation Service.
- Omernick, J.M.; Gallant, A.L. 1987a. Ecoregions of the south central United States: U.S. Environmental Protection Agency Map EPA/600/D-87/315. [1:2,500,000]. Adapted from: Omernick, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers*. 77(1).
- Omernick, J.M.; Gallant, A.L. 1987b. Ecoregions of the west central United States: U.S. Environmental Protection Agency Map EPA/600/D-87/317. [1:2,500,000]. Adapted from: Omernick, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers*. 77(1): 1.
- Peterson, F.F. 1990. A manual for describing NSSL soil-sampling sites. Draft report. Washington, DC: USDA Soil Conservation Service.
- Rocky Mountain Association of Geologists. 1972. *Geologic atlas of the Rocky Mountain Region*. Denver, CO: Rocky Mountain Association of Geologists. 331 p.
- Rogers, P. 1996. Disturbance ecology and forest management: a review of the literature. Gen. Tech. Rep. INT-GTR-336. Ogden, UT: USDA Forest Service Intermountain Research Station. 16 p.
- Russell, E.W.B. 1983. Indian-set fires in the forests of the northeastern United States. *Ecology*. 64: 78-88.
- Thelin, G.P.; Pike, R.J. 1991. Landforms of the conterminous U.S.: a digital shaded-relief portrayal. [1:3,500,000]. U.S. Geological Survey Map I-2206. 16 p.
- USDA Forest Service. 1977. Vegetation and environmental features of forest and range ecosystems. Agriculture Handbook No. 475. 68 p.
- USDA Forest Service. 1993. Standards for data and data structures handbook. FSH 6609.15.
- USDA Forest Service. 1995. Integrated resource inventory guide. Denver, CO: Region 2.
- USDA Forest Service. 2000. Instruction for completing the Ecological Site Description Form. Albuquerque, NM: Region 3.

Appendix C. Vegetation Ocular Forms and Codes

This appendix includes examples of forms for recording plot metadata, environmental attributes, and vegetation data for ocular macroplots which provides a minimum set of vegetation data required for Terrestrial Ecological Unity Inventory (TEUI).

Plot Location

Locate the plot within a representative and uniform portion of the vegetation and site conditions to be sampled. The plot should not cross-obvious ecotones of vegetation or site conditions. In some cases, you may locate the plot to sample vegetation and site conditions within broad ecotones.

Mark the center of the plot, measure, and flag the outside edge. Place flagging or metal pins upslope, downslope, and along the contour to the left and right of plot center. Once you mark the plot boundary, walk around the plot and become familiar with the plant species, ground cover, vegetation layering, and other ecological characteristics.

Calibration

Conduct ocular estimate calibration at the beginning of inventory projects and periodically throughout the life of the project. Calibrate ocular estimates by using cover frequency and/or line intercept transect methods (refer to *National Range Protocols* [USDA Forest Service 2003c] for these methods). Examiners usually calibrate their ocular estimates by periodically double sampling with cover frequency transects. Minimal variability usually exists between trained examiners on canopy cover estimates and is negated by the many samples that can be obtained with this method.

Cover Frequency

The cover frequency method uses a 20 cm x 50 cm Daubenmire frame systematically placed along a transect to record quantitative values for canopy cover and ground cover. Species composition is then determined from canopy cover, frequency, and ground cover. The cover frequency method is best for vegetation types of less than 1 meter in height. Specific methods for conducting cover frequency are identified in the *National Range Protocol's* "Cover Frequency Field Guide" (USDA Forest Service 2003a). Note: While the protocol requires a minimum of 3 transects and 60 frames, we recommend a total of only 30 frames.

Line Intercept

The line intercept method consists of a line transect, usually in multiples of 100 feet, where measurements are made of the crown spread of the various plants that are bisected by the transect line. The line intercept method is commonly used for measurement of semi-arid shrub and bunchgrass vegetation types. Specific methods for conducting line intercept sampling method are identified in the *National Range Protocol's* "Line Intercept Field Guide" (USDA Forest Service 2003b).

Absolute numbers facilitate the ease of data sharing, can be easily converted to cover classes, and, in the case of classes with wide ranges at the lower end, may increase accuracy in analysis. Absolute percent cover of the fixed area plot is the standard and is required. Cover classes are optional and are accommodated in the Natural Resource Information System (NRIS) Terra database. Class code sets will be stewarded by regions.

Species Identification

Vascular Species

Integrated plots require a list of all vascular species and their percent canopy cover. Lichens/nonvascular species are optional. Species should be organized on the field form by life form class. Use taxonomy supported by locally/regionally accepted floras. Identify to species level. In identifying subspecies/variety level, default to local/regional direction. (The NRIS Terra data form will display all four levels of scientific name when plant code is entered.) Natural Resources Conservation Service (NRCS) PLANTS database symbols (plant code) are the standard national coding system for plants. All codes in the NRCS PLANTS database are valid choices.

Coding and Collection of Unknown Species

Immature plants that cannot be identified to the species level should be identified to the genus level. The NRCS PLANTS database has symbols for the genus level when species cannot be determined. When species or genus cannot be determined, use the most appropriate general organism code for an unknown plant. Mature plants that cannot be identified in the field should be collected and pressed for later identification. Assign a collection number to the collection and record on a data line on the field form along with other required information (percent cover, etc.). For unknown species and/or species collected for subsequent identification, use an appropriate NRCS general organism code for the plant symbol (e.g., 2FORB = unknown forb). See the National PLANTS database (<http://plants.usda.gov>) for a complete list of these codes.

Collection Numbers

Assign collection numbers that enable pressed samples to be easily related back to field forms or database entries later. At a minimum, record collection number, examiner, and date on the collection. For example, label the collected plant with the site ID followed by a unique number for the plant collected on that plot. The collection number identifies that plant on the field form. For example, if three unknown plants were collected on plot 642, they could be recorded as 642-1, 642-2, and 642-3. It is not necessary to re-collect the same unknown species on every plot. If the same unknown species obviously is present on additional plots, that same collection number could be referenced on the field form for that plot. For example, if two unknown species occurred on plot 645, one a “new” discovery and the other collected previously on plot 642, they could be recorded as 645-1 (the new unknown) and 642-3 (the collection number assigned to a previously collected plant).

Legacy Plant Coding Systems

NRCS PLANTS database symbols (plant codes) are the required standard national coding system for plants. While the maintenance and continued use of local or “legacy” plant coding systems (such as Regional code sets) is discouraged, such codes still may have utility in working with non-Forest Service partners and with legacy data sets/publications. The NRIS Terra database accommodates legacy-coding systems by supporting a crosswalk table between legacy systems and the NRCS PLANTS database that is managed by the Regional Plants database steward. Coordinate with your Regional Plants database steward for access to legacy coding systems.

Productivity

Numerous methods can estimate the productivity potential for an ecological type or map unit component. TEUI projects should provide at least one measure of site productivity. Examples of productivity measures include site index, growth basal area, potential productivity, stand density index, and growth estimates.

Site index is a measure of site productivity expressed by the height-to-age relationship of dominant and co-dominant trees of a given species at a given base age. It is an index of site yield capability.

Growth basal area is an index of forest stand stockability (Hall 2003) It uses the relationship between current radial increment or dominant trees, current total stand basal area, and age to index the capability of a site to support and grow wood volume.

Potential productivity can be determined for rangelands by clipping and weighing vegetation, which is often done by either species or life form. Clipping by species should be done when characterizing ecological sites and correlating with NRCS.

Stand density-index based volume index is an index of yield capacity that uses spatial data interference adjustments to normal yield tables.

C.1 Instructions for General Site Data Form

Collect the following data elements at all sample sites: R=Required, O=Optional.

Field Name	Instructions
Site ID	R Record a plot number or site identifier that is unique within the project.
Project Name	R Record the name of the project.
Date	R Record the month, day, and year in the format MM-DD-YYYY.
Sample Type(s)	R Record the type(s) of data collected on the plot using the following codes: OCMA = Ocular macroplot FLLI = Flora line intercept FLCO = Flora cover/frequency FLPO = Flora point cover FLTR = Flora tree data SOPE = Soil pedon (individual tree measurements)
Examiner(s)	R Record the last name, first name, and middle initial of all crewmembers. Record the name of the principal investigator first.
Plot Location Type	R Record the approach used to locate the plot using the following codes: P = Preferential R = Random S = Stratified random (or systematic) See section C.2.3 for a discussion of sampling strategies.
Species List Type	R Record the completeness of the plant species list for the plot using the following codes: C = Complete. All plant species present at time of sampling are recorded. R = Reduced. Not all plant species are recorded. The list may be limited by a cover threshold (e.g. > 5% cover) or relative abundance (e.g., five most abundant species). S = Selected. Not all plant species recorded. A protocol- or project-specific list of species are recorded whenever they are present on a plot. L = Life form only. No species are recorded. Cover is only recorded for life forms, and usually by layer or size class within life form. A complete species list is required for developing and describing new associations and alliances. See section C.2.4.3 for more information.
Plot Area	R Record the area of the macroplot or belt-transect in either acres or square meters, and the unit of measure (UOM) used. See section C.2.4.1 for guidelines for determining plot size.
Plot Size	R Record actual plot dimensions, using radius for circular plots, and width and length for rectangular plots. Also record the UOM used.

Field Name	Instructions
Vegetation Classification	R Record as much classification information as known at the time of sampling including the potential natural vegetation (PNV) series, association, and reference; existing vegetation alliance, association, and reference; ecological type; and Federal Geographic Data Committee (FGDC) subclass. Subclass is determined in the field using the key in appendix 1C of the <i>Existing Vegetation Classification and Mapping Technical Guide</i> (Brohman and Bryant, eds. 2005).
GPS Location	R Record the location of the sample site using latitude-longitude or Universal Transverse Mercator with zone.

Field Name	Instructions
Aerial Photo ID	O Record the photo identification number.
Flight Line	O Record the three-digit photo flight line.
Roll #	O Record the three-digit roll number and contract fiscal year. For example, “189” identifies roll 1 taken in fiscal year 1989.
Plot Photo Label	O Record a descriptive alpha/numeric label to track photos. For example, roll number followed by exposure # “2-14” to help label and track photos after processing.
Photo Description	O Record a description of the photo subject.
Film Type	O Record the type of film when a film camera is used.
Digital Photo File Name	O Record the filename of the photo when a digital camera is used.
Elevation	R Record the sample site elevation, in feet, to the nearest 10 feet.
Slope	R Record the sample site average slope, in percent.
Aspect	R Record the sample site aspect, in degrees. For slopes that have no aspect, record a zero. For due north, record 360.
Horizontal Slope Shape	O Record the horizontal shape of the plot. See section C.1.1 and figure C.1 for values and codes.
Vertical Slope Shape	O Record the vertical shape of the plot. See section C.1.1 and figure C.1 for values and codes.
Slope Complexity	O Record the slope complexity of the plot using the following codes: S = Simple. Linear, convex, or concave in shape. C = Complex. Broken, undulating, or patterned in shape.
Slope Position	R Record the two-dimensional position of the plot on the landform using the following codes: SU = Summit SH = Shoulder BS = Backslope FS = Foothill TS = Toeslope
Slope Position Modifier	R Record the modifier which best describes the primary slope position using the following codes: LR = Lower MD = Mid UP = Upper
Ground Surface Cover Type	R Record each ground surface cover type present in the plot. See sections C.1.2 and C.1.3 for types, descriptions, and codes.
Ground Surface Cover Percent	R Record an ocular estimate of the percentage of the plot covered by each ground surface cover type.

Field Name	Instructions
Disturbance Type	O Record major disturbance events. See Section C.1.4 for a list of disturbance types and codes.
Disturbance Extent Affected	O Record the vegetation affected and/or the ground cover affected, in percent.
Disturbance Date	O Record the disturbance date, in years, to the nearest year.
Disturbance Notes	O Record notes relating to major disturbance event. Include the type of vegetation or species affected.

C.1.1 Vertical and Horizontal Shape Code

The following codes should be used for vertical and horizontal slope shape:

Code	Description
BR	Broken. Cliffs, knobs, and/or benches interspersed with steeper slopes; generally characterized by sharp, irregular breaks.
CV	Convex. Raised, arched up, curved out.
LI	Linear/Planar. Straight, even, or smooth.
CC	Concave. Depressional, curved in.
UN	Undulating (also rolling). Pattern of one or more low relief ridges or knolls and draws
PA	Patterned. Relief of hummocks and swales with several feet
FL	Flat. Straight and level.
XX	Unable to assess.

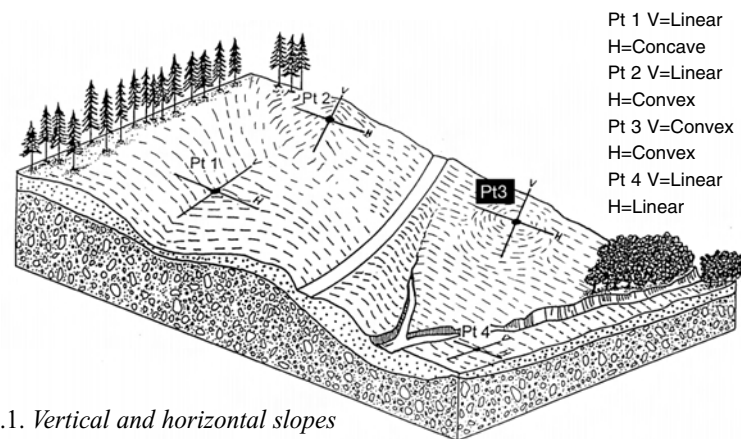


Figure C.1. *Vertical and horizontal slopes*

C.1.2 Ground Surface Cover

Ground surface cover estimates are ocular. Absolute percent cover of the fixed area plot is the standard and required. Ground surface cover is defined as the percentage of plot surface area that is occupied by the ground cover type. Estimate to the nearest 1 percent

in the 1 to 10 percent range, to the nearest 5 percent for amounts exceeding 10 percent. Figure C.2 illustrates some ground cover types. The following reduced set of ground cover categories is used in existing vegetation classification to describe and develop interpretations for ground cover and document disturbance effects:

Code	Description
BARE	Bare soil. Soil particles < 2 mm not covered by rock, cryptogams, or organic material. Does not include any part of a road, but does include foot trails.
Live Vegetation Categories	
BAVE	Basal vegetation. Basal vegetation is the soil surface occupied by live basal or root crown portion of vascular plants, including live trees. Typically ranges between 3 and 7%; 15% is very high and rarely encountered.
NONV	Nonvascular. Plants or plant-like organisms without specialized water or fluid conductive tissue (xylem and phloem). Includes mosses, liverworts, hornworts, lichens, algae, and bacterial soil crusts.
Organic Debris Categories	
LITT	Litter. Plant litter and duff not yet incorporated into the decomposed top humus layer. Includes twigs < 1/4 inch in diameter, ash from burned plants, dead nonvascular plants, and dung.
WOOD	Wood. Any dead woody material > 1/4 inch in diameter, small and large woody debris, regardless of depth. Includes bases of standing dead trees and shrubs.
Rock Categories	
BEDR	Bedrock. A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.
BOUL	Boulders. Rock > 600 mm (24 inches) in diameter or length.
COBB	Cobbles. Rock fragments between 75 and 250 mm (3 and 10 inches) in diameter.
GRAV	Gravel. Rock fragments between 2 and 75 mm in diameter.
PAVE	Pavement. A natural concentration of closely packed and polished stones at the soil surface in a desert (may or may not be an erosional lag). Also, rock fragments < 19.1mm in diameter.
ROCK	Total rock. Relatively hard, naturally formed mineral or petrified matter > 2mm in diameter.
RROC	Range rock. Rock fragments > 3/4 inch (19.1 mm) in diameter.
STON	Stones. Rock fragments between 250 and 600 mm (10 and 24 inches) in diameter.
Miscellaneous Categories	
PEIS	Permanent ice and snow. Surface area covered by apparently permanent ice and/or snow at the time of plot measurement.
ROAD	Road. Any road or vehicle trail that is regularly maintained or in long-term continuous use. Includes cutbanks and fills.
TRIS	Transient ice and snow. Surface area covered by apparently transient ice and/or snow at the time of plot measurement.
WATE	Water. Includes transient water that obscures other cover types and permanent water where the water table is above the ground bogs, swamps, marshes, and ponds.

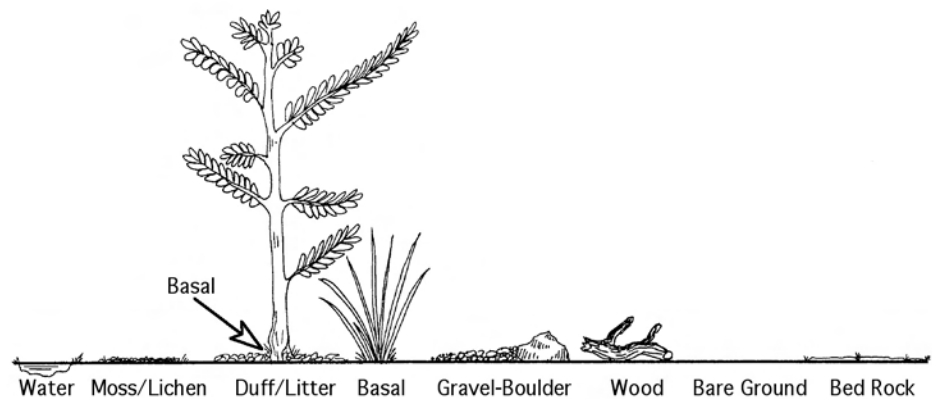


Figure C.2. *Ground surface cover types*

The following ground cover types should be recorded whenever present and are included on the example General Site Data form: bare soil, basal vegetation, nonvascular, litter, and wood. More detailed subdivisions of these categories are available in the NRIS Terra database, but are not recommended for vegetation classification. The miscellaneous categories should also be recorded whenever present. Rock cover must be recorded using one of the three sets of categories described below.

C.1.3 Rock Ground Cover Types

Rock cover on the ground surface should be described using one of the following sets of ground cover types. Set 1 is the minimum requirement. Set 2 is used primarily for specific rangeland monitoring methods. Set 3 is recommended for vegetation classification and description done in conjunction with TEUI.

Rock Set 1		Rock Set 2		Rock Set 3	
ROCK	All rock from gravel to bedrock.	PAVE	Pavement (2–19.1 mm diam.)	GRAV	Gravel (2–75 mm diam.)
		PROC	Rock (> 19.1 mm diam.)	COBB	Cobbles (75–250 mm diam.)
				STON	Stones (250–600 mm diam.)
				BOUL	Boulders (> 600 mm diam.)
				BEDR	Bedrock

C.1.4 Disturbance Event Code Categories

The following codes should be used for disturbance and treatment types:

Code	Disturbance or Treatment	Code	Disturbance or Treatment
10000	Insects (general)	50003	Drought
10011	Ant (Formicidae)	50004	Flooding/high water
11000	Bark beetles	50011	Snow/ice
12000	Defoliators	50013	Wind/tornado
13000	Chewing insects	50015	Avalanche
14000	Sucking insects	50016	Mud/landslide
15000	Boring insects	51001	Channel erosion
16000	Seed/cone/flower/fruit insects	51002	Soil creep
17000	Gallmaker insects	51010	Slump
18000	Insect predators	70005	Land clearing
19000	General diseases	70006	Land use conversion
20000	Biotic damage	70008	Mechanical
21000	Root/butt diseases	71000	Timber harvest
22000	Stem decay/cankers	71002	Firewood harvest
23000	Parasitic/epiphytic plants	71027	Natural changes (no cut)
23001	Mistletoe	73000	Regeneration activities (general)
24000	Decline complexes/dieback/wilts	73004	Seeding (trees-natural)
25000	Foliage diseases	73005	Seeding (trees-artificial)
26000	Stem rusts	73008	Grass seeding
27000	Broom rusts	73015	Site preparation
30000	Fire	73016	Brush control
41002	Beaver	74000	Timber stand improvement (general/noncommercial)
41003	Big game (e.g., deer)	75000	Prescribe burning (general)
41016	Browsing	75004	Planned ignition/prescribed burn/natural fuels
41021	Rodents	75005	Unplanned ignition/prescribed burn/natural fuels
41022	Elk	78007	Miscellaneous upland recreation activities
42001	Cattle	78008	Miscellaneous riparian recreation activities
42004	Sheep	80000	Multi-damage (insects/diseases)
		90000	Unknown

General Site Data Form
USDA Forest Service

SITE ID #		PROJECT NAME	
DATE (MM-DD-YYYY)		SAMPLE TYPE(S)	
EXAMINER: LAST		First	Initial
PLOT LOCATION TYPE:	SPECIES LIST TYPE:	PLOT AREA:	UOM
PLOT SIZE: RADIUS	WIDTH	LENGTH	UOM
			STATE:

VEGETATION CLASSIFICATION		
PNV SERIES:	PNV ASSOC:	PNV REFERENCE:
EV ALLIANCE:	EV ASSOC:	EV REFERENCE:
ECOLOGICAL TYPE:		FGDC SUBCLASS:

GPS LOCATION		
LAT.	UTM	NORTH
LONG.	ZONE	EAST

AERIAL PHOTO INFORMATION						
DATE	SOURCE	SCALE	PROJ/CODE	FLIGHT LINE	ROLL #	EXP. #

PLOT PHOTO INFORMATION			
LABEL	PHOTO DESCRIPTION	FILM TYPE	DIGITAL PHOTO FILE NAME

MORPHOMETRY						
ELEVATION	SLOPE	ASPECT	SHAPE HOR.	SHAPE VERT.	COMPLEXITY	POSITION _____ MOD _____

GROUND SURFACE COVER							
TYPE	PERCENT	TYPE	PERCENT	TYPE	PERCENT	TYPE	PERCENT
BAVE		BARE					
NONV							
LITT							
WOOD							

MAJOR DISTURBANCE EVENTS			
DISTURBANCE TYPE	EXTENT AFFECTED	DISTURBANCE DATE	NOTES:
	VEGETATION GROUND COVER		

Remarks:

C.2 Instructions for Vegetation Composition Form

The Vegetation Composition Form can be used to record or summarize data for a number of sampling methods. Its use for the ocular macroplot method is described here.

C.2.1 Vegetation Sampling Metadata

The first part of the Vegetation Composition Form records metadata about the vegetation sampling methods and who collected the data. The plot location should be recorded on the General Site Data Form.

Field Name		Instructions
Site ID	R	Record a plot number or site identifier that is unique within the project. This must match the Site ID on the General Site Data Form.
Date	R	Record the month, day, and year in the format MM-DD-YYYY.
Examiner(s)	R	Record the last name, first name, and middle initial of all crewmembers. Record the name of the principal investigator first.
Sample Type	R	Record the type of data collected on the plot using one of the following codes: OCMA = Ocular macroplot FLLI = Flora line intercept FLCO = Flora cover/frequency FLPO = Flora point cover FLTR = Flora tree data
Species List Type	R	Record the completeness of the plant species list for the plot using the following codes: C = Complete. All plant species present at time of sampling are recorded. R = Reduced. Not all plant species are recorded. The list may be limited by a cover threshold (e.g., > 5% cover) or relative abundance (e.g., five most abundant species). S = Selected. Not all plant species recorded. A protocol- or project-specific list of species are recorded whenever they are present on a plot. L = Life form only. No species are recorded. Cover is only recorded for life forms, and usually by layer or size class within life form. A complete species list is required for developing and describing new associations and alliances. See section C.2.4.3 for more information.
Plot Area	R	Record the area of the macroplot or belt transect in either acres or square meters, and the UOM used. See section C.2.4.1 for guidelines for determining plot size.
Area UOM	R	Record the UOM for the plot area, either acres or square meters.
Plot Size	R	Record actual plot dimensions, using radius for circular plots, and width and length for rectangular plots. Also record the UOM used.
Size UOM	R	Record the UOM for the plot dimensions, either feet or meters.
Height UOM	R	Record the UOM for plant heights, either feet or meters.
Diameter UOM	R	Record the UOM for tree diameters.

C.2.2 Canopy Cover by Life Form

Record the canopy cover for each item in this part of the form. Canopy cover is “the percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings within the canopy are included” (SRM 1998, USDA NRCS 1997). See sections 2.2.3.3 and 2.4.5 of the *Existing Vegetation Classification and Mapping Technical Guide* (Brohman and Bryant, eds. 2005) for more information about canopy cover and ocular estimation techniques.

Complete the fields in this part of the form as follows:

All vegetation	Total vegetation cover. Record the percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of all vascular plants within the sample unit (plot or transect).
Trees	Tree cover. Record the total cover of trees, defined as woody plants that generally have a single main stem, have more or less definite crowns, and are usually equal to or greater than 5 meters in height at maturity (see section 2.4.2.1 of Brohman and Bryant 2005).
Shrubs	Shrub cover. Record the total cover of shrubs, defined as woody plants that generally have several erect, spreading, or prostrate stems which give it a bushy appearance, and are usually less than 5 meters in height at maturity (see section 2.4.2.1 of Brohman and Bryant 2005). Shrub cover includes the cover of dwarf shrubs.
Dwarf shrubs	Dwarf shrub cover. Record the total cover of dwarf shrubs, defined as caespitose, suffrutescent, matted, or cushion-forming shrubs which are typically less than 50 cm tall at maturity due to genetic and/or environmental constraints (see section 2.4.2.1 of Brohman and Bryant 2005).
Herbs	Herb cover. Record the total cover of herbs, defined as vascular plants without significant woody tissue above the ground, with perennating buds borne at or below the ground surface (see section 2.4.2.1 of Brohman and Bryant 2005). Includes forbs, graminoids, ferns, and fern allies. Herb cover must be equal to or less than the sum of graminoid cover and forb cover.
Graminoids	Graminoid Cover. Record the total cover of graminoids, defined as flowering herbs with relatively long narrow leaves and inconspicuous flowers with parts reduced to bracts. Include grasses, sedges, rushes, and arrowgrasses (see section 2.4.2.1 of Brohman and Bryant 2005).
Forbs	Forb Cover: Record the total cover of forbs, defined as spore-bearing herbs or flowering herbs with relatively broad leaves and/or showy flowers (see section 2.4.2.1 of Brohman and Bryant 2005). Include ferns or fern allies.

Dwarf shrubs are a subcategory of shrubs. Forbs, graminoids, and fern-like are subcategories of herbs. Total canopy cover of additional life forms can be recorded in part 3 of the Vegetation Composition Form as needed.

C.2.3 Canopy Cover by Species

The third part of the Vegetation Composition Form is used to record data about vegetation layers and individual plant species. This portion of the form is divided into a section for trees and shrubs and a section for herbs and nonvascular organisms.

Record a complete list of all plant species within the sampling unit. Record only those species present in the plot. Do not record species that are present in the stand but do not occur within the plot. Record the canopy cover for each species. Do not use cover classes. Estimate percent canopy cover of each species, life form, layer, or size class within the plot as follows:

- Use 0.1 as “trace” for items present but clearly less than 1 percent cover.
- Estimate to the nearest 1 percent between 1 and 10 percent cover.
- Estimate to at least the nearest 5 percent between 10 and 30 percent cover.
- Estimate to at least the nearest 10 percent for values exceeding 30 percent cover.

Record a life form and life form modifier for each species using the codes in tables 2.5 and 2.6, respectively, of the *Existing Vegetation Classification and Mapping Technical Guide* (Brohman and Bryant, eds. 2005). These codes are used for crosswalking to the FGDC physiognomic hierarchy and describing physiognomy of associations and alliances (Jennings et al. 2004).

C.2.4 Canopy Cover and Structural Data by Layer

Species data may also be recorded by layer if desired. The following instructions describe how to record data for tree and shrub layers, and for tree and shrub species by layer.

C.2.4.1 Tree Layer Definitions

Trees vary widely in mature height, from 5 meters to more than 50 meters (FGDC 1997). This variation must be taken into account when defining layers or height classes for trees. For this purpose, a dwarf tree is defined as a tree that is typically less than 12 meters tall at maturity due to genetic and/or environmental constraints. A stand of dwarf trees typically has a site-specific potential height growth of less than 12 meters. The layers described below are defined separately for dwarf trees where necessary.

The following tree layers must be described whenever they are present in the sampling unit (e.g., macroplot or transect):

Overstory (TO) The overstory layer includes all trees greater than or equal to 5 meters in height that make up the forest canopy. In dwarf tree stands, the

overstory consists of trees that have attained at least half of their site-specific potential height growth and make up the forest canopy.

Regeneration (TR) The regeneration layer includes all trees less than 5 meters in height. In dwarf tree stands the regeneration layer includes trees that have attained less than half of their site-specific potential height growth and are clearly overtopped by the overstory trees.

The overstory may optionally be subdivided into the following sublayers, if they occur, to describe stand structure in more detail:

Main canopy (TOMC) The dominant and co-dominant overstory trees that receive direct sunlight from above and make up the majority of the forest canopy.

Supercanopy (TOSP) Scattered overstory trees that clearly rise above the main canopy.

Subcanopy (TOSB) Overstory trees that are clearly overtopped by and separate from the main canopy, but are larger and taller than the regeneration layer.

The regeneration layer may optionally be subdivided into the following sublayers:

Saplings (TRSA) Regenerating trees greater than 1.4 meters (4.5 feet) in height, *or* regenerating dwarf trees greater than 1 meter in height.

Seedlings (TRSE) Regenerating trees less than 1.4 meters (4.5 feet) in height, *or* regenerating dwarf trees less than 1 meter in height.

C.2.4.2 Tree Layer Data Requirements and Instructions

Canopy cover, predominant plant height, and predominant crown height must be recorded for the tree overstory and regeneration layers. Predominant diameter must also be recorded for the overstory. Record these attributes using the following procedures:

Canopy cover	Record percent canopy cover for each layer and optional sublayer occurring within the sampling unit. Canopy cover of a layer cannot be greater than the sum of the canopy cover values of its sublayers. Layer cover, however, typically is less than the sum of the sublayer covers due to overlapping of the sublayers.
Predominant plant height	Record the predominant, or prevailing, tree height for the overstory and regeneration layers to the nearest meter and nearest foot, respectively. This attribute is determined by selecting a representative tree for the layer and estimating its height using a clinometer and measuring tape. The representative tree for the overstory layer must be in the main canopy. The representative tree for the regeneration layer must be from the sublayer (sapling or seedling) with the most canopy cover. Predominant plant height may also be recorded for each optional sublayer.

Predominant crown height	Record the predominant, or prevailing, crown height for the overstory and regeneration layers to the nearest meter. Crown height is the vertical distance from ground level to the lowest whorl with live branches in at least three of four quadrants around the stem. It is determined by selecting a representative tree for the layer and estimating its crown height using a clinometer and measuring tape. The representative tree for the overstory layer must be in the main canopy. The representative tree for the regeneration layer must be from the sublayer (sapling or seedling) with the most canopy cover. Predominant crown height may also be recorded for each optional sublayer.
Predominant diameter	Record the predominant, or prevailing, tree diameter for the overstory layer to the nearest inch. Predominant diameter is the prevailing diameter of the most abundant tree species in a layer or sublayer. It is determined by selecting a representative tree and measuring it with a diameter tape, using procedures described in the <i>Common Stand Exam Field Guide</i> . The representative tree for the overstory layer must be in the main canopy. Measure the diameter at breast height (d.b.h.) whenever possible; otherwise, measure diameter at root crown (d.r.c.), and record the diameter in the appropriate column (d.b.h. or d.r.c.) of the Vegetation Composition Form.

An example of both the required and optional data for tree layers is shown below.

Required layers and data are in bold text. Heights are in meters and diameters in inches.

Table C.1. *Example of completed data for tree layers and sublayers.*

Life form	LF mod.	Layer	Species	Canopy cover	Pred. plant height	Pred. crown height	Pred. d.b.h.	Pred. d.r.c.
T	—	TO	—	45	10	6	12	—
T	—	TOSP	—	5	12	8	15	—
T	—	TOMC	—	40	10	6	12	—
T	—	TOSB	—	10	7	2.5	8	—
T	—	TR	—	10	4	0.3		
T	—	TRSA	—	5	4	0.3		
T	—	TRSE	—	5	0.3	0		

C.2.4.3 Data for Shrub Layers

The following shrub layers may optionally be described when present in the sampling unit (e.g., macroplot or transect):

Tall shrubs Shrubs greater than 2 meters in height. (May occasionally include shrubs over 5 meters tall but clearly multi-stemmed.)

Medium shrubs Shrubs 0.5 to 2 meters in height.

Low shrubs Shrubs less than 0.5 meter in height.

When shrub layers are described, canopy cover and predominant plant height should be recorded for each layer. Predominant crown height may also be recorded. Record these attributes using the following procedures:

Canopy cover	Record percent canopy cover for each shrub layer occurring within the sampling unit. Total shrub cover cannot be greater than the sum of the individual layer cover values, but may be less.
Predominant plant height	Record the predominant, or prevailing, height of each shrub layer to at least the nearest foot. Predominant plant height is the prevailing upper height of the shrubs within a layer. It is determined by selecting a representative individual shrub and measuring its height with an appropriate method (e.g. tape measure for low to medium shrubs or clinometer for tall shrubs).
Predominant crown height	Record the predominant crown height for each shrub layer to at least the nearest foot. Crown height for shrubs is the vertical distance from ground level to the lowest live foliage or branches. It is determined by selecting a representative shrub for the layer and measuring or estimating its crown height.

An example of completed shrub layer data is shown below. Heights are in meters.

Table C.2. *Example of completed data for shrub layers.*

Life form	LF mod.	Layer	Species	Canopy cover	Pred. plant height	Pred. crown height
S	—	ST	—	1	3	1
S	—	SM	—	9	1	0.3
S	—	SL	—	Tr	0.3	0

C.2.5 Optional Canopy Cover and Structural Data by Species by Layer

Canopy cover and structural data may optionally be recorded separately for each species for each layer or sublayer in which it occurs.

C.2.5.1 Data for Tree Species by Layer

Canopy cover. Record the total canopy cover of each tree species and the canopy cover of each species within each layer in which it occurs. Cover by sublayer may also be recorded, requiring up to eight rows of data, depending on the number of sublayers in which a species occurs. An example is shown in table C.3 with required data in bold text. In this example, the canopy cover of Ponderosa pine (*Pinus ponderosa*) is 45 percent. Within the overstory and regeneration layers, its canopy cover is 35 and 10 percent, respectively, indicating no overlap between the two layers. No sapling or seedling occurs directly under an overstory tree. Overlap occurs, however, between main canopy and subcanopy trees. Ponderosa pine cover is 30 percent in the main canopy and 10

percent in the subcanopy, while overstory cover is only 35 percent. This indicates 5 percent overlap between main canopy and subcanopy Ponderosa pine.

The possibility of overlap between sublayers requires that overstory and regeneration cover for each tree species be estimated or measured directly, not calculated by summing the sublayer values. When recording species cover by sublayer using the ocular macroplot method, it is most efficient to first estimate canopy cover by sublayer, then estimate the overlap (if any) between sublayers to derive canopy cover for the overstory and regeneration layers.

Table C.3. *Example of tree species by layer canopy cover data.*

Life Form	LF Mod	Layer	Species	Canopy Cover
<i>T</i>	<i>TN</i>	—	<i>PIPO</i>	45
<i>T</i>	<i>TN</i>	<i>TO</i>	<i>PIPO</i>	35
<i>T</i>	<i>TN</i>	<i>TOMC</i>	<i>PIPO</i>	30
<i>T</i>	<i>TN</i>	<i>TOSB</i>	<i>PIPO</i>	10
<i>T</i>	<i>TN</i>	<i>TR</i>	<i>PIPO</i>	10
<i>T</i>	<i>TN</i>	<i>TRSA</i>	<i>PIPO</i>	6
<i>T</i>	<i>TN</i>	<i>TRSE</i>	<i>PIPO</i>	4

Predominant plant height. Record predominant height of each tree species for each layer in which it occurs. It is determined by selecting a representative tree and estimating its height using a clinometer and measuring tape, using procedures described in the *Common Stand Exam Field Guide* (2005).

Predominant crown height. Record predominant crown height of each tree species for each layer in which it occurs. It is determined by selecting a representative tree and estimating or measuring the vertical distance from the ground to the canopy base.

Predominant age. Record the predominant age of each tree species in the overstory layer. Refer to the *Common Stand Exam Field Guide* (2005) for methods of determining tree age.

Predominant diameter. Record predominant diameter (d.b.h. or d.r.c. as appropriate) for the overstory layer. It is determined by selecting a representative tree and measuring it with a diameter tape, using procedures described in the *Common Stand Exam Field Guide* (2005).

Stem count. Record stem counts for each tree species occurring in the regeneration layer. Stems may optionally be recorded by sublayer (sapling and seedling). Counts can be made on the entire plot or on a portion of the plot depending on the density of

each species. When stems are counted on a portion of the plot, the fraction of the plot and the raw count are recorded in the remarks section of the form. These are then used to calculate a count for the entire plot, which is recorded in the stem count column of the form.

An example of a completed data set for one tree species is shown in table C.4. Predominant plant height, crown height, diameter, age, and stem count have been added

Life form	LF mod.	Layer	Species	Canopy cover	Pred plant ht.	Pred. crown height	Pred. d.b.h.	Pred. d.r.c.	Pred. age	Stem count
<i>T</i>	<i>TN</i>	—	<i>PIPO</i>	45						
<i>T</i>	<i>TN</i>	<i>TO</i>	<i>PIPO</i>	35	40	15	30	—	150	
<i>T</i>	<i>TN</i>	<i>TOMC</i>	<i>PIPO</i>	30	40	15	30	—	150	
<i>T</i>	<i>TN</i>	<i>TOSB</i>	<i>PIPO</i>	10	20	5	12	—	80	
<i>T</i>	<i>TN</i>	<i>TR</i>	<i>PIPO</i>	10	4	0.5				13
<i>T</i>	<i>TN</i>	<i>TRSA</i>	<i>PIPO</i>	6	4	0.5				4
<i>T</i>	<i>TN</i>	<i>TRSE</i>	<i>PIPO</i>	4	0.3	0				9

C.2.5.2 Data for Shrub Species by Layer

Canopy cover. Record the total canopy cover of each shrub species. The canopy cover of each species within each layer in which it occurs may be recorded optionally. This process may require up to four rows of data, depending on the number of layers in which a shrub species occurs. The possibility of overlap between layers requires that total canopy cover for each shrub species be estimated or measured directly, not calculated by summing the species by layer cover values.

Predominant crown height. Record predominant crown height of each shrub species for each layer in which it occurs. It is determined by selecting a representative shrub and estimating or measuring the vertical distance from the ground to the lowest live foliage.

Predominant height. Record predominant height of each shrub species or optionally for each layer in which the species occurs. Predominant height is the prevailing upper height of the shrub species within a layer. It is determined by selecting a representative individual shrub and measuring its height with an appropriate method (e.g., tape measure for low to medium shrubs or clinometer for tall shrubs).

An example of completed shrub species and species by layer data is shown below. Heights are in meters.

Table C.5. Example of completed data for shrub species by layers.

Life form	LF mod.	Layer	Species	Canopy cover	Pred. plant height	Pred. crown height
<i>S</i>	<i>SBD</i>	—	<i>QUGA</i>	9	1	0.2
<i>S</i>	<i>SBD</i>	<i>ST</i>	<i>QUGA</i>	1	3	1
<i>S</i>	<i>SBD</i>	<i>SM</i>	<i>QUGA</i>	8	1	0.2
<i>S</i>	<i>SM</i>	—	<i>ARTRP4</i>	1	0.7	0.2
<i>S</i>	<i>SM</i>	<i>SM</i>	<i>ARTRP4</i>	1	0.7	0.2

C.2.6 Basal Area Data

Basal area may optionally be collected using a single prism point at the center of a macroplot or midpoint of a transect. Follow the procedures in the *Common Stand Exam Field Guide* (2005). Record the basal area, in square feet per acre, and the expansion factor of the prism used.

C.2.7 Blank Vegetation Composition Form and Completed Examples

A blank Vegetation Composition Form is provided below, followed by examples of a completed General Site Data Form and Vegetation Composition Form.

Plot Area:				Area UOM:	Height UOM:
Plot Size:	Radius	Length	Width	Size UOM:	Diameter UOM:

Life Form:	All Veg	Trees	Shrubs	Dwarf Shrubs	Herbs	Grasses	Forbs
% Cover:							

[illegible]

Remarks:

General Site Data Form

USDA Forest Service

SITE ID # <i>FSR4BT92DT127</i>		PROJECT NAME <i>B-T East TEUI</i>	
DATE (MM-DD-YYYY) <i>08-23-1995</i>		SAMPLE TYPE(S) <i>OCMA, SOPE</i>	
EXAMINER: LAST <i>Tart Ferwerda</i>		First <i>David Martin</i>	Initial <i>L</i>
PLOT LOCATION TYPE: <i>P</i>	SPECIES LIST TYPE: <i>C</i>	PLOT AREA: <i>1/10</i>	UOM <i>ACRE</i>
PLOT SIZE: RADIUS <i>37.2</i>	WIDTH	LENGTH	UOM <i>FEET</i> STATE: <i>WY</i>

VEGETATION CLASSIFICATION		
PNV SERIES: <i>ABLA</i>	PNV ASSOC: <i>VASC, PIAL</i>	PNV REFERENCE: <i>Steele&1983</i>
EV ALLIANCE: <i>PIAL</i>	EV ASSOC: <i>VASC</i>	EV REFERENCE: <i>NONE</i>
ECOLOGICAL TYPE:		FGDC SUBCLASS: <i>IIA</i>

GPS LOCATION		
LAT. <i>43° 18' 44"</i>	UTM	NORTH
LONG. <i>110° 12' 33"</i>	ZONE	EAST

AERIAL PHOTO INFORMATION						
DATE	SOURCE	SCALE	PROJ/CODE	FLIGHT LINE	ROLL #	EXP. #
<i>09-01-1989</i>					<i>1715</i>	<i>87</i>

PLOT PHOTO INFORMATION			
LABEL	PHOTO DESCRIPTION	FILM TYPE	DIGITAL PHOTO FILE NAME

MORPHOMETRY							
ELEVATION	SLOPE	ASPECT	SHAPE HOR.	SHAPE VERT.	COMPLEXITY	POSITION	MOD
<i>9900'</i>	<i>9%</i>	<i>19°</i>	<i>UN</i>	<i>UN</i>	<i>C</i>	<i>BS</i>	<i>UP</i>

GROUND SURFACE COVER							
TYPE	PERCENT	TYPE	PERCENT	TYPE	PERCENT	TYPE	PERCENT
<i>BAVE</i>	<i>8</i>	<i>BARE</i>	<i>2</i>	<i>STON</i>	<i>7</i>		
<i>NONV</i>	<i>4</i>	<i>BEDR</i>	<i>5</i>	<i>BOUL</i>	<i>5</i>		
<i>LITT</i>	<i>50</i>	<i>GRAV</i>	<i>1</i>				
<i>WOOD</i>	<i>15</i>	<i>COBB</i>	<i>3</i>				

MAJOR DISTURBANCE EVENTS				
DISTURBANCE TYPE	EXTENT AFFECTED		DISTURBANCE DATE	NOTES:
	VEGETATION	GROUND COVER		

Remarks: *Stop# B0606B. Location from pin-pricked photo, not GPS.*

VEGETATION COMPOSITION FORM

Site ID #: FSR4BT92DT127	Date: 08-23-1995	Examiner(s): David L. Tart
Sample Type: OCMA	Species List: (C) or R or S or L	Martin Ferwerda

Plot Area: 1/10	Area UOM: <i>acre</i>	Height UOM: <i>feet</i>
Plot Size: 37.2 Length Width	Size UOM: <i>feet</i>	Diameter UOM:

Percent Canopy Cover by Life Form

Life Form:	All Veg	Trees	Shrubs	Dwarf Shrubs	Herbs	Grasses	Forbs
% Cover:	(80)	45	35	35	12	7	5

Percent Canopy Cover and Structure Data by Layer and Species

Trees and Shrubs											Herbaceous and Nonvascular Life					
Form	LF Mod.	Layer	Plant Code	Can. Cover	Pred. Plant Ht.	Pred. Crown Ht.	Pred. d.b.h.	Pred. d.r.c.	Pred. Age	Stem Count	Form	LF Mod.	Layer	Plant Code	Can. Cover	Pred. Ht.
T	—	TO	—	37	50	17					H	HF		ASTER	0.1	1
T	—	TOSP	—	—	—	—					H	HF		EPAN2	0.1	1
T	—	TOMC	—	29	50	17					H	HF		ERIGE2	0.1	0
T	—	TOSB	—	12	30	12					H	HF		HIGR	0.1	1
T	—	TR	—	17	—	—										
T	—	TRSA	—	8	—	—					H	HG		CAR05	2	0
T	—	TRSE	—	9	—	—					H	HG		JUDR	0.1	1
S	—	ST	—	—	—	—					H	HG		POCU	0.1	2
S	—	SM	—	—	—	—					H	HG		PONEW	5	3
S	—	SL	—	35	1	—					H	HG		POP43	0.1	1
T	TN	—	ABLA	20	—	—										
T	TN	TO	ABLA	7	30	12										
T	TN	TR	ABLA	16	—	—										
T	TN	—	PIAL	20	—	—										
T	TN	TO	PIAL	20	45	15										
T	TN	TR	PIAL	0.1	—	—										
T	TN	—	PIEN	13	—	—										
T	TN	TO	PIEN	12	60	20										
T	TN	TR	PIEN	1	—	—										
S	SD	SL	VASC	35	1	0										

Basal Area:

BAF Used:

Remarks:

Appendix D. Geology and Geomorphology Form

SITE ID #		DATE (MM-DD-YYYY)				EXAMINER:				
BEDROCK GEOLOGY										
SEQUENCE NUMBER	PRIMARY LITHOLOGY	SECONDARY LITHOLOGY	TEXTURE MODIFIER	DEPTH TO BEDROCK CLASS	WEATHERING	CHEMISTRY MODIFIER	STRUCTURE TYPE	AZIMUTH INCLINATION	FRACTURE INTERVAL	STRATI-GRAPHY
PARENT/SURFICIAL MATERIAL										
SEQUENCE NUMBER	ORIGIN	KIND	KIND MODIFIER	CHEMISTRY MODIFIER	SIZE CLASS	STRATIGRAPHY				
GEOMORPHOLOGY										
GENERATION	GEOMORPHIC CLASSIFICATION									
ACTIVE										
DORMANT										
RELICT										
NOTES										

Geology and Geomorphology Form Instructions

Field Name	Description and Action To Be Taken
Site ID	Record the identifier that is unique within a specific project or inventory area.
Date	Enter the date the site was described. Example: 7-8-97.
Examiner	Enter the name of the person(s) describing the site.

Bedrock Geology

Field Name	Description and Action To Be Taken
Sequence Number	If more than one rock type will be described at the site, number from the top down.
Primary Lithology	Select primary lithology term from the table on page 152. Example: Sedimentary.
Secondary Lithology	Select secondary lithology term from the table on page 152. Example: Sandstone.
Texture Modifier	Select term from the table on page 160. Example: Clastic.
Depth to Bedrock Class	Estimate the depth to bedrock and place in appropriate class from the table on page 152. Example: DEEP.
Weathering	Determine weathering state from the table on page 152. Example: PDS – Partially Decomposed.
Chemistry Modifier	Select appropriate term from the table on page 163. Example: AC – Acidic.
Structure Type	Select appropriate term from Appendix A. Example: BE – Bedding.
Azimuth/Inclination	Record the azimuth of the strike and inclination of the dip in degrees. Example: 200/15.
Fracture Interval	Select appropriate class from the table on page 163. Example: 1 < 10 cm between fractures.
Stratigraphy	Locally determined values for unit name and age. Example: Kbb – Blind Bull Formation.

Parent/Surficial Material

Field Name	Description and Action To Be Taken
Sequence Number	If more than one rock type will be described at the site, number from the top down.
Origin	Select either primary lithology or secondary lithology from the table on page 152. Example: Sandstone.

Field Name	Description and Action To Be Taken
Kind	Select secondary lithology code from Parent/Surficial Materials table on page 163.
Kind Modifier	Select modifier from the table on page 166 if kind needs to be further defined.
Weathering	Determine weathering state from the table on page 152. Example: PDS – Partially Decomposed.
Chemistry Modifier	Select appropriate term from the table on page 163. Example: AC – Acidic.
Size Class	Select appropriate term from the table on page 167. Example: 7 – Loamy.
Stratigraphy	Locally determined values for unit name and age. Example: Kbb – Blind Bull Formation.

Geologic Terms and Definitions

Bedrock Characteristics

Depth to Bedrock Class

Depth Class	Definition
DEEP	Deep – 10 to 20 feet deep
MOD	Moderate – 5 to 10 feet deep
SHAL	Shallow – < 5 feet deep
VDEP	Very deep – > 20 feet deep

Bedrock Weathering

Weathering Code	Meaning – Definition
MFS	Micro fresh state – absence of oxidation alteration under hand lens.
VFS	Visually fresh state – uniform color with unaided eye.
STS	Stained state – partial or complete discoloration of mineral.
PDS	Partially decomposed state – solid in place, disaggregate by hand.
CDS	Completely decomposed – disaggregated or remolded to soil.

Bedrock Lithologies

Primary Lithology	Secondary Code	Secondary Description
Igneous Extrusive	ANBA	Analcite Basalt
Igneous Extrusive	ANDE	Andesite
Igneous Extrusive	ANPO	Andesite Porphyry
Igneous Extrusive	BASA	Basalt
Igneous Extrusive	BAPO	Basalt Porphyry
Igneous Extrusive	BAAN	Basaltic Andesite
Igneous Extrusive	BASN	Basanite
Igneous Extrusive	DACI	Dacite
Igneous Extrusive	DAPO	Dacite Porphyry
Igneous Extrusive	FELS	Felsite
Igneous Extrusive	LATI	Latite
Igneous Extrusive	LAPO	Latite Porphyry
Igneous Extrusive	LEBA	Leucite Basanite
Igneous Extrusive	LEPH	Leucite Phonolite
Igneous Extrusive	LETE	Leucite Tephrite
Igneous Extrusive	LIMB	Limburgite
Igneous Extrusive	LIPO	Limburgite Porphyry

Primary Lithology	Secondary Code	Secondary Description
Igneous Extrusive	MELI	Melilitite
Igneous Extrusive	NELA	Nepheline Latite
Igneous Extrusive	NELAPO	Nepheline Latite Porphyry
Igneous Extrusive	NEPH	Nephelinite
Igneous Extrusive	OBSI	Obsidian
Igneous Extrusive	OCEA	Oceanite
Igneous Extrusive	OLBA	Olivine Basalt
Igneous Extrusive	OLNE	Olivine Nephelinite
Igneous Extrusive	PERL	Perlite
Igneous Extrusive	PHON	Phonolite
Igneous Extrusive	PHPO	Phonolite Porphyry
Igneous Extrusive	PITC	Pitchstone
Igneous Extrusive	PUMI	Pumice
Igneous Extrusive	QUBA	Quartz Basalt
Igneous Extrusive	QULA	Quartz Latite
Igneous Extrusive	QULAPO	Quartz Latite Porphyry
Igneous Extrusive	RHYO	Rhyolite
Igneous Extrusive	RHPO	Rhyolite Porphyry
Igneous Extrusive	SCOR	Scoria
Igneous Extrusive	TEPR	Tephrite
Igneous Extrusive	TEPO	Tephrite Porphyry
Igneous Extrusive	TING	Tinguaite
Igneous Extrusive	TRAC	Trachyte
Igneous Extrusive	TRPO	Trachyte Porphyry
Igneous Extrusive	TRAP	Trap
Igneous Extrusive	VITR	Vitrophyre
Igneous Extrusive	WYOM	Wyomingite
Igneous Intrusive	ALSK	Alaskite
Igneous Intrusive	ALGR	Alkali Granite
Igneous Intrusive	ALSY	Alkali Syenite
Igneous Intrusive	ANOR	Anorthosite
Igneous Intrusive	APLI	Aplite
Igneous Intrusive	CHAR	Charnockite
Igneous Intrusive	DIAB	Diabase
Igneous Intrusive	DIOR	Diorite
Igneous Intrusive	DIPO	Diorite Porphyry
Igneous Intrusive	DITR	Ditroite
Igneous Intrusive	DUNI	Dunite
Igneous Intrusive	FERG	Fergusite
Igneous Intrusive	FOYA	Foyaite
Igneous Intrusive	GABB	Gabbro

Primary Lithology	Secondary Code	Secondary Description
Igneous Intrusive	GAPO	Gabbro Porphyry
Igneous Intrusive	GADI	Gabbro/Diorite
Igneous Intrusive	GRAN	Granite
Igneous Intrusive	GRPO	Granite Porphyry
Igneous Intrusive	GRAO	Granodiorite
Igneous Intrusive	GDPO	Granodiorite Porphyry
Igneous Intrusive	GRGR	Graphic Granite
Igneous Intrusive	HARZ	Harzburgite
Igneous Intrusive	LAMP	Lamprophyre
Igneous Intrusive	LARV	Larvikite
Igneous Intrusive	LESY	Leucite Syenite
Igneous Intrusive	LUXU	Luxullianite
Igneous Intrusive	MALI	Malignite
Igneous Intrusive	MISS	Missourite
Igneous Intrusive	MONZ	Monzonite
Igneous Intrusive	MOPO	Monzonite Porphyry
Igneous Intrusive	NEMO	Nepheline Monzonite
Igneous Intrusive	NEMOPO	Nepheline Monzonite Porphyry
Igneous Intrusive	NESY	Nepheline Syenite
Igneous Intrusive	NESYPO	Nepheline Syenite Porphyry
Igneous Intrusive	NORD	Nordmarkite
Igneous Intrusive	NORI	Norite
Igneous Intrusive	OLGA	Olivine Gabbro
Igneous Intrusive	PEGM	Pegmattite
Igneous Intrusive	PERI	Peridotite
Igneous Intrusive	PICR	Picrite
Igneous Intrusive	PULA	Pulaskite
Igneous Intrusive	PYRO	Pyroxenite
Igneous Intrusive	QUDI	Quartz Diorite
Igneous Intrusive	QUDIPO	Quartz Diorite Porphyry
Igneous Intrusive	QUGA	Quartz Gabbro
Igneous Intrusive	QUMO	Quartz Monzonite
Igneous Intrusive	QUMOPO	Quartz Monzonite Porphyry
Igneous Intrusive	QUSY	Quartz Syenite
Igneous Intrusive	SHON	Shonikite
Igneous Intrusive	SOSY	Sodalite Syenite
Igneous Intrusive	SYEN	Syenite
Igneous Intrusive	SYPO	Syenite Porphyry
Igneous Intrusive	SYEO	Syenodiorite
Igneous Intrusive	THER	Theralite
Igneous Intrusive	THPO	Theralite Porphyry

Primary Lithology	Secondary Code	Secondary Description
Igneous Intrusive	TROC	Troctolite
Igneous Intrusive	UNCO	Uncompahgrite
Igneous Intrusive	UOLI	Uolite
Metamorphic	ACHO	Actinolite Hornfels
Metamorphic	ACMA	Actinolite Marble
Metamorphic	ACSC	Actinolite Schist
Metamorphic	ACEPMA	Actinolite-Epidote Marble
Metamorphic	ALMISC	Albite-Mica Schist
Metamorphic	AMPH	Amphibolite
Metamorphic	AMGN	Amphibolite Gneiss
Metamorphic	ANHO	Andalusite Hornfels
Metamorphic	ANSC	Andalusite Schist
Metamorphic	ANSPSL	Andalusite Spotted Slate
Metamorphic	ANBIHO	Andalusite-Biotite Hornfels
Metamorphic	ANGN	Anorthosite Gneiss
Metamorphic	ATHO	Anthophyllite Hornfels
Metamorphic	ARGN	Arkose Gneiss
Metamorphic	AUGN	Augen Gneiss
Metamorphic	BIGN	Biotite Gneiss
Metamorphic	BISPSL	Biotite Spotted Slate
Metamorphic	BICLSC	Biotite-Chlorite Schist
Metamorphic	BLSL	Black Slate
Metamorphic	BRMA	Brucite Marble
Metamorphic	CAHO	Calc-silicate Hornfels
Metamorphic	CLSL	Calcareous Slate
Metamorphic	CASC	Calcite Schist
Metamorphic	CASL	Carbonaceous Slate
Metamorphic	CHSC	Chiastolite Schist
Metamorphic	CHSPSL	Chiastolite Spotted Slate
Metamorphic	CLMA	Chlorite Marble
Metamorphic	CLSC	Chlorite Schist
Metamorphic	CDSC	Chloritoid Schist
Metamorphic	CHMA	Chondrodite Marble
Metamorphic	COGN	Conglomerate Gneiss
Metamorphic	COHO	Cordierite Hornfels
Metamorphic	COANHO	Cordierite-Anthophyllite Hornfels
Metamorphic	CRME	Crystalline Metamorphic
Metamorphic	DBGN	Diabase Gneiss
Metamorphic	DIMA	Diopside Marble
Metamorphic	DIGN	Diorite Gneiss
Metamorphic	ECLO	Eclogite

Primary Lithology	Secondary Code	Secondary Description
Metamorphic	EPAM	Epidote Amphibolite
Metamorphic	EPGN	Epidote Gneiss
Metamorphic	EPHO	Epidote Hornfels
Metamorphic	EPCHSC	Epidote-Chlorite Schist
Metamorphic	FLCO	Flaser Conglomerate
Metamorphic	FLDI	Flaser Diorite
Metamorphic	FLGR	Flaser Granite
Metamorphic	GBGN	Gabbro Gneiss
Metamorphic	GABIGN	Garnet Biotite Gneiss
Metamorphic	GAGN	Garnet Gneiss
Metamorphic	GAHO	Garnet Hornfels
Metamorphic	GACLSC	Garnet-Chlorite Schist
Metamorphic	GAPYAM	Garnet-Pyroxene Amphibolite
Metamorphic	GLSC	Glaucophane Schist
Metamorphic	GNEI	Gneiss
Metamorphic	GRGN	Granite Gneiss
Metamorphic	GDGN	Granodiorite Gneiss
Metamorphic	GRNO	Granofels
Metamorphic	GRNU	Granulite
Metamorphic	GRMA	Graphite Marble
Metamorphic	GRSC	Graphite Schist
Metamorphic	GWGN	Graywacke Gneiss
Metamorphic	GRSL	Green Slate
Metamorphic	GREN	Greenschist
Metamorphic	GREE	Greenstone
Metamorphic	HOBISC	Hornblende-Biotite Schist
Metamorphic	HORN	Hornfels
Metamorphic	KYHO	Kyanite Hornfels
Metamorphic	KYSC	Kyanite Schist
Metamorphic	MAGN	Magnetite
Metamorphic	MARB	Marble
Metamorphic	MEAR	Meta-Argillite
Metamorphic	METC	Metaconglomerate
Metamorphic	METQ	Metaquartzite
Metamorphic	MEME	Metasedimentary Melange
Metamorphic	METS	Metasedimentary Rocks
Metamorphic	MSCA	Metasedimentary calcareous
Metamorphic	MSNC	Metasedimentary non-calcareous
Metamorphic	METV	Metavolvanic Rocks
Metamorphic	MISC	Mica Schist
Metamorphic	MIGM	Migmatite

Primary Lithology	Secondary Code	Secondary Description
Metamorphic	MOGN	Monzonite Gneiss
Metamorphic	MYLO	Mylonite
Metamorphic	OLMA	Olivine Marble
Metamorphic	PEGN	Peridotite Gneiss
Metamorphic	PHYL	Phyllite
Metamorphic	PHLN	Phyllonite
Metamorphic	PLGN	Plagioclase Gneiss
Metamorphic	PYSC	Pyrophyllite Schist
Metamorphic	PRGN	Pyroxene Gneiss
Metamorphic	PYHO	Pyroxene Hornfels
Metamorphic	PRSC	Pyroxene Schist
Metamorphic	QUDIGN	Quartz Diorite Gneiss
Metamorphic	QUPOGN	Quartz Porphyry Gneiss
Metamorphic	QUMISC	Quartz-Mica Schist
Metamorphic	QUSESC	Quartz-Sericite Schist
Metamorphic	QUAR	Quartzite
Metamorphic	QUGN	Quartzite Gneiss
Metamorphic	RHGN	Rhyolite Gneiss
Metamorphic	SAGN	Sandstone Gneiss
Metamorphic	SCHI	Schist
Metamorphic	SCQU	Schistose Quartzite
Metamorphic	SERP	Serpentine
Metamorphic	SEMA	Serpentine Marble
Metamorphic	SEME	Serpentine Melange
Metamorphic	SIGASC	Sillimanite Garnet Schist
Metamorphic	SIGN	Sillimanite Gneiss
Metamorphic	SISC	Sillimanite Schist
Metamorphic	SISL	Silty Slate
Metamorphic	SKAR	Skarn
Metamorphic	SKGN	Skarn Gneiss
Metamorphic	SLAT	Slate
Metamorphic	SOAP	Soapstone
Metamorphic	SPSL	Spotted Slate
Metamorphic	STGN	Staurolite Gneiss
Metamorphic	STSC	Staurolite Schist
Metamorphic	SYGN	Syenite Gneiss
Metamorphic	TASC	Talc Schist
Metamorphic	TOHO	Tourmaline Hornfels
Metamorphic	TOSC	Tourmaline Schist
Metamorphic	TOMISC	Tourmaline-Mica Schist
Metamorphic	TRGN	Trachyte Gneiss

Primary Lithology	Secondary Code	Secondary Description
Metamorphic	TRHO	Tremolite Hornfels
Metamorphic	TRMA	Tremolite Marble
Metamorphic	ULTR	Ultramylonite
Metamorphic	WOHO	Wollastonite Hornfels
Metamorphic	WOMA	Wollastonite Marble
Sedimentary	AGGL	Agglomerate
Sedimentary	ANHY	Anhydrite
Sedimentary	ARGI	Argillite
Sedimentary	ARKO	Arkose
Sedimentary	ARAR	Arkose Argillaceous
Sedimentary	ARCA	Arkose Calcareous
Sedimentary	ARSI	Arkose Siliceous
Sedimentary	ASPH	Asphalt
Sedimentary	BENT	Bentonite
Sedimentary	BREC	Breccia
Sedimentary	CALI	Caliche
Sedimentary	CHAL	Chalk
Sedimentary	CHER	Chert
Sedimentary	CHOO	Chert Oolitic
Sedimentary	CLAS	Claystone
Sedimentary	CLSI	Claystone Siliceous
Sedimentary	COAN	Coal, Anthracite
Sedimentary	COBI	Coal, Bituminous
Sedimentary	CONG	Conglomerate
Sedimentary	COQU	Coquina
Sedimentary	DIAT	Diatomite
Sedimentary	DOLO	Dolomite
Sedimentary	GILS	Gilsonite
Sedimentary	GRAY	Graywacke
Sedimentary	GRCA	Graywacke Calcareous
Sedimentary	GRSA	Greensand
Sedimentary	GYPS	Gypsum
Sedimentary	HALI	Halite
Sedimentary	HEMA	Hematite
Sedimentary	INLISA	Interbedded Limestone and Sandstone
Sedimentary	INLISH	Interbedded Limestone and Shale
Sedimentary	INLISI	Interbedded Limestone and Siltstone
Sedimentary	INSASH	Interbedded Sandstone and Shale
Sedimentary	INSASI	Interbedded Sandstone and Siltstone
Sedimentary	IRON	Ironstone

Primary Lithology	Secondary Code	Secondary Description
Sedimentary	LIGN	Lignite
Sedimentary	LIME	Limestone
Sedimentary	LIAN	Limestone Arenaceous
Sedimentary	LIAR	Limestone Argillaceous
Sedimentary	LIBI	Limestone Bituminous
Sedimentary	LICR	Limestone Carbonaceous
Sedimentary	LICH	Limestone Cherty
Sedimentary	LICL	Limestone Clastic
Sedimentary	LIFE	Limestone Iron-rich
Sedimentary	LIOO	Limestone Oolitic
Sedimentary	LIOR	Limestone Organic
Sedimentary	LIPH	Limestone Phosphatic
Sedimentary	LISI	Limestone Siliceous
Sedimentary	LISICL	Limestone Siliciclastic
Sedimentary	LIMO	Limonite
Sedimentary	MARLST	Marlstone
Sedimentary	MUDS	Mudstone
Sedimentary	MUSI	Mudstone Siliceous
Sedimentary	OOCA	Oolite Calcareous
Sedimentary	OOFE	Oolite Iron-rich
Sedimentary	OOPH	Oolite Phosphatic
Sedimentary	OOSI	Oolite Siliceous
Sedimentary	ORTH	Orthoquartzite
Sedimentary	ORFS	Orthoquartzite Feldspathic
Sedimentary	ORLI	Orthoquartzite Lithic
Sedimentary	PHOS	Phosphorite
Sedimentary	PORC	Porcellanite
Sedimentary	RADI	Radiolarite
Sedimentary	ROSA	Rock Salt
Sedimentary	SANS	Sandstone
Sedimentary	SAAR	Sandstone Argillaceous
Sedimentary	SAARFS	Sandstone Argillaceous Feldspathic
Sedimentary	SAARLI	Sandstone Argillaceous Lithic
Sedimentary	SAARQU	Sandstone Argillaceous Quartz
Sedimentary	SACA	Sandstone Calcareous
Sedimentary	SACAFS	Sandstone Calcareous Feldspathic
Sedimentary	SACALI	Sandstone Calcareous Lithic
Sedimentary	SACAQU	Sandstone Calcareous Quartz
Sedimentary	SACRQU	Sandstone Carbonaceous Quartz
Sedimentary	SAFS	Sandstone Feldspathic
Sedimentary	SAFE	Sandstone Iron-rich

Primary Lithology	Secondary Code	Secondary Description
Sedimentary	SAFEQU	Sandstone Iron-rich Quartz
Sedimentary	SALI	Sandstone Lithic
Sedimentary	SAQU	Sandstone Quartz
Sedimentary	SHAL	Shale
Sedimentary	SHBI	Shale Bituminous
Sedimentary	SHCA	Shale Calcareous
Sedimentary	SHCR	Shale Carbonaceous
Sedimentary	SHFE	Shale Iron-rich
Sedimentary	SHPH	Shale Phosphatic
Sedimentary	SHSI	Shale Siliceous
Sedimentary	SIDE	Siderite
Sedimentary	SILS	Siltstone
Sedimentary	SICA	Siltstone Calcareous
Sedimentary	SICR	Siltstone Carbonaceous
Sedimentary	SIFE	Siltstone Iron-rich
Sedimentary	SUBG	Subgraywacke
Sedimentary	SUCA	Subgraywacke Calcareous
Sedimentary	TRAV	Travertine
Sedimentary	TUFA	Tufa
Sedimentary	TUFF	Tuff
Sedimentary	VOBR	Volcanic Breccia
Sedimentary	VOLC	Volcaniclastic
Undifferentiated	MIEXME	Mixed Extrusive and Metamorphic
Undifferentiated	MIEXSE	Mixed Extrusive and Sedimentary
Undifferentiated	MIIG	Mixed Igneous (extrusive & intrusive)
Undifferentiated	MIIGME	Mixed Igneous and Metamorphic
Undifferentiated	MIIGSE	Mixed Igneous and Sedimentary
Undifferentiated	MIINME	Mixed Intrusive and Metamorphic
Undifferentiated	MIINSE	Mixed Intrusive and Sedimentary
Undifferentiated	MIMESE	Mixed Metamorphic and Sedimentary

Bedrock Texture Modifiers

Code	Modifier	Definition
AMOR	Amorphous	Sediment or sed. rock composed of noncrystalline, authigenic material.
AMYG	Amygdaloidal	Igneous rock with vesicle fillings composed of secondary minerals.
APHA	Aphanitic	Igneous rock composed of grains not individually visible to unaided eye.

Code	Modifier	Definition
AUGE	Augen	Metamorph texture of larger eye-shaped mineral masses in finer grained matrix.
BIOC	Bioclastic	Composed of fragments of fossils.
BOUL	Bouldery	Sediment or sed. rock containing more than 15% particles with a diameter greater than 256 mm.
CATA	Cataclastic	Metamorph texture developed by severe mechanical crushing of the component grains.
CHEM	Chemical	Sediment or sed. rock rock composed primarily of material formed by precip. from soln or colloidal suspension.
CLAS	Clastic	Sediment or sed. rock composed of frags made of preexisting rocks or minerals transported from their origins.
COBB	Cobbly	Sediment or sed. rock with more than 15% rock fragments with a diameter between 64 mm and 256 mm.
CRYP	Cryptocrystalline	Rock composed of crystals or grains not visable with a microscope.
CRYS	Crystalline	Rock composed of interlocking mineral crystals or grains.
DETR	Detrital	Sediment or sed. rock rock composed mostly of particles eroded or weathered from preexisting rocks.
DIAB	Diabasic	Igneous rock composed of anhedral pyrox. between unoriented laths of plag.
EQUI	Equigranular	Igneous rock composed of grains of nearly uniform size.
FISS	Fissile	Sediment or sed. rock rock with very thin bedding planes easily split.
FLAS	Flaser	Metamorph rock with lenses of original minerals surrounded by highly sheared and crushed material.
FOLI	Foliation	Met. rock with planar structure that results from flattening the constituent grains.
GLAS	Glassy	Holohyaline igneous rock.
GNEI	Gneissose	Met. rock with foliation due to alteration of granulose and schistose bands.
GRAT	Granitic	Igneous rock composed of a mixture of anhedral and subhedral grains.
GRAN	Granular	Igneous rock composed of nearly equidimensional mineral xls.
GRAL	Granulose	Met. rock with granular texture with nondirectional structure.
GRAV	Gravelly	Sediment or sed. rock with at least 15% of particles between 2 mm and 10 mm in diameter.
HOLO	Holocrystalline	Igneous rock composed of essentially all crystalline grains.
HLHY	Holohyaline	Igneous rock that is essentially all glass.
HORN	Hornfelsic	Metamorph rock with nondirectional structure.

Code	Modifier	Definition
HYPH	Hypocrystalline	Igneous rock in part composed of glass.
LINE	Lineation	Met. rock with parallel directional structure of mineral grains.
MICR	Microcrystalline	Igneous rock composed of xls individually visible with a microscope.
MIGM	Migmatic	Metamorphic host rocks with granitic layers or lenses.
MYLO	Mylonitic	Met. rock with foliated, fine-grained cataclastic structure.
OOLI	Oolitic	Sediment or sed. rock composed of spheroids less than 2 mm in diameter.
OPHI	Ophitic	Igneous rock composed of plagioclase laths enclosed in plates of pyroxene.
PEBB	Pebbly	Sediment or sed. rock with more than 15% particles between 2 mm and 64 mm in diameter.
PEGM	Pegmatitic	Igneous rock composed of xls conspicuously larger than surrounding rock.
PHCG	Phan-coarse grained	Igneous rock composed of xls more than 5 mm in diameter.
PHFG	Phan-fine grained	Igneous rock composed of xls less than 1 mm in diameter.
PHMG	Phan-medium grained	Igneous rock composed of xls 1-5 mm in diameter.
PHAN	Phaneritic	Igneous rock composed of xls individually visible to the unaided eye. PHYL Phyllitic Met. rock with foliation intermediate between slaty and schistose.
PISO	Pisolitic	Sediment or sed. rock composed of spheroids greater than 2 mm in diameter.
PORP	Porphyritic	Igneous rock composed of larger xls in a fine-grained groundmass.
PUMI	Pumiceous	Igneous rock that is highly vesicular and finely cellular.
SAND	Sandy	Sediment or sed. rock with more than 15% grains between 1/16 mm and 2mm in diameter.
SCHI	Schistose	Met. rock with foliation due to parallel orientation of phan., flaky minerals.
SCOR	Scoriaceous	Igneous rock that is highly vesicular and coarsely cellular.
SILT	Silty	Sediment or sed. rock with more than 15% particles between 1/256 mm and 1/16 mm in diameter.
SLAT	Slaty	Met. rock with foliation in aphanitic metamorphic rocks.
SPHE	Spherulitic	Igneous rock with spherical bodies of xls.
VESI	Vesicular	Igneous rock with spherical, ovoid, or tubular openings (vesicles).

Bedrock and Surficial Materials Chemistry Modifiers

Code	Meaning	Definition
AC	Acidic	Igneous rocks or sediments that contain more than 65% SiO ₂ .
BA	Basic	Igneous rocks or sediments with a relatively low silica content: 44–53%.
CA	Calcareous	Rocks or sediments containing calcium carbonate up to 50%.
CB	Carbonaceous	Sediments that contain considerable original or introduced organic material.
IM	Intermediate	Igneous rocks or sediments transitional between basic and acidic, with silica content of 54–64%.
SI	Siliceous	Rocks or sediments containing abundant free silica (rather than silicate minerals).
UL	Ultrabasic	Igneous rocks or sediments with a silica content lower than 44%.

Bedrock Fracture Interval

Code	Meaning
1	< 10 cm between fractures.
2	10 cm to 45 cm between fractures.
3	45 cm to 1.0 m between fractures.
4	1.0 to 2.0 m between fractures.
5	> 2.0 m between fractures.

Geological Structure Type

Code	Meaning	Definition
BE	Bedding	Planar surfaces that visibly separate layers of stratified rock.
FA	Fold Axis	The line that, moved parallel to itself, generates the form of a fold.
FO	Foliation	Planar structure from flattening of the rock's constituent grains.
FT	Fault	Fracture or a zone of fractures along which displacement has occurred.
JO	Joint	Fracturing or parting in rock, without displacement.
LI	Lineation	Any linear structure in a rock; e.g., mineral streaking and stretching from compression.

Parent/Surficial Materials

Primary and Secondary Lithology

Primary Lithology	Secondary Code	Secondary Description	Definition
Unconsolidated	ALLU	Alluvium	Clastic material deposited by moving water.
Unconsolidated	ASLO	Ash/Loess Mixture	Mixed volcanic ash and wind-blown silt.

Primary Lithology	Secondary Code	Secondary Description	Definition
Unconsolidated	CIND	Cinders	Pyroclastic material > 2 mm in size.
Unconsolidated	COLL	Colluvium	Nonsorted materials deposited on or at the base of a slope through gravitational forces.
Unconsolidated	CRYO	Cryoturbate	Earth material moved or disturbed by frost action.
Unconsolidated	DIAM	Diamicton	Nonsorted or poorly sorted, noncalcareous, terrigenous sediment that contains a wide range of particle sizes.
Unconsolidated	DIEA	Diatomaceous Earth	Light-colored siliceous sediment, consisting chiefly of opaline frustules of the diatom.
Unconsolidated	EOLI	Eolian Deposit	Deposit of wind-blown sediment.
Unconsolidated	GLAC	Glacial Deposit	Material deposited by a glacier.
Unconsolidated	GLMO	Glacial Moraine Deposit	Distinct accumulation of unsorted, unstratified material deposited chiefly by direct action of glacial ice.
Unconsolidated	GLTI	Glacial Till Deposit	Unsorted and unstratified material deposited directly by and underneath a glacier without subsequent reworking by meltwater.
Unconsolidated	GLFL	Glaciofluvial Deposit	Material transported and deposited by running water emanating from a glacier.
Unconsolidated	GLLA	Glaciolacustrine Deposit	Deposit composed of suspended material brought by meltwater streams flowing into lakes bordering a glacier.
Unconsolidated	GLMA	Glaciomarine Deposit	Deposit composed of suspended material brought by meltwater streams flowing into seas bordering a glacier.
Unconsolidated	GRSA	Greensand	Marine sediment consisting largely of dark greenish grains of glauconite.
Unconsolidated	GYSA	Gypsum Sand	Sediment consisting primarily of gypsum particles > 0.05 mm.

Primary Lithology	Secondary Code	Secondary Description	Definition
Unconsolidated	HUCA	Human Caused/Constructed	Sediments deposited by direct human action.
Unconsolidated	LACU	Lacustrine Sediments	Deposit composed of suspended material brought by streams flowing into lakes.
Unconsolidated	LAHA	Lahar	Water-saturated volcanic materials that flowed down the volcano's slopes.
Unconsolidated	LADE	Landslide Deposit	Deposit of material resulting from the downslope transport, under gravitational influence, of soil and rock material en masse.
Unconsolidated	MARI	Marine Sediments	Deposit composed of suspended material brought by streams flowing into seas.
Unconsolidated	MARL	Marl	Deposits consisting chiefly of an intimate mixture of clay and calcium carbonate.
Unconsolidated	MIXE	Mixed	Deposits of undifferentiated materials.
Unconsolidated	MUCK	Muck	Dark, finely divided, well-decomposed organic material, intermixed with a high percentage of mineral matter, usually silt.
Unconsolidated	ORGA	Organic Deposits	Deposit in which carbon is an essential, substantial component.
Unconsolidated	PEAT	Peat	Deposit of semicarbonized plant remains in a water-saturated environment.
Unconsolidated	RESI	Residium	Deposit of rock debris formed by weathering, remaining essentially in place after all but the least soluble constituents have been removed.
Unconsolidated	TALU	Talus Deposit	Rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope.

Primary Lithology	Secondary Code	Secondary Description	Definition
Unconsolidated	TEPH	Tephra (Undifferentiated)	Deposit of particles ejected during a volcanic eruption.
Unconsolidated	TRAN	Transitional Marine/Continental Deposits	Undifferentiated materials deposited at or near the land/sea interface.
Unconsolidated	VOAS	Volcanic Ash	Pyroclastic material under 2 mm diameter.

Parent/Surficial Materials Modifiers

Modifier	Modifies	Modifier Definition
Creep	Colluvium	Deposit of earthy materials accumulating at or near a slope base through slow gravitational movement.
Scree	Colluvium	Deposit of coarse, rock debris mantling a slope with no rock overhang or cliff.
Dune Sand	Eolian Deposit	Wind-blown deposit composed of material > 0.05 mm in diameter.
Loess	Eolian Deposit	Wind-blown deposit composed of material < 0.05 mm in diameter.
Ablation	Glacial Till Deposit	Till deposited through down-wasting of a glacier (also called supraglacial).
Basal	Glacial Till Deposit	Till deposited at the base of a moving glacier (also called subglacial, lodgement, melt-out, flow).
Block Glide	Landslide Deposit	Deposit of largely intact rock/earth units that slid downslope along a planar surface.
Debris Avalanche	Landslide Deposit	Deposit of mixed rock and earth that moved rapidly-downslope as a dry, incoherent mass.
Debris Flow	Landslide Deposit	Deposit of mixed rock, earth, and mud (> 50% > 2 mm in size) that moved rapidly downslope as a wet to saturated, incoherent mass.
Debris Slide	Landslide Deposit	Hummocky deposit of mixed rock and earth that slid or rolled downslope as a relatively dry mass.
Earth Flow	Landslide Deposit	Deposit of mixed earth, mud, and rock (> 50% < 2 mm in size) that moved rapidly downslope as a wet to saturated, incoherent mass (also called mudflow).
Rockfall	Landslide Deposit	Deposit that accumulates at the base of a cliff from detached bodies of rock free-falling from above.
Rockfall Avalanche	Landslide Deposit	Deposit resulting from a massive rockfall that triggers an avalanche as it continues to the base of a slope and beyond.
Solifluction	Landslide Deposit	Deposit of water-saturated regolith that flowed slowly downslope; commonly occurring in frozen or permafrost terrain.
Topple	Landslide Deposit	Deposit created when a large block of rock falls over, rotating away from a low pivot point, and breaks apart.

Modifier	Modifies	Modifier Definition
Coprogenic	Organic Deposit	Deposit composed primarily of fecal material derived from aquatic animals.
Grassy	Organic Deposit	Deposit composed mostly of grassy materials.
Herbaceous	Organic Deposit	Deposit composed mostly of sedges, reeds, cattails, etc.
Mossy	Organic Deposit	Deposit composed mostly of mossy (e.g., sphagnum) materials.
Woody	Organic Deposit	Deposit composed mostly of woody debris.

Parent/Surficial Material Size Classes

Code	Meaning	Definition
1	Clayey	> 40% of material is clay (< .002 mm in diameter).
2	Coarse-loamy	> 15% of particles are 0.1 to 76 mm and < 18% of material is clay.
3	Coarse-silty	Material is < 18% clay, and < 15% of particles are 0.1 to 76 mm in size.
4	Fine-loamy	Material is 18 to 35% clay and > 15% of particles are 0.1 to 76 mm in diameter.
5	Fine-silty	Material is 18 to 35% clay and < 15% particles are .1 to 76 mm in size.
6	Gravelly	Material contains 15% or more rock fragments (particles between 2 and 76 mm in diameter).
7	Loamy	Material is 7 to 27% clay, 28 to 50% silt, and < 52% sand.
8	Sandy	At least 70% sand (between 0.05 and 2 mm in diameter).
9	Sandy and gravelly	At least 70% sand and 15% gravel.
10	Sandy and silty	At least 15% of grains between .05 and 2 mm in diameter, and 15% of grains between .002 mm and .05 (sand or loamy sand and silt or silt loam).
11	Silty	> 50% of particles between 0.02 and 0.5 mm in diameter.
12	Silty and clayey	> 40% of material is clay and > 40% is silt.
13	Stony	> 50% of particles between 250 and 600 mm in diameter.
14	Bouldery	> 50% of particles larger than 600 mm in diameter.
15	Cobbly	> 50% of particles between 76 and 250 mm in diameter.

Geomorphic Definitions and Codes

Hierarchy Geomorphology

Fluvial

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
Process	Fluvial	Fl	FL
Subpr	Basin Processes-Fluvial	Bapr-Fl	BAPR
LF	Bolson-Basin Processes-Fluvial	Bols-Bapr-Fl	BOLS-BAPR
ElemLF	Playa-Bolson-Basin Processes-Fluvial	Play-Bols-Bapr-Fl	PLAY-BOLS-BAPR
LF	Semi-Bolson-Basin Processes-Fluvial	Sebo-Bapr-Fl	SEBO-BAPR
ElemLF	Basin Floor Remnant-Semi-Bolson-Basin Processes-Fluvial	Bafr-Sebo-Bapr-Fl	BAFR-SEBO-BAPR
ElemLF	Playa-Semi-Bolson-Basin Processes-Fluvial	Play-Sebo-Bapr-Fl	PLAY-SEBO-BAPR
ElemLF	Valley Flat-Semi-Bolson-Basin Processes-Fluvial	Vafl-Sebo-Bapr-Fl	VAFL-SEBO-BAPR
ElemLF	Valley Floor-Semi-Bolson-Basin Processes-Fluvial	Vafo-Sebo-Bapr-Fl	VAFO-SEBO-BAPR
Subpr	Fluvial Slope Processes-Fluvial	Flsp-Fl	FLSP
Modifier	Deposition-Fluvial Slope Processes-Fluvial	Deps-Flsp-Fl	DEPS-FLSP
LF	Alluvial Fan-Deposition-Fluvial Slope Processes-Fluvial	Alfa-Deps-Flsp-Fl	ALFA-DEPS
ElemLF	Fan Apron-Alluvial Fan-Deposition-Fluvial Slope Processes-Fluvial	Faap-Alfa-Deps-Flsp-Fl	FAAP-ALFA-DEPS
ElemLF	Fanhead Collar-Alluvial Fan-Deposition-Fluvial Slope Processes-Fluvial	Fahc-Alfa-Deps-Flsp-Fl	FAHC-ALFA-DEPS
ElemLF	Fanhead Trench-Alluvial Fan-Deposition-Fluvial Slope Processes-Fluvial	Faht-Alfa-Deps-Flsp-Fl	FAHT-ALFA-DEPS
ElemLF	Fan Skirt-Alluvial Fan-Deposition-Fluvial Slope Processes-Fluvial	Fask-Alfa-Deps-	FASK-ALFA-DEPS
ElemLF	Inset Fan-Alluvial Fan-Deposition-Fluvial Slope Processes-Fluvial	Infa-Alfa-Deps-Flsp-Fl	INFA-ALFA-DEPS
LF	Bajada-Deposition-Fluvial Slope Processes-Fluvial	Baja-Deps-Flsp-Fl	BAJA-DEPS

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Fan Apron-Bajada-Deposition-Fluvial Slope Processes-Fluvial	Faap-Baja-Deps-Flsp-Fl	FAAP-BAJA-DEPS
ElemLF	Fanhead Collar-Bajada-Deposition-Fluvial Slope Processes-Fluvial	Fahc-Baja-Deps-Flsp-Fl	FAHC-BAJA-DEPS
ElemLF	Fanhead Trench-Bajada-Deposition-Fluvial Slope Processes-Fluvial	Faht-Baja-Deps-Flsp-Fl	FAHT-BAJA-DEPS
ElemLF	Fan Skirt-Bajada-Deposition-Fluvial Slope Processes-Fluvial	Fask-Baja-Deps-Flsp-Fl	FASK-BAJA-DEPS
ElemLF	Inset Fan-Bajada-Deposition-Fluvial Slope Processes-Fluvial	Infa-Baja-Deps-Flsp-Fl	INFA-BAJA-DEPS
LF	Mountain Valley Fan-Deposition-Fluvial Slope Processes-Fluvial	Movf-Deps-Flsp-Fl	MOVF-DEPS
ElemLF	Fan Apron-Mountain Valley Fan-Deposition-Fluvial Slope Processes-Fluvial	Faap-Movf-Deps-Flsp-Fl	FAAP-MOVF-DEPS
ElemLF	Fanhead Collar-Mountain Valley Fan-Deposition-Fluvial Slope Processes-Fluvial	Fahc-Movf-Deps-Flsp-Fl	FAHC-MOVF-DEPS
ElemLF	Fanhead Trench-Mountain Valley Fan-Deposition-Fluvial Slope Processes-Fluvial	Faht-Movf-Deps-Flsp-Fl	FAHT-MOVF-DEPS
ElemLF	Fan Skirt-Mountain Valley Fan-Deposition-Fluvial Slope Processes-Fluvial	Fask-Movf-Deps-Flsp-Fl	FASK-MOVF-DEPS
ElemLF	Inset Fan-Mountain Valley Fan-Deposition-Fluvial Slope Processes-Fluvial	Infa-Movf-Deps-Flsp-Fl	INFA-MOVF-DEPS
LF	Fan Piedmont-Deposition-Fluvial Slope Processes-Fluvial	Fapi-Deps-Flsp-Fl	FAPI-DEPS
Modifier	Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Dfec-Flsp-Fl	DFEC-FLSP
LF	Butte-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Butt-Dfec-Flsp-Fl	BUTT-DFEC
LF	Cuesta-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Cues-Dfec-Flsp-Fl	CUES-DFEC
ElemLF	Dipslope-Cuesta-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Disl-Cues-Dfec-Flsp-Fl	DISL-CUES-DFEC

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Scarpslope-Cuesta-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Scsl-Cues-Dfec-Flsp-Fl	SCSL-CUES-DFEC
LF	Dike-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Dike-Dfec-Flsp-Fl	DIKE-DFEC
LF	Hogback-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Hogb-Dfec-Flsp-Fl	HOGB-DFEC
ElemLF	Dipslope-Hogback-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Disl-Hogb-Dfec-Flsp-Fl	DISL-HOGB-DFEC
ElemLF	Scarpslope-Hogback-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Scsl-Hogb-Dfec-Flsp-Fl	SCSL-HOGB-DFEC
LF	Hoodoo-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Hood-Dfec-Flsp-Fl	HOOD-DFEC
LF	Mesa-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Mesa-Dfec-Flsp-Fl	MESA-DFEC
LF	Structural Bench-Differential Fluvial Erosion W/ Structural Control-Fluvial Slope Processes-Fluvial	Strb-Dfec-Flsp-Fl	STRB-DFEC
Modifier	Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Unfe-Flsp-Fl	UNFE-FLSP
LF	Badland-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Badl-Unfe-Flsp-Fl	BADL-UNFE
LF	Ballena-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Ball-Unfe-Flsp-Fl	BALL-UNFE
LF	Erosion Fan Remnant-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Erfr-Unfe-Flsp-Fl	ERFR-UNFE
LF	Fan Remnant-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Fare-Unfe-Flsp-Fl	FARE-UNFE

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
LF	Inselberg-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Inse-Unfe-Flsp-FI	INSE-UNFE
LF	Monadnock-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Mona-Unfe-Flsp-FI	MONA-UNFE
LF	Non-Buried Fan Remnant-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Nbfr-Unfe-Flsp-FI	NBFR-UNFE
LF	Partial Ballena-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Paba-Unfe-Flsp-FI	PABA-UNFE
LF	Pediment-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Pedi-Unfe-Flsp-FI	PEDI-UNFE
LF	Surface Eroding Slope-Uniform Fluvial Erosion W/O Structural Control-Fluvial Slope Processes-Fluvial	Sues-Unfe-Flsp-FI	SUES-UNFE
Subpr	Stream Processes-Fluvial	Stpr-FI	STPR
Modifier	Deposition-Stream Processes-Fluvial	Deps-Stpr-FI	DEPS-STPR
LF	Bank-Deposition-Stream Processes-Fluvial	Bank-Deps-Stpr-FI	BANK-DEPS
LF	Bar-Deposition-Stream Processes-Fluvial	Bar-Deps-Stpr-FI	BAR-DEPS
ElemLF	Longitudinal Bar-Bar-Deposition-Stream Processes-Fluvial	Loba-Bar-Deps-Stpr-FI	LOBA-BAR-DEPS
ElemLF	Point Bar-Bar-Deposition-Stream Processes-Fluvial	Poba-Bar-Deps-Stpr-FI	POBA-BAR-DEPS
LF	Channel-Deposition-Stream Processes-Fluvial	Chan-Deps-Stpr-FI	CHAN-DEPS
LF	Cutoff Channel-Deposition-Stream Processes-Fluvial	Cuch-Deps-Stpr-FI	CUCH-DEPS
LF	Depositional Stream Terrace-Deposition-Stream Processes-Fluvial	Dest-Deps-Stpr-FI	DEST-DEPS
LF	Floodplain-Deposition-Stream Processes-Fluvial	Flpl-Deps-Stpr-FI	FLPL-DEPS
ElemLF	Alluvial Flat-Floodplain-Deposition-Stream Processes-Fluvial	Alfl-Flpl-Deps-Stpr-FI	ALFL-FLPL-DEPS

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Levee-Floodplain-Deposition-Stream Processes-Fluvial	Leve-Flpl-Deps-Stpr-Fl	LEVE-FLPL-DEPS
ElemLF	Meander Scar-Floodplain-Deposition-Stream Processes-Fluvial	Mesr-Flpl-Deps-Stpr-Fl	MESR-FLPL-DEPS
ElemLF	Meander Scroll-Floodplain-Deposition-Stream Processes-Fluvial	Mesc-Flpl-Deps-Stpr-Fl	MESC-FLPL-DEPS
ElemLF	Oxbow-Floodplain-Deposition-Stream Processes-Fluvial	Oxbo-Flpl-Deps-Stpr-Fl	OXBO-FLPL-DEPS
LF	Floodplain Playa-Deposition-Stream Processes-Fluvial	Flpp-Deps-Stpr-Fl	FLPP-DEPS
LF	Floodplain Splay-Deposition-Stream Processes-Fluvial	Flps-Deps-Stpr-Fl	FLPS-DEPS
LF	Island-Deposition-Stream Processes-Fluvial	Isla-Deps-Stpr-Fl	ISLA-DEPS
LF	Stream-Deposition-Stream Processes-Fluvial	Stre-Deps-Stpr-Fl	STRE-DEPS
LF	Stream Terrace (Undif)-Deposition-Stream Processes-Fluvial	Stte-Deps-Stpr-Fl	STTE-DEPS
LF	Thalweg-Deposition-Stream Processes-Fluvial	Thal-Deps-Stpr-Fl	THAL-DEPS
Modifier	Erosion-Stream Processes-Fluvial	Eros-Stpr-Fl	EROS-STPR
LF	Channel-Erosion-Stream Processes-Fluvial	Chan-Eros-Stpr-Fl	CHAN-EROS
LF	Cutoff Channel-Erosion-Stream Processes-Fluvial	Cuch-Eros-Stpr-Fl	CUCH-EROS
LF	Erosional Stream Terrace-Erosion-Stream Processes-Fluvial	Erst-Eros-Stpr-Fl	ERST-EROS
LF	Stream-Erosion-Stream Processes-Fluvial	Stre-Eros-Stpr-Fl	STRE-EROS
LF	Thalweg-Erosion-Stream Processes-Fluvial	Thal-Eros-Stpr-Fl	THAL-EROS
Modifier	Terminal Deposition-Stream Processes-Fluvial	Tede-Stpr-Fl	TEDE-STPR
LF	Delta-Terminal Deposition-Stream Processes-Fluvial	Delt-Tede-Stpr-Fl	DELT-TEDE
ElemLF	Delta Plain-Delta-Terminal Deposition-Stream Processes-Fluvial	Depl-Delt-Tede-Stpr-Fl	DEPL-DELT-TEDE
Modifier	Transporting Stream Channel System-Stream Processes-Fluvial	Trsc-Stpr-Fl	TRSC-STPR

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
LF	Channel-Transporting Stream Channel System-Stream Processes-Fluvial	Chan-Trsc-Stpr-FI	CHAN-TRSC
LF	Cutoff Channel-Transporting Stream Channel System-Stream Processes-Fluvial	Cuch-Trsc-Stpr-FI	CUCH-TRSC
LF	Stream-Transporting Stream Channel System-Stream Processes-Fluvial	Stre-Trsc-Stpr-FI	STRE-TRSC
LF	Thalweg-Transporting Stream Channel System-Stream Processes-Fluvial	Thal-Trsc-Stpr-FI	THAL-TRSC
Modifier	Undiff Stream Channel System- Stream Processes-Fluvial	Unsc-Stpr-FI	UNSC-STPR
LF	Bank-Undiff Stream Channel System-Stream Processes-Fluvial	Bank-Unsc-Stpr-FI	BANK-UNSC
LF	Bar-Undiff Stream Channel System-Stream Processes-Fluvial	Bar-Unsc-Stpr-FI	BAR-UNSC
ElemLF	Longitudinal Bar-Bar-Undiff Stream Channel System-Stream Processes-Fluvial	Loba-Bar-Unsc- Stpr-FI	LOBA-BAR-UNSC
ElemLF	Point Bar-Bar-Undiff Stream Channel System-Stream Processes-Fluvial	Poba-Bar-Unsc- Stpr-FI	POBA-BAR-UNSC
LF	Channel-Undiff Stream Channel System-Stream Processes-Fluvial	Chan-Unsc-Stpr-FI	CHAN-UNSC
LF	Cutoff Channel-Undiff Stream Channel System-Stream Processes-Fluvial	Cuch-Unsc-Stpr-FI	CUCH-UNSC
LF	Depositional Stream Terrace-Undiff Stream Channel System-Stream Processes-Fluvial	Dest-Unsc-Stpr-FI	DEST-UNSC
LF	Erosional Stream Terrace-Undiff Stream Channel System-Stream Processes-Fluvial	Erte-Unsc-Stpr-FI	ERTE-UNSC
LF	Flood Plain Playa-Undiff Stream Channel System-Stream Processes- Fluvial	Flpp-Unsc-Stpr-FI	FLPP-UNSC
LF	Flood Plain Splay-Undiff Stream Channel System-Stream Processes- Fluvial	Flps-Unsc-Stpr-FI	FLPS-UNSC
LF	Flood Plain-Undiff Stream Channel System-Stream Processes-Fluvial	Flpl-Unsc-Stpr-FI	FLPL-UNSC
ElemLF	Alluvial Flat-Flood Plain-Undiff Stream Channel System-Stream Processes-Fluvial	Alfl-Flpl-Unsc- Stpr-FI	ALFL-FLPL-UNSC

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Levee-Flood Plain-Undiff Stream Channel System-Stream Processes-Fluvial	Leve-Flpl-Unsc-Stpr-Fl	LEVE-FLPL-UNSC
ElemLF	Meander Scar-Flood Plain-Undiff Stream Channel System-Stream Processes-Fluvial	Mesr-Flpl-Unsc-Stpr-Fl	MESR-FLPL-UNSC
ElemLF	Meander Scroll-Flood Plain-Undiff Stream Channel System-Stream Processes-Fluvial	Mesc-Flpl-Unsc-Stpr-Fl	MESC-FLPL-UNSC
ElemLF	Oxbow-Flood Plain-Undiff Stream Channel System-Stream Processes-Fluvial	Oxbo-Flpl-Unsc-Stpr-Fl	OXBO-FLPL-UNSC
LF	Island-Undiff Stream Channel System-Stream Processes-Fluvial	Isla-Unsc-Stpr-Fl	ISLA-UNSC
LF	Stream Terrace-Undiff Stream Channel System-Stream Processes-Fluvial	Stte-Unsc-Stpr-Fl	STTE-UNSC
LF	Stream-Undiff Stream Channel System-Stream Processes-Fluvial	Stre-Unsc-Stpr-Fl	STRE-UNSC
LF	Thalweg-Undiff Stream Channel System-Stream Processes-Fluvial	Thal-Unsc-Stpr-Fl	THAL-UNSC

Glacial

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
Process	Glacial	Gl	GL
Subpr	Active Ice And Snow Process-Glacial	Aisp-Gl	AISP
Mod	Alpine Glaciation-Active Ice And Snow Process-Glacial	Alpi-Aisp-Gl	ALPI-AISP
LF	Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Glcr-Alpi-Aisp-Gl	GLCR-ALPI
ElemLF	Bergshrund-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Berg-Glcr-Alpi-Aisp-Gl	BERG-GLCR-ALPI
ElemLF	Crevasse-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Crev-Glcr-Alpi-Aisp-Gl	CREV-GLCR-ALPI
ElemLF	Drainage Channel (Undiff)-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Drch-Glcr-Alpi-Aisp-Gl	DRCH-GLCR-ALPI
ElemLF	Fosse-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Foss-Glcr-Alpi-Aisp-Gl	FOSS-GLCR-ALPI
ElemLF	Ice Apron-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Icap-Glcr-Alpi-Aisp-Gl	ICAP-GLCR-ALPI
ElemLF	Moulin-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Moul-Glcr-Alpi-Aisp-Gl	MOUL-GLCR-ALPI

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Pressure Ridge-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Prri-Glcr-Alpi-Aisp-Gl	PRRI-GLCR-ALPI
ElemLF	Serac-Glacier-Alpine Glaciation-Active Ice And Snow Process-Glacial	Sera-Glcr-Alpi-Aisp-Gl	SERA-GLCR-ALPI
LF	Snowfield-Alpine Glaciation-Active Ice And Snow Process-Glacial	Snow-Alpi-Aisp-Gl	SNOW-ALPI
ElemLF	Nivation Hollow-Snowfield-Alpine Glaciation-Active Ice And Snow Process-Glacial	Niho-Snow-Alpi-Aisp-Gl	NIHO-SNOW-ALPI
ElemLF	Nivation Ridge-Snowfield-Alpine Glaciation-Active Ice And Snow Process-Glacial	Niri-Snow-Alpi-Aisp-Gl	NIRI-SNOW-ALPI
Mod	Continental Glaciation-Active Ice And Snow Process-Glacial	Cont-Aisp-Gl	CONT-AISP
LF	Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Glcr-Cont-Aisp-Gl	GLCR-CONT
ElemLF	Bergshrund-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Berg-Glcr-Cont-Aisp-Gl	BERG-GLCR-CONT
ElemLF	Crevasse-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Crev-Glcr-Cont-Aisp-Gl	CREV-GLCR-CONT
ElemLF	Drainage Channel (Undiff)-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Drch-Glcr-Cont-Aisp-Gl	DRCH-GLCR-CONT
ElemLF	Fosse-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Foss-Glcr-Cont-Aisp-Gl	FOSS-GLCR-CONT
ElemLF	Ice Apron-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Icap-Glcr-Cont-Aisp-Gl	ICAP-GLCR-CONT
ElemLF	Moulin-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Moul-Glcr-Cont-Aisp-Gl	MOUL-GLCR-CONT
ElemLF	Pressure Ridge-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Prri-Glcr-Cont-Aisp-Gl	PRRI-GLCR-CONT
ElemLF	Serac-Glacier-Continental Glaciation-Active Ice And Snow Process-Glacial	Sera-Glcr-Cont-Aisp-Gl	SERA-GLCR-CONT
LF	Snowfield-Continental Glaciation-Active Ice And Snow Process-Glacial	Snow-Cont-Aisp-Gl	SNOW-CONT
ElemLF	Nivation Hollow-Snowfield-Continental Glaciation-Active Ice And Snow Process-Glacial	Niho-Snow-Cont-Aisp-Gl	NIHO-SNOW-CONT
ElemLF	Nivation Ridge-Snowfield-Continental Glaciation-Active Ice And Snow Process-Glacial	Niri-Snow-Cont-Aisp-Gl	NIRI-SNOW-CONT
Subpr	Ice Contact Deposition-Glacial	Icde-Gl	ICDE

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
Mod	Alpine Glaciation-Ice Contact Deposition-Glacial	Alpi-Icde-Gl	ALPI-ICDE
LF	Crag And Tail-Alpine Glaciation-Ice Contact Deposition-Glacial	Crta-Alpi-Icde-Gl	CRTA-ALPI
LF	Disintegration Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Dimo-Alpi-Icde-Gl	DIMO-ALPI
ElemLF	Kettle-Disintegration Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Dimo-Alpi-Icde-Gl	KETT-DIMO-ALPI
LF	Drumlin-Alpine Glaciation-Ice Contact Deposition-Glacial	Drum-Alpi-Icde-Gl	DRUM-ALPI
LF	End Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Enmo-Alpi-Icde-Gl	ENMO-ALPI
ElemLF	Kettle-End Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Enmo-Alpi-Icde-Gl	KETT-ENMO-ALPI
LF	Fluted Morain Surface-Alpine Glaciation-Ice Contact Deposition-Glacial	Flms-Alpi-Icde-Gl	FLMS-ALPI
LF	Ground Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Grmo-Alpi-Icde-Gl	GRMO-ALPI
ElemLF	Kettle-Ground Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Grmo-Alpi-Icde-Gl	KETT-GRMO-ALPI
LF	Interlobate Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Inmo-Alpi-Icde-Gl	INMO-ALPI
ElemLF	Kettle-Interlobate Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Inmo-Alpi-Icde-Gl	KETT-INMO-ALPI
LF	Kame Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kamo-Alpi-Icde-Gl	KAMO-ALPI
ElemLF	Kettle-Kame Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Kamo-Alpi-Icde-Gl	KETT-KAMO-ALPI
LF	Lateral Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Lamo-Alpi-Icde-Gl	LAMO-ALPI
ElemLF	Kettle-Lateral Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Lamo-Alpi-Icde-Gl	KETT-LAMO-ALPI
LF	Medial Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Memo-Alpi-Icde-Gl	MEMO-ALPI
ElemLF	Kettle-Medial Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Memo-Alpi-Icde-Gl	KETT-MEMO-ALPI
LF	Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Mora-Alpi-Icde-Gl	MORA-ALPI
ElemLF	Kettle-Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Mora-Alpi-Icde-Gl	KETT-MORA-ALPI
LF	Recessional Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Remo-Alpi-Icde-Gl	REMO-ALPI

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Kettle-Recessional Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Remo-Alpi-Icde-Gl	KETT-REMO-ALPI
LF	Terminal Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Temo-Alpi-Icde-Gl	TEMO-ALPI
ElemLF	Kettle-Terminal Moraine-Alpine Glaciation-Ice Contact Deposition-Glacial	Kett-Temo-Alpi-Icde-Gl	KETT-TEMO-ALPI
Mod	Continental Glaciation-Ice Contact Deposition-Glacial	Cont-Icde-Gl	CONT-ICDE
LF	Crag And Tail-Continental Glaciation-Ice Contact Deposition-Glacial	Crta-Cont-Icde-Gl	CRTA-CONT
LF	Disintegration Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Dimo-Cont-Icde-Gl	DIMO-CONT
ElemLF	Kettle-Disintegration Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Dimo-Cont-Icde-Gl	KETT-DIMO-CONT
LF	Drumlin-Continental Glaciation-Ice Contact Deposition-Glacial	Drum-Cont-Icde-Gl	DRUM-CONT
LF	End Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Enmo-Cont-Icde-Gl	ENMO-CONT
ElemLF	Kettle-End Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Enmo-Cont-Icde-Gl	KETT-ENMO-CONT
LF	Fluted Moraine Surface-Continental Glaciation-Ice Contact Deposition-Glacial	Flms-Cont-Icde-Gl	FLMS-CONT
LF	Ground Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Grmo-Cont-Icde-Gl	GRMO-CONT
ElemLF	Kettle-Ground Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Grmo-Cont-Icde-Gl	KETT-GRMO-CONT
LF	Interlobate Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Inmo-Cont-Icde-Gl	INMO-CONT
ElemLF	Kettle-Interlobate Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Inmo-Cont-Icde-Gl	KETT-INMO-CONT
LF	Kame Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kamo-Cont-Icde-Gl	GI KAMO-CONT
ElemLF	Kettle-Kame Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Kamo-Cont-Icde-Gl	KETT-KAMO-CONT
LF	Lateral Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Lamo-Cont-Icde-Gl	LAMO-CONT
ElemLF	Kettle-Lateral Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Lamo-Cont-Icde-Gl	KETT-LAMO-CONT
LF	Medial Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Memo-Cont-Icde-Gl	MEMO-CONT
ElemLF	Kettle-Medial Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Memo-Cont-Icde-Gl	KETT-MEMO-CONT

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
LF	Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Mora-Cont-Icde-Gl	MORA-CONT
ElemLF	Kettle-Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Mora-Cont-Icde-Gl	KETT-MORA-CONT
LF	Recessional Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Remo-Cont-Icde-Gl	REMO-CONT
ElemLF	Kettle-Recessional Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Remo-Cont-Icde-Gl	KETT-REMO-CONT
LF	Terminal Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Temo-Cont-Icde-Gl	TEMO-CONT
ElemLF	Kettle-Terminal Moraine-Continental Glaciation-Ice Contact Deposition-Glacial	Kett-Temo-Cont-Icde-Gl	KETT-TEMO-CONT
Subpr	Ice Erosion-Glacial	Icer-Gl	ICER
Mod	Alpine Glaciation-Ice Erosion-Glacial	Alpi-Icer-Gl	ALPI-ICER
LF	Arete-Alpine Glaciation-Ice Erosion-Glacial	Aret-Alpi-Icer-Gl	ARET-ALPI
LF	Cirque-Alpine Glaciation-Ice Erosion-Glacial	Cirq-Alpi-Icer-Gl	CIRQ-ALPI
LF	Cirque Floor-Alpine Glaciation-Ice Erosion-Glacial	Cifl-Alpi-Icer-Gl	CIFL-ALPI
LF	Cirque Headwall-Alpine Glaciation-Ice Erosion-Glacial	Cihe-Alpi-Icer-Gl	CIHE-ALPI
LF	Col-Alpine Glaciation-Ice Erosion-Glacial	Col-Alpi-Icer-Gl	COL-ALPI
LF	Flute-Alpine Glaciation-Ice Erosion-Glacial	Flut-Alpi-Icer-Gl	FLUT-ALPI
LF	Glacial Quarry-Alpine Glaciation-Ice Erosion-Glacial	Glqu-Alpi-Icer-Gl	GLQU-ALPI
LF	Hanging Valley-Alpine Glaciation-Ice Erosion-Glacial	Hava-Alpi-Icer-Gl	HAVA-ALPI
LF	Horn-Alpine Glaciation-Ice Erosion-Glacial	Horn-Alpi-Icer-Gl	HORN-ALPI
LF	Nunatek-Alpine Glaciation-Ice Erosion-Glacial	Nuna-Alpi-Icer-Gl	NUNA-ALPI
LF	Riegel-Alpine Glaciation-Ice Erosion-Glacial	Rieg-Alpi-Icer-Gl	RIEG-ALPI
LF	Roche Moutonnee-Alpine Glaciation-Ice Erosion-Glacial	Romo-Alpi-Icer-Gl	ROMO-ALPI
LF	Scoured Basin-Alpine Glaciation-Ice Erosion-Glacial	Scba-Alpi-Icer-Gl	SCBA-ALPI
LF	Sidewall-Alpine Glaciation-Ice Erosion-Glacial	Side-Alpi-Icer-Gl	SIDE-ALPI
LF	Trough (Glacial Valley)-Alpine Glaciation-Ice Erosion-Glacial	Trou-Alpi-Icer-Gl	TROU-ALPI
LF	Trough Floor-Alpine Glaciation-Ice Erosion-Glacial	Trfl-Alpi-Icer-Gl	TRFL-ALPI

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Trough Wall-Alpine Glaciation-Ice Erosion-Glacial	Trwa-Alpi-Icer-Gl	TRWA-ALPI
Mod	Continental Glaciation-Ice Erosion-Glacial	Cont-Icer-Gl	CONT-ICER
LF	Arete-Continental Glaciation-Ice Erosion-Glacial	Aret-Cont-Icer-Gl	ARET-CONT
LF	Cirque-Continental Glaciation-Ice Erosion-Glacial	Cirq-Cont-Icer-Gl	CIRQ-CONT
LF	Cirque Floor-Continental Glaciation-Ice Erosion-Glacial	Cifl-Cont-Icer-Gl	CIFL-CONT
LF	Cirque Headwall-Continental Glaciation-Ice Erosion-Glacial	Cihe-Cont-Icer-Gl	CIHE-CONT
LF	Col-Continental Glaciation-Ice Erosion-Glacial	Col-Cont-Icer-Gl	COL-CONT
LF	Flute-Continental Glaciation-Ice Erosion-Glacial	Flut-Cont-Icer-Gl	FLUT-CONT
LF	Glacial Quarry-Continental Glaciation-Ice Erosion-Glacial	Glqu-Cont-Icer-Gl	GLQU-CONT
LF	Hanging Valley-Continental Glaciation-Ice Erosion-Glacial	Hava-Cont-Icer-Gl	HAVA-CONT
LF	Horn-Continental Glaciation-Ice Erosion-Glacial	Horn-Cont-Icer-Gl	HORN-CONT
LF	Nunatek-Continental Glaciation-Ice Erosion-Glacial	Nuna-Cont-Icer-Gl	NUNA-CONT
LF	Riegel-Continental Glaciation-Ice Erosion-Glacial	Rieg-Cont-Icer-Gl	RIEG-CONT
LF	Roche Moutonnee-Continental Glaciation-Ice Erosion-Glacial	Romo-Cont-Icer-Gl	ROMO-CONT
LF	Scoured Basin-Continental Glaciation-Ice Erosion-Glacial	Scba-Cont-Icer-Gl	SCBA-CONT
LF	Sidewall-Continental Glaciation-Ice Erosion-Glacial	Side-Cont-Icer-Gl	SIDE-CONT
LF	Trough (Glacial Valley)-Continental Glaciation-Ice Erosion-Glacial	Trou-Cont-Icer-Gl	TROU-CONT
LF	Trough Floor-Continental Glaciation-Ice Erosion-Glacial	Trfl-Cont-Icer-Gl	TRFL-CONT
LF	Trough Wall-Continental Glaciation-Ice Erosion-Glacial	Trwa-Cont-Icer-Gl	TRWA-CONT
Subpr	Meltwater Erosion-Glacial	Meer-Gl	MEER
Mod	Alpine Glaciation-Meltwater Erosion-Glacial	Alpi-Meer-Gl	ALPI-MEER
LF	Coulee-Alpine Glaciation-Meltwater Erosion-Glacial	Coul-Alpi-Meer-Gl	COUL-ALPI
LF	Ice Margin Channel-Alpine Glaciation-Meltwater Erosion-Glacial	Icmc-Alpi-Meer-Gl	ICMC-ALPI

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
LF	Spillway-Alpine Glaciation-Meltwater Erosion-Glacial	Spil-Alpi-Meer-Gl	SPIL-ALPI
LF	Tunnel Valley-Alpine Glaciation-Meltwater Erosion-Glacial	Tuva-Alpi-Meer- Gl	TUVA-ALPI
Mod	Continental Glaciation-Meltwater Erosion-Glacial	Cont-Meer-Gl	CONT-MEER
LF	Coulee-Continental Glaciation-Meltwater Erosion-Glacial	Coul-Cont-Meer- Gl	COUL-CONT
LF	Ice Margin Channel-Continental Glaciation- Meltwater Erosion-Glacial	Icmc-Cont-Meer- Gl	ICMC-CONT
LF	Spillway-Continental Glaciation- Meltwater Erosion-Glacial	Spil-Cont-Meer- Gl	SPIL-CONT
LF	Tunnel Valley-Continental Glaciation- Meltwater Erosion-Glacial	Tuva-Cont-Meer- Gl	TUVA-CONT
Subpr	Proglacial Deposition (Distal)-Glacial	Prde-Gl	PRDE
Mod	Alpine Glaciation-Proglacial Deposition (Distal)-Glacial	Alpi-Prde-Gl	ALPI-PRDE
LF	Kettled Outwash Plain (Kettled Sandur)- Alpine Glaciation-Proglacial Deposition (Distal)-Glacial	Keop-Alpi- Prde-Gl	KEOP-ALPI
LF	Outburst Floodplain-Alpine Glaciation- Proglacial Deposition (Distal)-Glacial	Oufl-Alpi-Prde-Gl	OUFL-ALPI
ElemLF	Giant Ripples-Outburst Floodplain-Alpine Glaciation-Proglacial Deposition (Distal)- Glacial	Giri-Oufl-Alpi- Prde-Gl	GIRI-OUFL- ALPI
LF	Outwash Fan-Alpine Glaciation- Proglacial Deposition (Distal)-Glacial	Oufa-Alpi-Prde-Gl	OUFA-ALPI
LF	Outwash Plain (Plain Sandur)-Alpine Glaciation-Proglacial Deposition (Distal)- Glacial	Oupl-Alpi-Prde-Gl	OUPL-ALPI
LF	Outwash Terrace-Alpine Glaciation- Proglacial Deposition (Distal)-Glacial	Oute-Alpi-Prde-Gl	OUTE-ALPI
LF	Valley Train (Valley Sandur)-Alpine Glaciation-Proglacial Deposition (Distal)- Glacial	Vatr-Alpi-Prde-Gl	VATR-ALPI
Mod	Continental Glaciation-Proglacial Deposition (Distal)-Glacial	Cont-Prde-Gl	CONT-PRDE
LF	Kettled Outwash Plain (Kettled Sandur)- Continental Glaciation-Proglacial Deposition Deposition (Distal)-Glacial	Keop-Cont- Prde-Gl	KEOP-CONT
LF	Outburst Floodplain-Continental Glaciation- Proglacial Deposition (Distal)-Glacial	Oufl-Cont-Prde-Gl	OUFL-CONT

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
ElemLF	Giant Ripples-Outburst Floodplain-Continental Glaciation-Proglacial Deposition (Distal)-Glacial	Giri-Oufl-Cont-Prde-Gl	GIRI-OUFL-CONT
LF	Outwash Fan-Continental Glaciation-Proglacial Deposition (Distal)-Glacial	Oufa-Cont-Prde-Gl	OUFA-CONT
LF	Outwash Plain (Plain Sandur)-Continental Glaciation-Proglacial Deposition (Distal)-Glacial	Oupl-Cont-Prde-Gl	OUPL-CONT
LF	Outwash Terrace-Continental Glaciation-Proglacial Deposition (Distal)-Glacial	Oute-Cont-Prde-Gl	OUTE-CONT
LF	Valley Train-Continental Glaciation-Proglacial Deposition (Distal)-Glacial	Vatr-Cont-Prde-Gl	VATR-CONT
Subpr	Water Deposition (Proximal)-Glacial	Wade-Gl	WADE
Mod	Alpine Glaciation-Water Deposition (Proximal)-Glacial	Alpi-Wade-Gl	ALPI-WADE
LF	Collapsed Ice-Floored Lakebed-Alpine Glaciation-Water Deposition (Proximal)-Glacial	Coil-Alpi-Wade-Gl	COIL-ALPI
LF	Collapsed Ice-Walled Lakebed-Alpine Glaciation-Water Deposition (Proximal)-Glacial	Ciwl-Alpi-Wade-Gl	CIWL-ALPI
LF	Crevasse Filling-Alpine Glaciation-Water Deposition (Proximal)-Glacial	Crfi-Alpi-Wade-Gl	CRFI-ALPI
LF	Eske-Alpine Glaciation-Water Deposition (Proximal)-Glacial	Eske-Alpi-Wade-Gl	ESKE-ALPI
LF	Kame-Alpine Glaciation-Water Deposition (Proximal)-Glacial	Kame-Alpi-Wade-Gl	KAME-ALPI
LF	Kame Terrace-Alpine Glaciation-Water Deposition (Proximal)-Glacial	Kate-Alpi-Wade-Gl	KATE-ALPI
Mod	Continental Glaciation-Water Deposition (Proximal)-Glacial	Cont-Wade-Gl	CONT-WADE
LF	Collapsed Ice-Floored Lakebed-Continental Glaciation-Water Deposition (Proximal)-Glacial	Coil-Cont-Wade-Gl	COIL-CONT
LF	Collapsed Ice-Walled Lakebed-Continental Glaciation-Water Deposition (Proximal)-Glacial	Ciwl-Cont-Wade-Gl	CIWL-CONT
LF	Crevasse Filling-Continental Glaciation-Water Deposition (Proximal)-Glacial	Crfi-Cont-Wade-Gl	CRFI-CONT
LF	Eske-Continental Glaciation-Water Deposition (Proximal)-Glacial	Eske-Cont-Wade-Gl	ESKE-CONT
LF	Kame-Continental Glaciation-Water Deposition (Proximal)-Glacial	Kame-Cont-Wade-Gl	KAME-CONT

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
LF	Kame Terrace-Continental Glaciation-Water Deposition (Proximal)-Glacial	Kate-Cont-Wade-Gl	KATE-CONT
Periglacial			
Geomorph Level	Class_Name	Class_Short _Name	Class_Code
Process	Periglacial	Pe	PE
Subpr	Frost Action-Periglacial	Frac-Pe	FRAC
LF	Patterned Ground (Undiff)-Frost Action-Periglacial	Pgun-Frac-Pe	PGUN-FRAC
LF	Patterned Ground-Frost Action-Periglacial	Pagr-Frac-Pe	PAGR-FRAC
ElemLF	Circles-Patterned Ground-Frost Action-Periglacial	Circ-Pagr-Frac-Pe	CIRC-PAGR-Pe FRAC
ElemLF	Nets-Patterned Ground-Frost Action-Periglacial	Nets-Pagr-Frac-Pe	NETS-PAGR-FRAC
ElemLF	Polygons-Patterned Ground-Frost Action-Periglacial	Poly-Pagr-Frac-Pe	POLY-PAGR-FRAC
ElemLF	Steps-Patterned Ground-Frost Action-Periglacial	Step-Pagr-Frac-Pe	STEP-PAGR-FRAC
ElemLF	Stripes-Patterned Ground-Frost Action-Periglacial	Stri-Pagr-Frac-Pe	STRI-PAGR-FRAC
Subpr	Permafrost-Periglacial	Perm-Pe	PERM
LF	Block (Rock) Field-Permafrost-Periglacial	Blfi-Perm-Pe	BLFI-PERM
LF	Palsa-Permafrost-Periglacial	Pals-Perm-Pe	PALS-PERM
LF	Pingo-Permafrost-Periglacial	Ping-Perm-Pe	PING-PERM
LF	Tor-Permafrost-Periglacial	Tor-Perm-Pe	TOR-PERM
LF	Thermokarst-Permafrost-Periglacial	Ther-Perm-Pe	THER-PERM
ElemLF	Alas-Thermokarst-Permafrost-Periglacial	Alas-Ther-Perm-Pe	ALAS-THER-PERM
Lacustrine			
Geomorph Level	Class_Name	Class_Short _Name	Class_Code
Process	Lacustrine	La	LA
Subpr	Anthropogenic-Lacustrine	Anth-La	ANTH
LF	Beach-Anthropogenic-Lacustrine	Beac-Anth-La	BEAC-ANTH
ElemLF	Backshore Terrace-Beach-Anthropogenic-Lacustrine	Bate-Beac-Anth-La	BATE-BEAC-ANTH
ElemLF	Beach Plain-Beach-Anthropogenic-Lacustrine	Bepl-Beac-Anth-La	BEPL-BEAC-ANTH

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
ElemLF	Beach Ridge-Beach-Anthropogenic-Lacustrine	Beri-Beac-Anth-La	BERI-BEAC-ANTH
LF	Island-Anthropogenic-Lacustrine	Isla-Anth-La	ISLA-ANTH
LF	Lake-Anthropogenic-Lacustrine	Lake-Anth-La	LAKE-ANTH
LF	Lake Bed-Anthropogenic-Lacustrine	Labe-Anth-La	LABE-ANTH
LF	Lake Plain-Anthropogenic-Lacustrine	Lapl-Anth-La	LAPL-ANTH
LF	Lake Terrace-Anthropogenic-Lacustrine	Late-Anth-La	LATE-ANTH
LF	Shoreline-Anthropogenic-Lacustrine	Shor-Anth-La	SHOR-ANTH
Subpr	Beaver-Lacustrine	Beav-La	BEAV
LF	Beach-Beaver-Lacustrine	Beac-Beav-La	BEAC-BEAV
ElemLF	Backshore Terrace-Beach-Beaver-Lacustrine	Bate-Beac-Beav-La	BATE-BEAC-BEAV
ElemLF	Beach Plain-Beach-Beaver-Lacustrine	BepI-Beac-Beav-La	BEPL-BEAC-BEAV
ElemLF	Beach Ridge-Beach-Beaver-Lacustrine	Beri-Beac-Beav-La	BERI-BEAC-BEAV
LF	Island-Beaver-Lacustrine	Isla-Beav-La	ISLA-BEAV
LF	Lake-Beaver-Lacustrine	Lake-Beav-La	LAKE-BEAV
LF	Lake Bed-Beaver-Lacustrine	Labe-Beav-La	LABE-BEAV
LF	Lake Plain-Beaver-Lacustrine	Lapl-Beav-La	LAPL-BEAV
LF	Lake Terrace-Beaver-Lacustrine	Late-Beav-La	LATE-BEAV
LF	Shoreline-Beaver-Lacustrine	Shor-Beav-La	SHOR-BEAV
Subpr	Eolian-Lacustrine	Eoli-La	EOLI
LF	Beach-Eolian-Lacustrine	Beac-Eoli-La	BEAC-EOLI
ElemLF	Backshore Terrace-Beach-Eolian-Lacustrine	Bate-Beac-Eoli-La	BATE-BEAC-EOLI
ElemLF	Beach Plain-Beach-Eolian-Lacustrine	BepI-Beac-Eoli-La	BEPL-BEAC-EOLI
ElemLF	Beach Ridge-Beach-Eolian-Lacustrine	Beri-Beac-Eoli-La	BERI-BEAC-EOLI
LF	Island-Eolian-Lacustrine	Isla-Eoli-La	ISLA-EOLI
LF	Lake-Eolian-Lacustrine	Lake-Eoli-La	LAKE-EOLI
LF	Lake Bed-Eolian-Lacustrine	Labe-Eoli-La	LABE-EOLI
LF	Lake Plain-Eolian-Lacustrine	Lapl-Eoli-La	LAPL-EOLI
LF	Lake Terrace-Eolian-Lacustrine	Late-Eoli-La	LATE-EOLI
LF	Shoreline-Eolian-Lacustrine	Shor-Eoli-La	SHOR-EOLI
Subpr	Fluvatile-Lacustrine	Flut-La	FLUT
LF	Beach-Fluvatile-Lacustrine	Beac-Flut-La	BEAC-FLUT

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Backshore Terrace-Beach-Fluvatile-Lacustrine	Bate-Beac-Flut-La	BATE-BEAC-FLUT
ElemLF	Beach Plain-Beach-Fluvatile-Lacustrine	Bepl-Beac-Flut-La	BEPL-BEAC-FLUT
ElemLF	Beach Ridge-Beach-Fluvatile-Lacustrine	Beri-Beac-Flut-La	BERI-BEAC-FLUT
LF	Island-Fluvatile-Lacustrine	Isla-Flut-La	ISLA-FLUT
LF	Lake-Fluvatile-Lacustrine	Lake-Flut-La	LAKE-FLUT
LF	Lake Bed-Fluvatile-Lacustrine	Labe-Flut-La	LABE-FLUT
LF	Lake Plain-Fluvatile-Lacustrine	Lapl-Flut-La	LAPL-FLUT
LF	Lake Terrace-Fluvatile-Lacustrine	Late-Flut-La	LATE-FLUT
LF	Oxbow Lake-Fluvatile-Lacustrine	Oxla-Flut-La	OXLA-FLUT
LF	Shoreline-Fluvatile-Lacustrine	Shor-Flut-La	SHOR-FLUT
Subpr	Glacial-Lacustrine	Glac-La	GLAC
LF	Beach-Glacial-Lacustrine	Beac-Glac-La	BEAC-GLAC
ElemLF	Backshore Terrace-Beach-Glacial-Lacustrine	Bate-Beac-Glac-La	BATE-BEAC-GLAC
ElemLF	Beach Plain-Beach-Glacial-Lacustrine	Bepl-Beac-Glac-La	BEPL-BEAC-GLAC
ElemLF	Beach Ridge-Beach-Glacial-Lacustrine	Beri-Beac-Glac-La	BERI-BEAC-GLAC
LF	Island-Glacial-Lacustrine	Isla-Glac-La	ISLA-GLAC
LF	Lake-Glacial-Lacustrine	Lake-Glac-La	LAKE-GLAC
LF	Lake Bed-Glacial-Lacustrine	Labe-Glac-La	LABE-GLAC
LF	Lake Plain-Glacial-Lacustrine	Lapl-Glac-La	LAPL-GLAC
LF	Lake Terrace-Glacial-Lacustrine	Late-Glac-La	LATE-GLAC
LF	Paternoster Lakes-Glacial-Lacustrine	Pala-Glac-La	PALA-GLAC
LF	Shoreline-Glacial-Lacustrine	Shor-Glac-La	SHOR-GLAC
LF	Tarn-Glacial-Lacustrine	Tarn-Glac-La	TARN-GLAC
Subpr	Lacustrine (Undiff)-Lacustrine	Lacu-La	LACU
LF	Beach-Lacustrine (Undiff)-Lacustrine	Beac-Lacu-La	BEAC-LACU
ElemLF	Backshore Terrace-Beach-Lacustrine (Undiff)-Lacustrine	Bate-Beac-Lacu-La	BATE-BEAC-LACU
ElemLF	Beach Plain-Beach-Lacustrine (Undiff)-Lacustrine	Bepl-Beac-Lacu-La	BEPL-BEAC-LACU
ElemLF	Beach Ridge-Beach-Lacustrine (Undiff)-Lacustrine	Beri-Beac-Lacu-La	BERI-BEAC-LACU
LF	Island-Lacustrine (Undiff)-Lacustrine	Isla-Lacu-La	ISLA-LACU
LF	Lake-Lacustrine (Undiff)-Lacustrine	Lake-Lacu-La	LAKE-LACU

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Lake Bed-Lacustrine (Undiff)-Lacustrine	Labe-Lacu-La	LABE-LACU
LF	Lake Plain-Lacustrine (Undiff)-Lacustrine	Lapl-Lacu-La	LAPL-LACU
LF	Lake Terrace-Lacustrine (Undiff)-Lacustrine	Late-Lacu-La	LATE-LACU
LF	Shoreline-Lacustrine (Undiff)-Lacustrine	Shor-Lacu-La	SHOR-LACU
Subpr	Landslide-Lacustrine	Land-La	LAND
LF	Beach-Landslide-Lacustrine	Beac-Land-La	BEAC-LAND
ElemLF	Backshore Terrace-Beach-Landslide-Lacustrine	Bate-Beac-Land-La	BATE-BEAC-LAND
ElemLF	Beach Plain-Beach-Landslide-Lacustrine	Bepl-Beac-Land-La	BEPL-BEAC-LAND
ElemLF	Beach Ridge-Beach-Landslide-Lacustrine	Beri-Beac-Land-La	BERI-BEAC-LAND
LF	Island-Landslide-Lacustrine	Isla-Land-La	ISLA-LAND
LF	Lake-Landslide-Lacustrine	Lake-Land-La	LAKE-LAND
LF	Lake Bed-Landslide-Lacustrine	Labe-Land-La	LABE-LAND
LF	Lake Plain-Landslide-Lacustrine	Lapl-Land-La	LAPL-LAND
LF	Lake Terrace-Landslide-Lacustrine	Late-Land-La	LATE-LAND
LF	Shoreline-Landslide-Lacustrine	Shor-Land-La	SHOR-LAND
LF	Slump Pond-Landslide-Lacustrine	Slpo-Land-La	SLPO-LAND
Subpr	Meteoric-Lacustrine	Mete-La	METE
LF	Beach-Meteoric-Lacustrine	Beac-Mete-La	BEAC-METE
ElemLF	Backshore Terrace-Beach-Meteoric-Lacustrine	Bate-Beac-Mete-La	BATE-BEAC-METE
ElemLF	Beach Plain-Beach-Meteoric-Lacustrine	Bepl-Beac-Mete-La	BEPL-BEAC-METE
ElemLF	Beach Ridge-Beach-Meteoric-Lacustrine	Beri-Beac-Mete-La	BERI-BEAC-METE
LF	Island-Meteoric-Lacustrine	Isla-Mete-La	ISLA-METE
LF	Lake-Meteoric-Lacustrine	Lake-Mete-La	LAKE-METE
LF	Lake Bed-Meteoric-Lacustrine	Labe-Mete-La	LABE-METE
LF	Lake Plain-Meteoric-Lacustrine	Lapl-Mete-La	LAPL-METE
LF	Lake Terrace-Meteoric-Lacustrine	Late-Mete-La	LATE-METE
LF	Shoreline-Meteoric-Lacustrine	Shor-Mete-La	SHOR-METE
Subpr	Organic-Lacustrine	Orga-La	ORGA
LF	Beach-Organic-Lacustrine	Beac-Orga-La	BEAC-ORGA
ElemLF	Backshore Terrace-Beach-Organic-Lacustrine	Bate-Beac-Orga-La	BATE-BEAC-ORGA

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Beach Plain-Beach-Organic-Lacustrine	Bepl-Beac- Orga-La	BEPL-BEAC- ORGA
ElemLF	Beach Ridge-Beach-Organic-Lacustrine	Beri-Beac- Orga-La	BERI-BEAC- ORGA
LF	Island-Organic-Lacustrine	Isla-Orga-La	ISLA-ORGA
LF	Lake-Organic-Lacustrine	Lake-Orga-La	LAKE-ORGA
LF	Lake Bed-Organic-Lacustrine	Labe-Orga-La	LABE-ORGA
LF	Lake Plain-Organic-Lacustrine	Lapl-Orga-La	LAPL-ORGA
LF	Lake Terrace-Organic-Lacustrine	Late-Orga-La	LATE-ORGA
LF	Shoreline-Organic-Lacustrine	Shor-Orga-La	SHOR-ORGA
Subpr	Shoreline-Lacustrine	Shor-La	SHOR
LF	Beach-Shoreline-Lacustrine	Beac-Shor-La	BEAC-SHOR
ElemLF	Backshore Terrace-Beach-Shoreline- Lacustrine	Bate-Beac- Shor-La	BATE-BEAC- SHOR
ElemLF	Beach Plain-Beach-Shoreline-Lacustrine	Bepl-Beac- Shor-La	BEPL-BEAC- SHOR
ElemLF	Beach Ridge-Beach-Solution-Lacustrine	Beri-Beac- Solu-La	BERI-BEAC- SOLU
LF	Island-Shoreline-Lacustrine	Isla-Shor-La	ISLA-SHOR
LF	Lake-Shoreline-Lacustrine	Lake-Shor-La	LAKE-SHOR
LF	Lake Bed-Shoreline-Lacustrine	Labe-Shor-La	LABE-SHOR
LF	Lake Plain-Shoreline-Lacustrine	Lapl-Shor-La	LAPL-SHOR
LF	Lake Terrace-Shoreline-Lacustrine	Late-Shor-La	LATE-SHOR
LF	Shoreline-Shoreline-Lacustrine	Shor-Shor-La	SHOR-SHOR
Subpr	Solution-Lacustrine	Solu-La	SOLU
LF	Beach-Solution-Lacustrine	Beac-Solu-La	BEAC-SOLU
ElemLF	Backshore Terrace-Beach-Solution- Lacustrine	Bate-Beac- Solu-La	BATE-BEAC- SOLU
ElemLF	Beach Plain-Beach-Solution-Lacustrine	Bepl-Beac- Solu-La	BEPL-BEAC- SOLU
ElemLF	Beach Ridge-Beach-Shoreline-Lacustrine	Beri-Beac- Shor-La	BERI-BEAC- SHOR
LF	Island-Solution-Lacustrine	Isla-Solu-La	ISLA-SOLU
LF	Lake-Solution-Lacustrine	Lake-Solu-La	LAKE-SOLU
LF	Lake Bed-Solution-Lacustrine	Labe-Solu-La	LABE-SOLU
LF	Lake Plain-Solution-Lacustrine	Lapl-Solu-La	LAPL-SOLU
LF	Lake Terrace-Solution-Lacustrine	Late-Solu-La	LATE-SOLU
LF	Shoreline-Solution-Lacustrine	Shor-Solu-La	SHOR-SOLU

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
Subpr	Tectonic-Lacustrine	Tect-La	TECT
LF	Beach-Tectonic-Lacustrine	Beac-Tect-La	BEAC-TECT
ElemLF	Backshore Terrace-Beach-Tectonic-Lacustrine	Bate-Beac-Tect-La	BATE-BEAC-TECT
ElemLF	Beach Plain-Beach-Tectonic-Lacustrine	Bepl-Beac-Tect-La	BEPL-BEAC-TECT
ElemLF	Beach Ridge-Beach-Tectonic-Lacustrine	Beri-Beac-Tect-La	BERI-BEAC-TECT
LF	Island-Tectonic-Lacustrine	Isla-Tect-La	ISLA-TECT
LF	Lake-Tectonic-Lacustrine	Lake-Tect-La	LAKE-TECT
LF	Lake Bed-Tectonic-Lacustrine	Labe-Tect-La	LABE-TECT
LF	Lake Plain-Tectonic-Lacustrine	Lapl-Tect-La	LAPL-TECT
LF	Lake Terrace-Tectonic-Lacustrine	Lapl-Tect-La	LATE-TECT
LF	Sag Pond-Tectonic-Lacustrine	Sapo-Tect-La	SAPO-TECT
LF	Shoreline-Tectonic-Lacustrine	Shor-Tect-La	SHOR-TECT
Subpr	Volcanic-Lacustrine	Volc-La	VOLC
LF	Beach-Volcanic-Lacustrine	Beac-Volc-La	BEAC-VOLC
ElemLF	Backshore Terrace-Beach-Volcanic-Lacustrine	Bate-Beac-Volc-La	BATE-BEAC-VOLC
ElemLF	Beach Plain-Beach-Volcanic-Lacustrine	Bepl-Beac-Volc-La	BEPL-BEAC-VOLC
ElemLF	Beach Ridge-Beach-Volcanic-Lacustrine	Beri-Beac-Volc-La	BERI-BEAC-VOLC
LF	Island-Volcanic-Lacustrine	Isla-Volc-La	ISLA-VOLC
LF	Lake-Volcanic-Lacustrine	Lake-Volc-La	LAKE-VOLC
LF	Lake Bed-Volcanic-Lacustrine	Labe-Volc-La	LABE-VOLC
LF	Lake Plain-Volcanic-Lacustrine	Lapl-Volc-La	LAPL-VOLC
LF	Lake Terrace-Volcanic-Lacustrine	Late-Volc-La	LATE-VOLC
LF	Shoreline-Volcanic-Lacustrine	Shor-Volc-La	SHOR-VOLC

Tectonic

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
Process	Tectonic	Te	TE
Subpr	Faulting-Tectonic	Faul-Te	FAUL
LF	Compound Fault Scarps-Faulting-Tectonic	Cofs-Faul-Te	COFS-FAUL
LF	Fault Scarp-Faulting-Tectonic	Fasc-Faul-Te	FASC-FAUL
LF	Fault Terrace-Faulting-Tectonic	Fate-Faul-Te	FATE-FAUL

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Fault Trace-Faulting-Tectonic	Fatr-Faul-Te	FATR-FAUL
LF	Fissure-Faulting-Tectonic	Fiss-Faul-Te	FISS-FAUL
LF	Graben-Faulting-Tectonic	Grab-Faul-Te	GRAB-FAUL
LF	Horst-Faulting-Tectonic	Hors-Faul-Te	HORS-FAUL
LF	Scarp Slope-Faulting-Tectonic	Scsl-Faul-Te	SCSL-FAUL
LF	Shutter Ridge-Faulting-Tectonic	Shri-Faul-Te	SHRI-FAUL
LF	Tilt Block-Faulting-Tectonic	Tibl-Faul-Te	TIBL-FAUL
Subpr	Folding-Tectonic	Fold-Te	FOLD
LF	Anticline-Folding-Tectonic	Anti-Fold-Te	ANTI-FOLD
LF	Dome-Folding-Tectonic	Dome-Fold-Te	DOME-FOLD
LF	Folds-Folding-Tectonic	Flds-Fold-Te	FLDS-FOLD
LF	Homocline-Folding-Tectonic	Homo-Fold-Te	HOMO-FOLD
LF	Laccolith-Structural-Tectonic	Lacc-Stru-Te	LACC-STRU
LF	Monocline-Folding-Tectonic	Mono-Fold-Te	MONO-FOLD
LF	Syncline-Folding-Tectonic	Sync-Fold-Te	SYNC-FOLD
LF	Synform-Folding-Tectonic	Synf-Fold-Te	SYNF-FOLD
Subpr	Structural-Tectonic	Stru-Te	STRU
LF	Batholith-Structural-Tectonic	Bath-Stru-Te	BATH-STRU
LF	Diapirs-Structural-Tectonic	Diap-Stru-Te	DIAP-STRU
LF	Stock-Structural-Tectonic	Stoc-Stru-Te	STOC-STRU
LF	Structural Basin-Structural-Tectonic	Stba-Stru-Te	STBA-STRU
LF	Structural Domes (Undiff)- Structural-Tectonic	Stdo-Stru-Te	STDO-STRU

Volcanic

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
Process	Volcanic	Vo	VO
Subpr	Constructional-Volcanic	Cons-Vo	CONS
LF	Aa Flow-Constructional-Volcanic	Aafl-Cons-Vo	AAFL-CONS
ElemLF	Pressure Ridge-Aa Flow-Constructional-Volcanic	Ppri-Aafl-Cons-Vo	PRRI-AAFL-CONS
ElemLF	Spatter Cone-Aa Flow-Constructional-Volcanic	Spco-Aafl-Cons-Vo	SPCO-AAFL-CONS
ElemLF	Trench-Aa Flow-Constructional-Volcanic	Tren-Aafl-Cons-Vo	TREN-AAFL-CONS
LF	Ash-Fall Tephra Field-Constructional-Volcanic	Aftf-Cons-Vo	AFTF-CONS
LF	Block Flow-Constructional-Volcanic	Blfl-Cons-Vo	BLFL-CONS

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Pressure Ridge-Block Flow-Constructional-Volcanic	Prri-Blfl-Cons-Vo	PRRI-BLFL-CONS
ElemLF	Spatter Cone-Block Flow-Constructional-Volcanic	Spco-Blfl-Cons-Vo	SPCO-BLFL-CONS
ElemLF	Trench-Block Flow-Constructional-Volcanic	Tren-Blfl-Cons-Vo	TREN-BLFL-CONS
LF	Cinder Cone-Constructional-Volcanic	Cico-Cons-Vo	CICO-CONS
LF	Composite Cone (Stratovolcano)-Constructional-Volcanic	Stra-Cons-Vo	STRA-CONS
LF	Exogenous Dome-Constructional-Volcanic	Exdo-Cons-Vo	EXDO-CONS
LF	Fissure Vent-Constructional-Volcanic	Five-Cons-Vo	FIVE-CONS
LF	Fumarole Field-Constructional-Volcanic	Fufi-Cons-Vo	FUFI-CONS
LF	Intrusive Dome-Constructional-Volcanic	Indo-Cons-Vo	INDO-CONS
LF	Lahar-Constructional-Volcanic	Laha-Cons-Vo	LAHA-CONS
LF	Lava Flow (Undiff)-Constructional-Volcanic	Lafl-Cons-Vo	LAFL-CONS
ElemLF	Pressure Ridge-Lava Flow (Undiff)-Constructional-Volcanic	Prri-Lafl- Cons-Vo	PRRI-LAFL-CONS
ElemLF	Spatter Cone-Lava Flow (Undiff)-Constructional-Volcanic	Spco-Lafl-Cons-Vo	SPCO-LAFL-CONS
ElemLF	Trench-Lava Flow (Undiff)-Constructional-Volcanic	Tren-Lafl-Cons-Vo	TREN-LAFL-CONS
LF	Mud Pot Field-Constructional-Volcanic	Mupf-Cons-Vo	MUPF-CONS
LF	Mud Volcano-Constructional-Volcanic	Muvo-Cons-Vo	MUVO-CONS
LF	Pahoehoe Flow-Constructional-Volcanic	Pafl-Cons-Vo	PAFL-CONS
ElemLF	Pressure Ridge-Pahoehoe Flow-Constructional-Volcanic	Prri-Pafl- Cons-Vo	PRRI-PAFL-CONS
ElemLF	Splatter Cone-Pahoehoe Flow-Constructional-Volcanic	Spco-Pafl-Cons-Vo	SPCO-PAFL-CONS
ElemLF	Trench-Pahoehoe Flow-Constructional-Volcanic	Tren-Pafl-Cons-Vo	TREN-PAFL-CONS
LF	Parasitic Cone-Constructional-Volcanic	Paco-Cons-Vo	PACO-CONS
LF	Pelean Dome-Constructional-Volcanic	Pado-Cons-Vo	PADO-CONS
LF	Plug Dome-Constructional-Volcanic	Pldo-Cons-Vo	PLDO-CONS
LF	Pumice Cone-Constructional-Volcanic	Puco-Cons-Vo	PUCO-CONS
LF	Pyroclastic Cone (Undiff)-Constructional-Volcanic	Pyco-Cons-Vo	PYCO-CONS
LF	Pyroclastic Flow (Ash Flow)-Constructional-Volcanic	Pyfl-Cons-Vo	PYFL-CONS
LF	Shield Volcano-Constructional-Volcanic	Shvo-Cons-Vo	SHVO-CONS
LF	Steptoe-Constructional-Volcanic	Step-Cons-Vo	STEP-CONS

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Upheaved Dome-Constructional-Volcanic	Updo-Cons-Vo	UPDO-CONS
LF	Volcanic Cone (Undiff)-Constructional-Volcanic	Voco-Cons-Vo	VOCO-CONS
LF	Volcanic Dome (Undiff)-Constructional-Volcanic	Vodo-Cons-Vo	VODO-CONS
Subpr	Destructional-Volcanic	Dest-Vo	DEST
LF	Caldera-Destructional-Volcanic	Cald-Dest-Vo	CALD-DEST
LF	Collapse Caldera-Destructional-Volcanic	Coca-Dest-Vo	COCA-DEST
LF	Crater-Destructional-Volcanic	Crat-Dest-Vo	CRAT-DEST
LF	Explosion Caldera-Destructional-Volcanic	Exca-Dest-Vo	EXCA-DEST
LF	Maar-Destructional-Volcanic	Maar-Dest-Vo	MAAR-DEST

Mass Wasting

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
Process	Mass Wasting	Mw	MW
Subpr	Complex-Mass Wasting	Comp-Mw	COMP
LF	Valley Inner Gorge-Complex-Mass Wasting	Vaig-Comp-Mw	VAIG-COMP
LF	Debris Slide Basin-Complex-Mass Wasting	Desb-Comp-Mw	DESB-COMP
LF	Intersted/Multiple Rotation-Translation Slides-Complex-Mass	Wasting Irts-Comp-Mw	IRTS-COMP
LF	Rock Fall Avalanche-Complex-Mass Wasting	Rofa-Comp-Mw	ROFA-COMP
ElemLF	Source Area-Rock Fall Avalanche-Complex-Mass Wasting	Soar-Rofa-Comp-Mw	SOAR-ROFA-COMP
ElemLF	Transport Zone-Rock Fall Avalanche-Complex-Mass Wasting	Trzo-Rofa-Comp-Mw	TRZO-ROFA-COMP
ElemLF	Deposit-Rock Fall Avalanche-Complex-Mass Wasting	Depo-Rofa-Comp-Mw	DEPO-ROFA-COMP
LF	Rock Slide-Rock Fall-Complex-Mass Wasting	Rsrfr-Comp-Mw	RSRF-COMP
ElemLF	Source Area-Rock Slide-Rock Fall-Complex-Mass Wasting	Soar-Rsrfr-Comp-Mw	SOAR-RSRF-COMP
ElemLF	Transport Zone-Rock Slide-Rock Fall-Complex-Mass Wasting	Trzo-Rsrfr-Comp-Mw	TRZO-RSRF-COMP
ElemLF	Deposit-Rock Slide-Rock Fall-Complex-Mass Wasting	Depo-Rsrfr-Comp-Mw	DEPO-RSRF-COMP
LF	Slump And Topple-Prone Slope-Complex-Mass Wasting	Stps-Comp-Mw	STPS-COMP
ElemLF	Source Area-Slump And Topple-Prone Slope-Complex-Mass Wasting	Soar-Stps-Comp-Mw	SOAR-STPS-COMP
ElemLF	Transport Zone-Slump And Topple-Prone Slope-Complex-Mass Wasting	Trzo-Stps-Comp-Mw	TRZO-STPS-COMP

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Deposit-Slump And Topple-Prone Slope-Complex-Mass Wasting	Depo-Stps-Comp-Mw	DEPO-STPS-COMP
LF	Slump-Earth Flow-Complex-Mass Wasting	Slef-Comp-Mw	SLEF-COMP
ElemLF	Main Scarp (Undiff)-Slump-Earth Flow-Complex-Mass Wasting	Masc-Slef-Comp-Mw	MASC-SLEF-COMP
ElemLF	DS-Prone Main Scarp-Slump-Earth Flow-Complex-Mass Wasting	Dspm-Slef-Comp-Mw	DSPM-SLEF-COMP
ElemLF	Nested Main Scarp-Slump-Earth Flow-Complex-Mass Wasting	Nems-Slef-Comp-Mw	NEMS-SLEF-COMP
ElemLF	Secondary Scarp (Undiff)-Slump-Earth Flow-Complex-Mass Wasting	Sesc-Slef-Comp-Mw	SESC-SLEF-COMP
ElemLF	DS-Prone Secondary Scarp-Slump-Earth Flow-Complex-Mass Wasting	Dsps-Slef-Comp-Mw	DSPS-SLEF-COMP
ElemLF	Nested Secondary Scarp-Slump-Earth Flow-Complex-Mass Wasting	Ness-Slef-Comp-Mw	NESS-SLEF-COMP
ElemLF	Lateral Scarp (Undiff)-Slump-Earth Flow-Complex-Mass Wasting	Lasc-Slef-Comp-Mw	LASC-SLEF-COMP
ElemLF	Nested Lateral Scarp-Slump-Earth Flow-Complex-Mass Wasting	Nels-Slef-Comp-Mw	NELS-SLEF-COMP
ElemLF	DS-Prone Lateral Scarp-Slump-Earth Flow-Complex-Mass Wasting	Dspl-Slef-Comp-Mw	DSPL-SLEF-COMP
ElemLF	Bench (Undiff)-Slump-Earth Flow-Complex-Mass Wasting	Benc-Slef-Comp-Mw	BENC-SLEF-COMP
ElemLF	Eroded Bench-Slump-Earth Flow-Complex-Mass Wasting	Erbe-Slef-Comp-Mw	ERBE-SLEF-COMP
ElemLF	Nested Bench-Slump-Earth Flow-Complex-Mass Wasting	Nebe-Slef-Comp-Mw	NEBE-SLEF-COMP
ElemLF	Toe Zone (Undiff)-Slump-Earth Flow-Complex-Mass Wasting	Tozo-Slef-Comp-Mw	TOZO-SLEF-COMP
ElemLF	Nested Toe Zone-Slump-Earth Flow-Complex-Mass Wasting	Netz-Slef-Comp-Mw	NETZ-SLEF-COMP
ElemLF	Debris Slide Prone Toe Zone-Slump-Earth Flow-Complex-Mass Wasting	Dspt-Slef-Comp-Mw	DSPT-SLEF-COMP
Subpr	Fall-Mass Wasting	Fall-Mw	FALL
LF	Fall-Prone Slope-Fall-Mass Wasting	Faps-Fall-Mw	FAPS-FALL
ElemLF	Source Area-Fall-Prone Slope-Fall-Mass Wasting	Soar-Faps-Fall-Mw	SOAR-FAPS-FALL
ElemLF	Deposit (Talus)-Fall-Prone Slope-Fall-Mass Wasting	Depo-Faps-Fall-Mw	DEPO-FAPS-FALL
Subpr	Flow-Mass Wasting	Flow-Mw	FLOW
LF	Debris Avalanche-Flow-Mass Wasting	Deav-Flow-Mw	DEAV-FLOW

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Source Area-Debris Avalanche-Flow-Mass Wasting	Soar-Deav-Flow-Mw	SOAR-DEAV-FLOW
ElemLF	Transport Zone-Debris Avalanche-Flow-MassWasting	Trzo-Deav-Flow-Mw	TRZO-DEAV-FLOW
ElemLF	Deposit-Debris Avalanche-Flow-Mass Wasting	Depo-Deav-Flow-Mw	DEPO-DEAV-FLOW
LF	Debris Flow-Flow-Mass Wasting	Defl-Flow-Mw	DEFL-FLOW
ElemLF	Source Area-Debris Flow-Flow-Mass Wasting	Soar-Defl-Flow-Mw	SOAR-DEFL-FLOW
ElemLF	Transport Zone-Debris Flow-Flow-Mass Wasting	Trzo-Defl-Flow-Mw	TRZO-DEFL-FLOW
ElemLF	Deposit-Debris Flow-Flow-Mass Wasting	Depo-Defl-Flow-Mw	DEPO-DEFL-FLOW
LF	Earth Flow-Flow-Mass Wasting	Eafl-Flow-Mw	EAFL-FLOW
ElemLF	Main Scarp-Earth Flow-Flow-Mass Wasting	Masc-Eafl-Flow-Mw	MASC-EAFL-FLOW
ElemLF	Secondary Scarp-Earth Flow-Flow-Mass Wasting	Sesc-Eafl-Flow-Mw	SESC-EAFL-FLOW
ElemLF	Bench-Earth Flow-Flow-Mass Wasting	Benc-Eafl-Flow-Mw	BENC-EAFL-FLOW
ElemLF	Eroded Bench-Earth Flow-Flow-Mass Wasting	Erbe-Eafl-Flow-Mw	ERBE-EAFL-FLOW
ElemLF	Toe Zone-Earth Flow-Flow-Mass Wasting	Tozo-Eafl-Flow-Mw	TOZO-EAFL-FLOW
LF	Dry Sand Flow-Flow-Mass Wasting	Drsf-Flow-Mw	DRSF-FLOW
ElemLF	Ravel Cone-Dry Sand Flow-Flow-Mass Wasting	Raco-Drsf-Flow-Mw	RACO-DRSF-FLOW
LF	Loess Flow-Flow-Mass Wasting	Lofl-Flow-Mw	LOFL-FLOW
LF	Frost Creep Slope-Flow-Mass Wasting	Frcs-Flow-Mw	FRCS-FLOW
LF	Soil Creep Slope-Flow-Mass Wasting	Socs-Flow-Mw	SOCS-FLOW
ElemLF	Ridgetop Bedrock Outcrop (Source)-Soil Creep Slope-Flow-Mass Wasting	Ribo-Socs-Flow-Mw	RIBO-SOCS-FLOW
ElemLF	Hillslope Bedrock Outcrop (Source)-Soil Creep Slope-Flow-Mass Wasting	Hibo-Socs-Flow-Mw	HIBO-SOCS-FLOW
ElemLF	Colluvial Shoulder-Soil Creep Slope-Flow-Mass Wasting	Cosh-Socs-Flow-Mw	COSH-SOCS-FLOW
ElemLF	Colluvial Slopes-Soil Creep Slope-Flow-Mass Wasting	Cosl-Socs-Flow-Mw	COSL-SOCS-FLOW
LF	Periglacial Flows (Undiff)-Flow-Mass Wasting	Pefl-Flow-Mw	PEFL-FLOW
LF	Rock Glaciers-Flow-Mass Wasting	Rogl-Flow-Mw	ROGL-FLOW

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Rock Stream-Flow-Mass Wasting	Rost-Flow-Mw	ROST-FLOW
LF	Solifluction Lobe-Flow-Mass Wasting	Solo-Flow-Mw	SOLO-FLOW
LF	Solifluction Sheet-Flow-Mass Wasting	Sosh-Flow-Mw	SOSH-FLOW
LF	Solifluction Terrace-Flow-Mass Wasting	Sote-Flow-Mw	SOTE-FLOW
LF	Snow Avalanche Slope-Flow-Mass Wasting	Snas-Flow-Mw	SNAS-FLOW
ElemLF	Source Area-Snow Avalanche Slope-Flow-Mass Wasting	Soar-Snas-Flow-Mw	SOAR-SNAS-FLOW
ElemLF	Transport Zone (Chute)-Snow Avalanche Slope-Flow-Mass Wasting	Trzo-Snas-Flow-Mw	TRZO-SNAS-FLOW
ElemLF	Runout Zone-Snow Avalanche Slope-Flow-Mass Wasting	Ruzo-Snas-Flow-Mw	RUZO-SNAS-FLOW
ElemLF	Avalanche Talus-Snow Avalanche Slope-Flow-Mass Wasting	Avta-Snas-Flow-Mw	AVTA-SNAS-FLOW
Subpr	Lateral Spread-Mass Wasting	Lasp-Mw	LASP
LF	Earth Lateral Spread-Lateral Spread-Mass Wasting	Eals-Lasp-Mw	EALS-LASP
LF	Rock Spread-Lateral Spread-Mass Wasting	Rosp-Lasp-Mw	ROSP-LASP
Subpr	Slide-Mass Wasting	Slid-Mw	SLID
LF	Rotational Slide-Slide-Mass Wasting	Rosl-Slid-Mw	ROSL-SLID
ElemLF	Main Scarp (Undiff)-Rotational Slide-Slide-Mass Wasting	Masc-Rosl-Slid-Mw	MASC-ROSL-SLID
ElemLF	DS-Prone Main Scarp-Rotational Slide-Slide-Mass Wasting	Dspm-Rosl-Slid-Mw	DSPM-ROSL-SLID
ElemLF	Nested Main Scarp-Rotational Slide-Slide-Mass Wasting	Nems-Rosl-Slid-Mw	NEMS-ROSL-SLID
ElemLF	Secondary Scarp (Undiff)-Rotational Slide-Slide-Mass Wasting	Sesc-Rosl-Slid-Mw	SESC-ROSL-SLID
ElemLF	DS-Prone Secondary Scarp-Rotational Slide-Slide-Mass Wasting	Dsps-Rosl-Slid-Mw	DSPS-ROSL-SLID
ElemLF	Nested Secondary Scarp-Rotational Slide-Slide-Mass Wasting	Ness-Rosl-Slid-Mw	NESS-ROSL-SLID
ElemLF	Bench (Undiff)-Rotational Slide-Slide-Mass Wasting	Benc-Rosl-Slid-Mw	BENC-ROSL-SLID
ElemLF	Eroded Bench-Rotational Slide-Slide-Mass Wasting	Erbe-Rosl-Slid-Mw	ERBE-ROSL-SLID
ElemLF	Nested Bench-Rotational Slide-Slide-Mass Wasting	Nebe-Rosl-Slid-Mw	NEBE-ROSL-SLID
ElemLF	Debris Slide Prone Toe Zone-Rotational Slide-Slide-Mass Wasting	Dspt-Rosl-Slid-Mw	DSPT-ROSL-SLID
ElemLF	Toe Zone (Undiff)-Rotational Slide-Slide-Mass Wasting	Tozo-Rosl-Slid-Mw	TOZO-ROSL-SLID

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Nested Toe Zone-Rotational Slide-Slide-Mass Wasting	Netz-Rosl-Slid-Mw	NETZ-ROSL-SLID
LF	Rotational-Translational Slide-Slide-Mass Wasting	Rots-Slid-Mw	ROTS-SLID
ElemLF	Main Scarp (Undiff)-Rotational-Translational Slide-Slide-Mass Wasting	Masc-Rots-Slid-Mw	MASC-ROTS-SLID
ElemLF	DS-Prone Main Scarp-Rotational-Translational Slide-Slide-Mass Wasting	Dspm-Rots-Slid-Mw	DSPM-ROTS-SLID
ElemLF	Nested Main Scarp-Rotational-Translational Slide-Slide-Mass Wasting	Nems-Rots-Slid-Mw	NEMS-ROTS-SLID
ElemLF	Secondary Scarp (Undiff)-Rotational-Translational Slide-Slide-Mass Wasting	Sesc-Rots-Slid-Mw	SESC-ROTS-SLID
ElemLF	DS-Prone Secondary Scarp-Rotational-Translational Slide-Slide-Mass Wasting	Dsps-Rots-Slid-Mw	DSPS-ROTS-SLID
ElemLF	Nested Secondary Scarp-Rotational-Translational Slide-Slide-Mass Wasting	Ness-Rots-Slid-Mw	NESS-ROTS-SLID
ElemLF	Bench (Undiff)-Rotational-Translational Slide-Slide-Mass Wasting	Benc-Rots-Slid-Mw	BENC-ROTS-SLID
ElemLF	Eroded Bench-Rotational-Translational Slide-Slide-Mass Wasting	Erbe-Rots-Slid-Mw	ERBE-ROTS-SLID
ElemLF	Nested Bench-Rotational-Translational Slide-Slide-Mass Wasting	Nebe-Rots-Slid-Mw	NEBE-ROTS-SLID
ElemLF	Toe Zone (Undiff)-Rotational-Translational Slide-Slide-Mass Wasting	Tozo-Rots-Slid-Mw	TOZO-ROTS-SLID
ElemLF	Nested Toe Zone-Rotational-Translational Slide-Slide-Mass Wasting	Netz-Rots-Slid-Mw	NETZ-ROTS-SLID
ElemLF	Debris Slide Prone Toe Zone-Rotational-Translational Slide-Slide-Mass Wasting	Dspt-Rots-Slid-Mw	DSPT-ROTS-SLID
LF	Translational - Block Slide-Slide-Mass Wasting	Trbs-Slid-Mw	TRBS-SLID
ElemLF	Main Scarp (Undiff)-Translational-Masc-Block Slide-Slide-Mass Wasting	Trbs-Slid-Mw	MASC-TRBS-SLID
ElemLF	DS-Prone Main Scarp-Translational - Block Slide-Slide-Mass Wasting	Dspm-Trbs-Slid-Mw	DSPM-TRBS-SLID
ElemLF	Nested Main Scarp-Translational - Block Slide-Slide-Mass Wasting	Nems-Trbs-Slid-Mw	NEMS-TRBS-SLID
ElemLF	Secondary Scarp (Undiff)-Translational - Block Slide-Slide-Mass Wasting	Sesc-Trbs-Slid-Mw	SESC-TRBS-SLID
ElemLF	DS-Prone Secondary Scarp-Translational - Block Slide-Slide-Mass Wasting	Dsps-Trbs-Slid-Mw	DSPS-TRBS-SLID
ElemLF	Nested Secondary Scarp-Translational- Block Slide-Slide-Mass Wasting	Ness-Trbs-Slid-Mw	NESS-TRBS-SLID

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
ElemLF	Bench (Undiff)-Translational - Block Slide-Slide-Mass Wasting	Benc-Trbs-Slid-Mw	BENC-TRBS-SLID
ElemLF	Eroded Bench-Translational - Block Slide-Slide-Mass Wasting	Erbe-Trbs-Slid-Mw	ERBE-TRBS-SLID
ElemLF	Nested Bench-Translational - Block Slide-Slide-Mass Wasting	Nebe-Trbs-Slid-Mw	NEBE-TRBS-SLID
ElemLF	Toe Zone (Undiff)-Translational - Block Slide-Slide-Mass Wasting	Tozo-Trbs-Slid-Mw	TOZO-TRBS-SLID
ElemLF	Nested Toe Zone-Translational - Block Slide-Slide-Mass Wasting	Netz-Trbs-Slid-Mw	NETZ-TRBS-SLID
ElemLF	Debris Slide Prone Toe Zone-Translational - Block Slide-Slide- Mass Wasting	Dspt-Trbs-Slid-Mw	DSPT-TRBS-SLID
LF	Translational - Debris Slide-Slide-Mass Wasting	Trds-Slid-Mw	TRDS-SLID
ElemLF	Main Scarp-Translational - Debris Slide-Slide-Mass Wasting	Masc-Trds-Slid-Mw	MASC-TRDS-SLID
ElemLF	Secondary Scarp-Translational - Debris Slide-Slide-Mass Wasting	Sesc-Trds-Slid-Mw	SESC-TRDS-SLID
ElemLF	Bench-Translational - Debris Slide-Slide-Mass Wasting	Benc-Trds-Slid-Mw	BENC-TRDS-SLID
ElemLF	Eroded Bench-Translational - Debris Slide-Slide-Mass Wasting	Erbe-Trds-Slid-Mw	ERBE-TRDS-SLID
ElemLF	Toe Zone-Translational - Debris Slide-Slide-Mass Wasting	Tozo-Trds-Slid-Mw	TOZO-TRDS-SLID
LF	Undifferentiated Slide-Slide-Mass Wasting	Undi-Slid-Mw	UNDI-SLID
ElemLF	Main Scarp-Undifferentiated Slide-Slide-Mass Wasting	Masc-Undi-Slid-Mw	MASC-UNDI-SLID
ElemLF	Secondary Scarp-Undifferentiated Slide-Slide-Mass Wasting	Sesc-Undi-Slid-Mw	SESC-UNDI-SLID
ElemLF	Bench-Undifferentiated Slide-Slide-Mass Wasting	Benc-Undi-Slid-Mw	BENC-UNDI-SLID
ElemLF	Eroded Bench-Undifferentiated Slide-Slide-Mass Wasting	Erbe-Undi-Slid-Mw	ERBE-UNDI-SLID
ElemLF	Toe Zone-Undifferentiated Slide-Slide-Mass Wasting	Tozo-Undi-Slid-Mw	TOZO-UNDI-SLID
Subpr	Topples-Mass Wasting Topp-Mw TOPP		
LF	Topples-Prone Slope-Topples-Mass Wasting	Tops-Topp-Mw	TOPS-TOPP
ElemLF	Source Area-Topples-Prone Slope-Topples-Mass Wasting	Soar-Tops-Topp-Mw	SOAR-TOPS-TOPP
ElemLF	Deposit (Talus)-Topples-Prone Slope-Topples-Mass Wasting	Depo-Tops-Topp-Mw	DEPO-TOPS-TOPP

Coastal Marine

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
Process	Coastal Marine	Cm	CM
Subpr	Backshore/Backbeach-Coastal Marine	Babp-Cm	BABP
LF	Backwater-Backshore/Backbeach-Coastal Marine	Back-Babp-Cm	BACK-BABP
LF	Estuary-Backshore/Backbeach-Coastal Marine	Estu-Babp-Cm	ESTU-BABP
LF	Lagoon-Backshore/Backbeach-Coastal Marine	Lago-Babp-Cm	LAGO-BABP
LF	Mud Flat-Backshore/Backbeach-Coastal Marine	Mufl-Babp-Cm	MUFL-BABP
Subpr	Emergence-Coastal Marine	Emer-Cm	EMER
LF	Carolina Bay-Emergence-Coastal Marine	Caba-Emer-Cm	CABA-EMER
LF	Chenier Plain-Emergence-Coastal Marine	Chpl-Emer-Cm	CHPL-EMER
LF	Chenier-Emergence-Coastal Marine	Chen-Emer-Cm	CHEN-EMER
LF	Coastal Plain-Emergence-Coastal Marine	Copl-Emer-Cm	COPL-EMER
LF	Marine Terrace (Undiff)-Emergence-Coastal Marine	Mate-Emer-Cm	MATE-EMER
LF	Raised Beach-Emergence-Coastal Marine	Rabe-Emer-Cm	RABE-EMER
ElemLF	Raised Beach Ridge-Raised Beach-Emergence-Coastal Marine	Rabr-Rabe-Emer-Cm	RABR-RABE-EMER
ElemLF	Raised Inner Beach-Raised Beach-Emergence-Coastal Marine	Raib-Rabe-Emer-Cm	RAIB-RABE-EMER
LF	Raised Estuary-Emergence-Coastal Marine	Raes-Emer-Cm	RAES-EMER
LF	Raised Tidal Flat-Emergence-Coastal Marine	Ratf-Emer-Cm	RATF-EMER
LF	Relict Coastline-Emergence-Coastal Marine	Reco-Emer-Cm	RECO-EMER
LF	Strand Plain-Emergence-Coastal Marine	Stpl-Emer-Cm	STPL-EMER
LF	Wave Built Terrace-Emergence-Coastal Marine	Wabt-Emer-Cm	WABT-EMER
LF	Wave Cut Platform-Emergence-Coastal Marine	Wacp-Emer-Cm	WACP-EMER
Subpr	Shoreline Process-Coastal Marine	Shpr-Cm	SHPR
LF	Barrier Island-Shoreline Process-Coastal Marine	Bais-Shpr-Cm	BAIS-SHPR
ElemLF	Barrier Beach-Barrier Island-Shoreline Process-Coastal Marine	Babe-Bais-Shpr-Cm	BABE-BAIS-SHPR
ElemLF	Barrier Flat-Barrier Island-Shoreline Process-Coastal Marine	Bafl-Bais-Shpr-Cm	BAFL-BAIS-SHPR
LF	Barrier Reef-Shoreline Process-Coastal	Marine Bare-Shpr-Cm	BARE-SHPR

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
LF	Beach-Shoreline Process-Coastal Marine	Beac-Shpr-Cm	BEAC-SHPR
ElemLF	Backshore Terrace (Berm)-Beach-Shoreline Process-Coastal Marine	Bate-Beac-Shpr-Cm	BATE-BEAC-SHPR
ElemLF	Beach Plain-Beach-Shoreline Process-Coastal Marine	Bepl-Beac-Shpr-Cm	BEPL-BEAC-SHPR
ElemLF	Beach Ridge-Beach-Shoreline Process-Coastal Marine	Beri-Beac-Shpr-Cm	BERI-BEAC-SHPR
LF	Corral Pinnacle-Shoreline Process-Coastal Marine	Copi-Shpr-Cm	COPI-SHPR
LF	Dunes-Shoreline Process-Coastal Marine	Dune-Shpr-Cm	DUNE-SHPR
LF	Faros-Shoreline Process-Coastal Marine	Faro-Shpr-Cm	FARO-SHPR
LF	Fringing Reef-Shoreline Process-Coastal Marine	Frre-Shpr-Cm	FRRE-SHPR
LF	Headland-Shoreline Process-Coastal Marine	Hedl-Shpr-Cm	HEDL-SHPR
LF	Island-Shoreline Process-Coastal Marine	Isla-Shpr-Cm	ISLA-SHPR
LF	Longshore Bar-Shoreline Process-Coastal Marine	Loba-Shpr-Cm	LOBA-SHPR
LF	Oceanic Atoll-Shoreline Process-Coastal Marine	Ocat-Shpr-Cm	OCAT-SHPR
LF	Organic Reef (Undiff)-Shoreline Process-Coastal Marine	Orre-Shpr-Cm	ORRE-SHPR
LF	Patch Reef-Shoreline Process-Coastal Marine	Pare-Shpr-Cm	PARE-SHPR
LF	Platform Reef-Shoreline Process-Coastal Marine	Plre-Shpr-Cm	PLRE-SHPR
LF	Sea Cliff-Shoreline Process-Coastal Marine	Secl-Shpr-Cm	SECL-SHPR
LF	Shelf Atoll-Shoreline Process-Coastal Marine	Shat-Shpr-Cm	SHAT-SHPR
LF	Spit-Shoreline Process-Coastal Marine	Spit-Shpr-Cm	SPIT-SHPR
LF	Stack-Shoreline Process-Coastal Marine	Stac-Shpr-Cm	STAC-SHPR
LF	Storm Berm-Shoreline Process-Coastal Marine	Stbe-Shpr-Cm	STBE-SHPR
LF	Tidal Flat-Shoreline Process-Coastal Marine	Tifl-Shpr-Cm	TIFL-SHPR
LF	Tombolo-Shoreline Process-Coastal Marine	Tomb-Shpr-Cm	TOMB-SHPR
LF	Washover Fan-Shoreline Process-Coastal Marine	Wafn-Shpr-Cm	WAFN-SHPR

Solution

Geomorph Level	Class_Name	Class_Short _Name	Class_Code
Process	Solution	So	SO
Subpr	General Chemical Weathering-Solution	Gecw-So	GECW

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Chemically Denuding Surface-General Chemical Weathering-Solution	Chds-Gecw-So	CHDS-GECW
Subpr	Karstification-Solution	Kars-So	KARS
LF	Blind Valley-Karstification-Solution	Blva-Kars-So	BLVA-KARS
LF	Cockpits-Karstification-Solution	Cock-Kars-So	COCK-KARS
LF	Collapse Sinkhole-Karstification-Solution	Cosi-Kars-So	COSI-KARS
LF	Karst Tower-Karstification-Solution	Kato-Kars-So	KATO-KARS
LF	Karst Window-Karstification-Solution	Kawi-Kars-So	KAWI-KARS
LF	Kegel Karst-Karstification-Solution	Kege-Kars-So	KEGE-KARS
LF	Poljes-Karstification-Solution	Polj-Kars-So	POLJ-KARS
LF	Sinkhole (Undiff)-Karstification-Solution	Sink-Kars-So	SINK-KARS
LF	Solution Sinkhole-Karstification-Solution	Sosi-Kars-So	SOSI-KARS
LF	Subjacent Karst Collapse Sinkhole-Karstification-Solution	Skcs-Kars-So	SKCS-KARS
LF	Subsidence Sinkhole-Karstification-Solution	Susi-Kars-So	SUSI-KARS
LF	Tower Karst-Karstification-Solution	Toka-Kars-So	TOKA-KARS
LF	Uvalas (Karst Valley)-Karstification-Solution	Uval-Kars-So	UVAL-KARS

Eolian

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
Process	Eolian	Eo	EO
Subpr	Deposition-Eolian	Deps-Eo	DEPS
LF	Barchan Dune-Deposition-Eolian	Badu-Deps-Eo	BADU-DEPS
LF	Barchanoid Ridge-Deposition-Eolian	Bari-Deps-Eo	BARI-DEPS
LF	Blowout Dune-Deposition-Eolian	Bldu-Deps-Eo	BLDU-DEPS
LF	Dune (Undiff)-Deposition-Eolian	Duun-Deps-Eo	DUUN-DEPS
LF	Dune Field-Deposition-Eolian	Dufi-Deps-Eo	DUFI-DEPS
LF	Foredune-Deposition-Eolian	Fodu-Deps-Eo	FODU-DEPS
LF	Interdune Flat-Deposition-Eolian	Infl-Deps-Eo	INFL-DEPS
LF	Loess Deposit (Undiff)-Deposition-Eolian	Lode-Deps-Eo	LODE-DEPS
LF	Paha-Deposition-Eolian	Paha-Deps-Eo	PAHA-DEPS
LF	Parabolic Dune-Deposition-Eolian	Padu-Deps-Eo	PADU-DEPS
LF	Parna Dune-Deposition-Eolian	Prdu-Deps-Eo	PRDU-DEPS
LF	Reversing Dune-Deposition-Eolian	Redu-Deps-Eo	REDU-DEPS
LF	Sand Ramp-Deposition-Eolian	Sara-Deps-Eo	SARA-DEPS

Geomorph Level	Class_Name	Class_Short_Name	Class_Code
LF	Sand Seas-Deposition-Eolian	Sase-Deps-Eo	SASE-DEPS
LF	Sand Sheet-Deposition-Eolian	Sash-Deps-Eo	SASH-DEPS
LF	Seif Dune-Deposition-Eolian	Sedu-Deps-Eo	SEDU-DEPS
LF	Star Dune-Deposition-Eolian	Stdu-Deps-Eo	STDU-DEPS
LF	Transverse Dune-Deposition-Eolian	Trdu-Deps-Eo	TRDU-DEPS
Subpr	Erosion-Eolian	Eros-Eo	EROS
LF	Yardang Trough-Erosion-Eolian	Yatr-Eros-Eo	YATR-EROS
LF	Yardang-Erosion-Eolian	Yard-Eros-Eo	YARD-EROS
LF	Deflation Basin-Erosion-Eolian	Deba-Eros-Eo	DEBA-EROS
ElemLF	Desert Pavement-Deflation Basin-Erosion-Eolian	Depa-Deba-Eros-Eo	DEPA-DEBA-EROS

Landscape Terms

Class_Name	Class_Short_Name	Class_Code
Badlands (Lf)	Badlands	BADL
Bajada (Lf)	Bajada	BAJA
Barrier Islands (Singular Lf)	Barrier Islands	BAIS
Basin (Lf)	Basin	BASI
Basin And Range	Basin And Range	BAAR
Basin Floor	Basin Floor	BAFL
Bolson (Lf)	Bolson	BOLS
Bottomland	Bottomland	BOTT
Breaks	Breaks	BREA
Canyon	Canyon	CANY
Canyonland	Canyonland	CALA
Coast	Coast	COAS
Coastal Plain (Lf)	Coastal Plain	COPL
Delta	Delta	DELT
Drumlin Field	Drumlin Field	DRFI
Dune Field	Dune Field	DUFI
Fan Piedmont (Lf)	Fan Piedmont	FAPI
Flatlands	Flatlands	FLLA
Foothills	Foothills	FOOT
Front	Front	FRON
Glaciated Uplands	Glaciated Uplands	GLUP
Highland	High	HIGH
Hills	Hills	HILL
Intermontane Basin	Intermontane Basin	INBA
Island	Island	ISLA

Class_Name	Class_Short_Name	Class_Code
Karst	Karst	KRST
Lava Plain	Lava Plain	LAPA
Lava Plateau	Lava Plateau	LAPL
Lowlands	Lowlands	LOWL
Meander Belt	Meander Belt	MEBE
Mountains	Mountains	MTNS
Outwash Plain (LF)	Outwash Plain	OUPL
Peninsula	Peninsula	PENI
Piedmont	Piedmont	PIED
Plains	Plains	PLAI
Plateau	Plateau	PLAT
Range	Range	RANG
Ridge And Valley	Ridge And Valley	RIAV
Rift Valley	Rift Valley	RIVA
Sandhills	Sandhills	SAND
Scabland	Scabland	SCAB
Semi-Bolson (Lf)	Semi-Bolson	SEBO
Tableland	Tableland	TABL
Thermokarst	Thermokarst	THER
Till Plain	Till Plain	TIPL
Upland	Upland	UPLA
Valleys	Valleys	VALL
Volcanic Mountains	Volcanic Mountains	VOMO

Common Landforms

Class_Name	Class_Short_Name	Class_Code
Arch	Arch	ARCH
Arroyo	Arroyo	ARRO
Bald	Bald	BALD
Ballon	Ballon	BALO
Bay	Bay	BAY
Bench	Bench	BNCH
Blowout	Blow	BLOW
Bluff	Bluff	BLUF
Breaks	Breaks	BREA
Channel	Channel	CHAN
Cliff	Cliff	CLIF
Depression	Depression	DEPR
Divide	Divide	DIVI
Drainage	Drainage	DRAI
Draw	Draw	DRAW

Class_Name	Class_Short_Name	Class_Code
Escarpment	Escarpment	ESCA
Faceted Spur	Faceted Spur	FASP
Flat	Flat	FLAT
Floor	Floor	FLOO
Fluve	Fluve	FLUV
Free Face	Free Face	FRFA
Gap	Gap	GAP
Gorge	Gorge	GORG
Gulch	Gulch	GULC
Gully	Gull	GULL
Headwall	Headwall	HEWA
Hill	Hill	HILL
Hillslope	Hillslope	HISL
Hummock	Hummock	HUMM
Interfluve	Interfluve	INTE
Knob	Knob	KNOB
Ledge	Ledge	LEDG
Mound	Mound	MOUN
Mountain	Mountain	MTNS
Mountain Slope	Mountain slope	MOSL
Mountain Valley	Mountain Valley	MOVA
Noseslope	Nose	NOSE
Notch	Notch	NOTC
Outwash Plain (LF)	Outwash Plain (LF)	OUPL
Peak	Peak	PEAK
Pinnacle	Pinnacle	PINN
Pothole	Pothole	POTH
Ravine	Ravine	RAVI
Ridge	Ridge	RIDG
Rim	Rim	RIM
Rise	Rise	RISE
Riser	Riser	RISR
Saddle	Saddle	SADD
Scarp	Scar	SCAR
Scour	Scour	SCOU
Seep	Seep	SEEP
Shoal	Shoal	SHOA
Slough	Slough	SLOU
Splay	Splay	SPLA
Spur	Spur	SPUR
Step	Step	STP

Class_Name	Class_Short_Name	Class_Code
Swale	Swale	SWAL
Talus Slope	Talus Slope	TASL
Terracettes	Terracettes	TERR
Tread	Tread	TRED
Trench	Trench	TRNC
V-Notch	V-Notch	VNOT
Wash	Wash	WASH

Microfeatures

Class_Name	Class_Short_Name	Class_Code
Bar	Bar	BAR
Bar and Channel	Bar and Channel	BACH
Channel	Channel	CHAN
Circle	Circle	CIRC
Earth Pillar	Earth Pillar	EAPI
Earth Hummock	Earth Hummock	EAHU
Frost Boil	Frost Boil	FRBO
Frost Mound	Frost Mound	FRMO
Gilgai	Gilgai	GILG
Ice Wedge	Ice Wedge	ICWE
Lava Blister	Lava Blister	LABL
Mima Mound	Mima Mound	MIMO
Net	Net	NET
Nonsorted Circle	Nonsorted Circle	NOSC
Patterned Ground	Patterned Ground	PAGR
Pedestal	Pedestal	PEDE
Polygon	Polygon	POLY
Rill	Rill	RILL
Ripple Mark	Ripple Mark	RIMA
Sand Boil	Sand Boil	SABO
Shrub-coppice Dune	Shrub-coppice Dune	SHCD
Sorted Circle	Sorted Circle	SOCI
Step	Step	STEP
Stone Stripe	Stone Stripe	STST
Stripe	Stripe	STRI
Terracette	Terracette	TERR
Tree-tip Mound	Tree-tip Mound	TRTM
Tree-tip Pit	Tree-tip Pit	TRTP
Turf Hummock	Turf Hummock	TUHU

Slope Terms

Slope Position

Code	Meaning
SU	Summit
SH	Shoulder
BS	Backslope
FS	Footslope
TS	Toeslope

Slope Shape

Code	Meaning
BR	Broken
CC	Concave
CV	Convex
FL	Flat
LI	Linear or planar
PA	Patterned
UN	Undulating
XX	Unable to assess

Slope Complexity

Code	Meaning
C	Complex
CB	Complex, broken
CP	Complex, patterned
CU	Complex, undulating
S	Simple
SCV	Simple concave
SCX	Simple convex
SL	Simple linear/planar

Dissection

Dissection Frequency Class

Code	Meaning
U	Undissected (0 channels/mile)
S	Slightly dissected (1–3 channels/mile)
M	Moderately dissected (3–10 channels/mile)
H	Highly dissected (> 10 channels/mile)

Dissection Depth Class

Code	Meaning
S	Shallowly incised (0–50 ft)
M	Moderately incised (50–100 ft)
D	Deeply incised (100–500 ft)
VD	Very deeply incised (500–1,000 ft)
ED	Extremely incised (> 1,000 ft)

Appendix E. Soil Pedon Description

Soil Pedon Description Form

Site ID #		Map Unit SYMBOL		Date (mm-dd-yyyy)		Examiner:	
Soil Classification:		Family or Series		Modal			
Erosion A. Kind B. Class		Water Table A. Kind B. Depth		Depth to Lithic Contact Depth to Paralithic Contact Root Restrict Layer Type Depth		Surface Runoff Class	
Box Sampled		Lab Sampled		Particle Size Control Section: Depth Avg. Clay Avg. RF		Drainage Class	
Soil Temp		Soil Temp		Diagnostic Horizons: Surface: Subsurface 1: Subsurface 2:			

Hor. Seq.	Horizon	Depth Low High	Boundary	Color	Moisture State	Color Cond.	Texture class %s - %c	Structure	Consistence Dry Moist Wet D M W	Clay Films	% Rock Fragments				Roots	Eff. Class	Field pH	Special Features and Notes
											GR	ST	CB	BY				
1																		
2																		
3																		
4																		

Hor. Seq.	Horizon.	Depth Low High	Boun- dary	Color	Mois- ture State	Color Cond	Texture			Struc- ture	Consist- ence Dry Moist Wet D M W			clay Films	% Rock Fragments			Roots	Effer. Class	Field pH	Special Features and Notes	
							class	%S -	%C		GR	ST	CB		BY	Pores						
5																						
6																						
7																						
8																						
9																						
10																						

Soil Pedon Description Form Instructions

Soil Pedon Description Form

Field Name	Description and Action To Be Taken
Site ID	Record the identifier that is unique within a specific project or inventory area.
Map Unit Symbol	Enter the map unit symbol (if known), typically a two- or three-digit number, in which the site occurs.
Date	Enter the date the profile was described in MMDDYYYY. Example: 07081997.
Examiner	Enter the name of the person(s) describing the site.
Soil Classification	Use the most recent edition of <i>Keys to Soil Taxonomy</i> (USDA NRCS 2003a) and enter the soil classification. Example: loamy-skeletal, mixed Typic Cryalfs.
Family or Series	Enter the family name or series name. Indicate the latter by drawing a circle around the word(s) "Family" or "Series," respectively.
Taxonomic Modal	Enter Yes or No if this is the modal pedon description for the taxonomic unit (ecological type).
Erosion	A. Kind: Wind – Deflation by wind. Water: S – sheet. Even soil loss, no channels. R – rill. Small channels. G – gully. Big channels. T – tunnel. Subsurface voids within soil that enlarge by running water (i.e., piping). B. Degree class. Estimated % loss of the original A & E horizons or the estimated loss of the upper 20 cm (if original, combined A & E horizons were < 20 cm thick). Class 0: 0% Class 1: > 0 up to 25% Class 2: 25 up to 75% Class 3: 75 up to 100% Class 4: > 75% and total removal of A (Schoeneberger et al. 2002, 1–23)
Water Table	Measure or estimate the depth from the ground surface to the stabilized contact with free-standing water in an open bore hole or well. a. Kind: AP – apparent. Level of stabilized water in a fresh, unlined borehole. PE – perched. A water table that lies above an unsaturated zone. The water table will fall if the borehole is extended.

Field Name	Description and Action To Be Taken																																	
Depth to Lithic or Paralithic Contact	b. Depth: Measurement in cm of the depth to water table. (Schoeneberger et al. 2002, 1-14)																																	
	Lithic Contact. The boundary between soil and a coherent underlying material. Except in Ruptic-Lithic subgroups, the underlying material must be virtually continuous within the limits of the pedon. Cracks that can be penetrated by roots are few, and their horizontal spacing is 10 cm or more. The underlying material must be sufficiently coherent when moist to make hand digging with a spade impractical, although the material may be chipped or scraped with a spade (USDA NRCS 2003a).																																	
	Paralithic Contact. A paralithic contact is a contact between soil and paralithic materials in which the paralithic materials have no cracks or the spacing of the cracks that roots can enter is 10 cm or more. Paralithic materials are relatively unaltered materials that have an extremely weakly cemented to moderately cemented rupture-resistance (USDA NRCS 2003a). Root Restricting Depth. The root restricting depth is where root penetration would be strongly inhibited because of physical and/or chemical characteristics. (Soil Survey Division Staff 1993). Restriction kinds include: <table> <tr><td>ABR</td><td>Abrupt textural change</td></tr> <tr><td>CALC</td><td>Petrocalcic</td></tr> <tr><td>CTEX</td><td>Strongly contrasting textural stratification</td></tr> <tr><td>DENS</td><td>Dense material</td></tr> <tr><td>DUR</td><td>Duripan</td></tr> <tr><td>FE</td><td>Petroferric</td></tr> <tr><td>FPAN</td><td>Fragipan</td></tr> <tr><td>IRON</td><td>Plinthite</td></tr> <tr><td>LITH</td><td>Bedrock (lithic)</td></tr> <tr><td>NATR</td><td>Natric</td></tr> <tr><td>ORST</td><td>Ortstein</td></tr> <tr><td>PARA</td><td>Bedrock (paralithic)</td></tr> <tr><td>PERM</td><td>Permafrost</td></tr> <tr><td>PGYP</td><td>Petrogypsic</td></tr> <tr><td>PLAC</td><td>Placic</td></tr> <tr><td>SAL</td><td>Salic</td></tr> <tr><td>SULF</td><td>Sulfuric</td></tr> </table>	ABR	Abrupt textural change	CALC	Petrocalcic	CTEX	Strongly contrasting textural stratification	DENS	Dense material	DUR	Duripan	FE	Petroferric	FPAN	Fragipan	IRON	Plinthite	LITH	Bedrock (lithic)	NATR	Natric	ORST	Ortstein	PARA	Bedrock (paralithic)	PERM	Permafrost	PGYP	Petrogypsic	PLAC	Placic	SAL	Salic	SULF
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PARA	Bedrock (paralithic)																																	
PERM	Permafrost																																	
PGYP	Petrogypsic																																	
PLAC	Placic																																	
SAL	Salic																																	
SULF	Sulfuric																																	
Surface Runoff Class	Surface Runoff. The flow of water from an area that occurs over the surface to the soil. Surface runoff differs from internal flow or throughflow that results when infiltrated water moves laterally or vertically																																	

Field Name	Description and Action To Be Taken
	within a soil, above the water table. The Index Surface Runoff Classes are relative estimates of surface runoff based on slope gradient and saturated hydraulic conductivity. This index is specific to the following conditions: • The soil surface is assumed to be bare. • The soil is free of ice. • Retention of water by ground surface irregularities is negligible or low. • Infiltration is assumed to be at the steady ponded infiltration stage. • Water is added to the soil by precipitation or snowmelt that yields 50 mm in 24 hours with no more than 25 mm in any 1-hour period. • Antecedent soil water state is assumed to be very moist or wet to: (a) the base of the solum, (b) a depth of 1 m, or (c) through the horizon that has the minimum Ksat within the top 1 meter; whichever is the least depth. Use table E.1 and the above conditions to estimate the Index Surface Runoff Class for the site. If seasonal or permanent, internal free water occurs at a depth of ≤ 50 cm (very shallow and shallow internal free water classes), use a Ksat of Very Low. If seasonal or permanent, internal free water is deeper than 50 cm, use the appropriate Ksat from the table (Schoeneberger et al. 2002, 1-24).

Index of Surface Runoff Classes						
Saturated Hydraulic Conductivity (Ksat) Class						
Slope Gradient Percent	Very High	High	Mod. High	Mod. Low	Low	Very Low
cm/hour	> 36	3.6 – < 36	0.36 – < 3.6	0.036 – < 0.36	0.0036 – < 0.036	< 0.0036
Concave ^a	N	N	N	N	N	N
< 1	N	N	N	L	M	H
1–5	N	LV	L	M	H	HV
5–10	LV	L	M	H	HV	HV
10–20	LV	L	M	H	HV	HV
> 20	LV	L	M	H	HV	HV

Table E.1. *Index Surface Runoff Classes based on slope gradient and saturated hydraulic conductivity (adapted from Schoeneberger et al. 2002, 1–24).*

Negligible – N; Very Low – LV; Low – L; Medium – M; High – H; Very High – HV

^a Areas from which little or no water escapes by flow over the ground surface.

Field Name	Description and Action To Be Taken
Soil Temperature	Measure the soil temperature at 50 cm and enter the degrees F. If a restrictive layer is encountered above 50 cm, record the depth and temperature at the maximum depth possible. Soil temperature should be read as soon as the soil pit is excavated.
Diagnostic Horizons	a. Surface. Use the current edition of <i>Keys to Soil Taxonomy</i> (USDA NRCS 2003a) to determine the surface diagnostic horizon. b. Subsurface. Use the current edition of <i>Keys to Soil Taxonomy</i> (USDA NRCS 2003a) to determine the subsurface diagnostic horizons.
Box Sampled	Enter Yes or No if a box sample of the pedon was collected.
Lab Sampled	Enter Yes or No if a lab sample was collected.
Particle Size Control Section	a. Depth. Enter the depth range for the particle size control section. Example: 20–40 inches. b. Avg. Clay and Avg. RF Content. Enter the weighted average rock fragments by volume and the weighted average clay by weight. The weighted average is calculated by multiplying the percentage of rock fragments or clay in each horizon by the thickness of the horizon, then adding the total percentage and dividing by the total thickness of the control section.
Drainage Class	Use the following definitions (USDA NRCS 1993, 98-99) to determine the drainage class: ED—Excessively Drained. Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have very high-saturated hydraulic conductivity or are very shallow. SE—Somewhat Excessively Drained. Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high-saturated hydraulic conductivity or are very shallow. WD—Well Drained. Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness. MW—Moderately Well Drained. Water is removed from the soil somewhat slowly during some periods of the year. Internal free occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.

Field Name	Description and Action To Be Taken
	SP—<i>Somewhat Poorly Drained</i>. Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall. PD—<i>Poorly Drained</i>. Water is removed so slowly that the soil is wet at shallow depths periodically during the growing seasons or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity or nearly continuous rainfall, or of a combination of these. VP—<i>Very Poorly Drained</i>. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

Horizon

Field Name	Description and Action To Be Taken
Hor. Seq. #	The horizon sequence number used when entering the data in a database. The number 1 implies the 1st horizon.
Horizon Designation	Using the current edition of <i>Keys to Soil Taxonomy</i> (USDA NRCS 2003a), enter the appropriate symbol and suffix(es) for each horizon.
Depth	Enter the thickness of each layer in cm, using the surface of the mineral soil as the base from which to measure. Example: 0–8 cm; 8–18 cm; 18–40 cm; 40–60 cm. Duff layers recorded in reverse depths. Example: 2–0.
Boundary	A surface or transitional layer between two adjoining horizons or layers. Most boundaries are zones of transition rather than sharp lines of division. Boundaries vary in distinctness and in topography.

Distinctness

Code	Meaning	Description
V	Very abrupt	< 0.5 cm
A	Abrupt	0.5 to 2 cm thick
C	Clear	2 to 5 cm thick
G	Gradual	5 to 15 cm thick
D	Diffuse	More than 15 cm thick

Table E.2. *Boundary distinctness codes.*

Topography

Code	Meaning	Description
S	Smooth	The boundary is a plane with few or no irregularities.
W	Wavy	The boundary has undulations in which the depressions are wider than they are deep.
I	Irregular	The boundary has pockets that are deeper than they are wide.
B	Broken	One or both of the horizons or layers separated by the boundary are discontinuous and the boundary is interrupted.

Table E.3. *Boundary topography codes.*

Soil Color

Field Name	Description and Action To Be Taken
Soil Color and Mottles	The <i>Soil Survey Manual</i> (USDA NRCS 1993) states that the elements of soil descriptions are “the color name, the Munsell notation, the water state, and the physical state: brown (10YR 5/3), dry, crushed and smoothed.” Physical state is recorded as broken, rubbed, crushed, or crushed and smoothed. The term “crushed” usually applies to dry samples and “rubbed” to moist samples. If unspecified, the surface is broken. The color of the soil is recorded for a surface broken through a ped if a ped can be broken as a unit. The color value of most soil material becomes lower after moistening. Consequently, the water state of a sample is always given. The water state is either moist or dry. The dry state for color determinations is air-dry and should be made at the site where the color does not change with additional drying. Color in the moist state is determined on moderately moist or very moist soil material and should be made at the point where the soil color does not change with additional moistening.

Field Name	Description and Action To Be Taken
	Mottling refers to repetitive color changes that cannot be associated with compositional properties of the soil. Redoximorphic features are a type of mottling that is associated with wetness. A color pattern that can be related to proximity to a ped surface or other organizational or compositional feature is not mottling. Mottling description follows the dominant color. Mottles are described by quantity, size, contrast, color, and other attributes, in that order.

Redoximorphic Features

Type of feature	Code	Meaning
Redox features	CLD	Clay depletions
Redox features	F2M	Masses of reduced iron (Fe+2) accumulation
Redox features	F3M	Masses of oxidized iron (Fe+3) accumulation
Redox features	FED	Iron depletions
Redox features	FEF	Ferriargillan coats (Fe+3 stained clay films)
Redox features	FMC	Iron-manganese concretions
Redox features	FMM	Masses of iron-manganese accumulation
Redox features	FMN	Iron-manganese nodules
Redox features	FSN	Ironstone nodules
Redox features	MNF	Manganese surface coats/films or hypocoats
Redox features	MNM	Masses of manganese accumulation
Redox features	PLN	Plinthite nodules
Redox features	RC	Redoximorphic concentrations (undifferentiated)
Redox features	RD	Redoximorphic depletions (undifferentiated)
Redox features	RMX	Reduced matrix

Table E.4. *Redox feature codes.*

Quantity and Size Classes

Code	Meaning	Description
F	Few	Less than 2 percent
C	Common	2 to 20 percent
M	Many	More than 20 percent

Table E.5. *Quantity classes.*

Code	Meaning	Description
F	Fine	Smaller than 5 mm
M	Medium	5 to 15 mm
C	Coarse	Larger than 15 mm

Table E.6. *Size classes.*

Contrast

Contrast refers to the degree of visual distinction evident between associated colors.

Code	Meaning	Description
F	Faint	Evident only on close examination. Faint mottles commonly have the same hue as the color to which they are compared, and differ by no more than 1 unit of chroma or 2 units of value. Some faint mottles of similar but low chroma and value differ by 2.5 units (1 card) of hue.
D	Distinct	Readily seen, but contrast only moderately with the color to which they are compared. Distinct mottles commonly have the same hue as the color to which they are compared, but differ by 2 to 4 units of chroma or 3 to 4 units of value; or differ from the color to which they are compared by 2.5 units (1 card) of hue, but by no more than 1 unit of chroma or 2 units of value.
P	Prominent	Contrast strongly with the color to which they are compared. Prominent mottles are commonly the most obvious color feature of the section described. Prominent mottles that have medium chroma and value commonly differ from the color to which they are compared by at least 5 units (2 pages) of hue if chroma and value are the same; at least 4 units of value or chroma if the hue is the same; or at least 1 unit of chroma or 2 units of value if hue differs by 2.5 units (1 card).

Table E.7. *Contrast codes.*

Location of Redoximorphic and Mottles.

Code	Meaning	Description
Redox features	CRK	Cracks
Redox features	BRF	On bottom of rock fragments
Redox features	BPF	Between peds
Redox features	MPO	Infused into the matrix adjacent to pores (hypocoating)
Redox features	MAT	Matrix adjacent to pores
Redox features	MAC	Matrix surrounding redox concentrations
Redox features	MAD	Matrix surrounding redox depletions
Redox features	MPF	Matrix
Redox features	APF	Ped faces
Redox features	HPF	Ped horizontal faces
Redox features	VPF	Ped vertical faces
Redox features	LPO	Pore lining
Redox features	ARF	Around rock fragments
Redox features	SPO	On surface along pores
Redox features	TOT	Throughout
Redox features	TOH	Top of horizon
Redox features	PEPO	Ped faces and pores

Code	Meaning	Description
Mottles	BRF	On bottom of rock fragments
Mottles	MPF	Matrix
Mottles	ARF	Around rock fragments

Table E.8. *Redox feature and mottle location codes.*

Texture

Field Name	Description and Action To Be Taken
Texture	The <i>Soil Survey Manual</i> (Soil Survey Division Staff 1993) directs researchers to hand texture each horizon, enter the texture, texture modifier, and estimated % clay and % sand.

Code	Meaning	Code	Meaning
C	Clay	S	Sand
CL	Clay loam	SC	Sandy clay
COS	Coarse sand	SCL	Sandy clay loam
COSL	Coarse sandy loam	SI	Silt
FS	Fine sand	SIC	Silty clay
FSL	Fine sandy loam	SICL	Silty clay coam
L	Loam	SIL	Silt loam
LCOS	Loamy coarse sand	SL	Sandy loam
LFS	Loamy fine sand	VFS	Very fine sand
LS	Loamy sand	VFSL	Very fine sandy loam
LVFS	Loamy very fine sand		

Table E.9. *Texture classes.*

Rock Fragments

Spherical, cubelike, or equiaxial

Shape and size	Noun	Adjective	Code
2–75 mm diameter	Pebbles	Gravelly	GR
2–5 mm diameter	Fine	Fine gravelly	GRF
5–20 mm diameter	Medium	Medium gravelly	GRM
20–75 mm diameter	Coarse	Coarse gravelly	GRC
75–250 mm diameter	Cobbles	Cobbly	CB
250–600 mm diameter	Stones	Stony	ST
> 600 mm diameter	Boulders	Bouldery	BY

Flat

Shape and size	Noun	Adjective	Code
2–150 mm long	Channers	Channery	CN
150–380 mm long	Flagstones	Flaggy	FL
380–600 mm long	Stones	Stony	ST
>600 mm long	Boulders	Bouldery	BY

Table E.10. *Rock fragment terms.*

Texture Modifier Classes

- *Less than 15 percent.* No terms are used for contrast with soils having less than 15 percent pebbles, cobbles, or flagstones. The adjective “slightly” may be used, however, to recognize those soils used for special purposes.
- *15 to < 35 percent.* The adjectival term of the dominant kind of rock fragment is used as a modifier of the textural term: “gravelly loam (GRL),” “channery loam (CNL),” “cobbly loam (CBL).”
- *35 to < 60 percent.* The adjectival term of the dominant kind of rock fragment is used with the word “very (V)” as a modifier of the textural term: “very gravelly loam (GRVL),” “very flaggy loam (FLV).”
- *60 to < 90 percent.* If enough fine earth is present to determine the textural class (approximately 10 percent or more by volume) the adjectival term of the dominant kind of rock fragment is used with the word “extremely (X)” as a modifier of the textural term: “extremely gravelly loam (GRXL),” “extremely bouldery loam (BYXL).” If there is too little fine earth to determine the textural class (less than 10 percent by volume), the term “gravel,” “cobbles,” “stones,” or “boulders” is used as appropriate.

Code	Meaning	Code	Meaning
BY	Bouldery	PBY	Parabouldery
BYV	Very Bouldery	PBYV	Very parabouldery
BYX	Extremely bouldery	PBYX	Extremely parabouldery
CB	Cobbly	PCB	Paracobbly
CBV	Very cobbly	PCBV	Very paracobbly
CBX	Extremely paracobbly	PCBX	Extremely paracobbly
CN	Channery	PCN	Parachannery
CNV	Very channery	PCNV	Very parachannery
CNX	Extremely channery	PCNX	Extremely parachannery
FL	Flaggy	PFL	Paraflaggy
FLV	Very flaggy	PFLV	Very paraflaggy
FLX	Extremely flaggy	PFLX	Extremely paraflaggy
GR	Gravelly	PGR	Paragravelly
GRC	Coarse gravelly	PGRV	Very paragravelly
GRF	Fine gravelly	PGRX	Extremely paragravelly
GRM	Medium gravelly	PST	Parastony
GRV	Very gravelly	PSTV	Very parastony
GRX	Extremely gravelly	PSTX	Extremely parastony
		ST	Stony
		STV	Very stony
		STX	Extremely stony

Table E.11. *Texture modifiers.*

Compositional Texture Modifier

Code	Meaning	Code	Meaning
ASHY	Ashy	MEDL	Medial
COP	Coprogenous	MK	Mucky
DIA	Diatomaceous	MR	Marly
GS	Grassy	MS	Mossy
GYP	Gypsiferous	PF	Permanently frozen
HB	Herbaceous	PT	Peaty
HYDR	Hydrous	WD	Woody

Table E.12. *Compositional texture modifiers.*

Terms Used in Lieu of Texture

Terms used in lieu of texture are substitute terms applied to materials that do not fit into a texture class because of organic matter content, size, rupture resistance, solubility, or another reason. Examples include muck, duripan, gravel, and bedrock.

Code	Meaning	Code	Meaning
BR	Bedrock	PC	Petrocalcic
BY	Boulders	PCB	Paracobbles
CB	Cobbles	PCN	Parachanners
CN	Channers	PEAT	Peat
DUR	Duripan	PF	Petroferric
FL	Flagstones	PFL	Paraflagstones
GR	Gravel	PG	Paragravel
HPM	Highly decomposed plant material	PGP	Petrogypsic
MAT	Material	PL	Placic
MPM	Moderately decomposed plant material	PST	Parastones
MPT	Mucky peat	SPM	Slightly decomposed
MUCK	Muck	ST	Stones
OR	Ortstein	W	Water
PBY	Paraboulders plant material		

Table E.13. *Terms used in lieu of texture.*

Structure

Field Name	Description and Action To Be Taken
Structure (Shape, size, and grade)	Soil structure refers to units composed of primary particles. The cohesion within these units is greater than the adhesion among units. As a consequence, under stress, the soil mass tends to rupture along predetermined planes or zones. Some soils lack structure and are referred to as structureless. In structureless layers or horizons, no units are observable in place or after the soil has been gently disturbed, such as by tapping a spade containing a slice of soil against a hard surface or dropping a large fragment on the ground. (USDA NRCS 1993, 157-163). In soils that have structure, the shape, size, and grade (distinctness) of the units are described. Field terminology for soil structure consists of separate sets of terms designating each of the three properties, which by combination form the names for structure.

Field Name	Description and Action To Be Taken
	Shape. Several basic shapes of structural units are recognized in soils. Supplemental statements about the variations in shape of individual peds are needed in detailed descriptions of some soils. The following terms describe the basic shapes and related arrangements: Platy. The units are flat and platelike. They are generally oriented horizontally. A special form, lenticular platy structure, is recognized for plates that are thickest in the middle and thin toward the edges. Prismatic. The individual units are bounded by flat to rounded vertical faces. Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units. Vertices are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat. Columnar. The units are similar to prisms and are bounded by flat or slightly rounded vertical faces. The tops of the columns, in contrast to those of prisms, are very distinct and normally rounded. Blocky. The units are blocklike or polyhedral. They are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds. Typically, blocky structural units are nearly equidimensional but grade to prisms and to plates. The structure is described as angular blocky if the faces intersect at relatively sharp angles; it is described as subangular blocky if the faces are a mixture of rounded and plane faces and the corners are mostly rounded.

Code	Description	Code	Description
ABK	Angular blocky	PL	Platy
CDY	Cloddy	PR	Prismatic
COL	Columnar	SGR	Single grain
GR	Granular	SBK	Subangular blocky
LP	Lenticular platy	WEG	Wedged shaped aggregates
MA	Massive		

Table E.14. *Structure shape codes.*

Size. Five classes are employed: very fine, fine, medium, coarse, and very coarse. The size limits of the classes differ according to the shape of the units. The size limits refer to the smallest dimension of the plates, prisms, and columns. If the units are more than twice the minimum size of “very coarse,” the actual size is given: “prisms 30 to 40 cm across.” In describing plates, “thin” is used instead of “fine” and “thick” instead of “coarse.”

Size Classes	Platy	Prismatic and Columnar	Blocky	Granular
Very fine	< 1 mm	< 10 mm	< 5 mm	< 1 mm
Fine	1–2 mm	10–20 mm	5–10 mm	1–2 mm
Medium	2–5 mm	20–50 mm	10–20 mm	2–5 mm
Coarse	5–10 mm	50–100 mm	20–50 mm	5–10 mm
Very coarse	> 10 mm	> 100 mm	> 50 mm	> 10 mm

Table E.15. *Structural size classes.*

Code	Description	Code	Description	Code	Description
VN	Very thin	F	Fine	VC	Very coarse
TN	Thin	M	Medium	VF	Very fine
TK	Thick	C	Coarse	EC	Extremely coarse
VK	Very thick				

Table E.16. *Size codes.*

Grade. Grade describes the distinctness of the units. Criteria are the ease of separation into discrete units and the proportion of the units that hold together when the soil is handled. Three classes are used:

1. **Weak.** The units are barely observable in place. When gently disturbed, the soil material parts into a mixture of whole and broken units and much material that exhibits no planes of weakness. Faces that indicate persistence through wet-dry cycles are evident if the soil is handled carefully. Distinguishing structurelessness from weak structure is sometimes difficult. Weakly expressed structural units in virtually all soil materials have surfaces that differ in some way from the interiors.
2. **Moderate.** The units are well formed and evident in undisturbed soil. When disturbed, the soil material parts into a mixture of mostly whole units, some broken units, and material that is not in units. Peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fractured surfaces.
3. **Strong.** The units are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed, the soil material separates mainly into whole units. Peds have distinctive surface properties.

Code	Description
1	Weak
2	Moderate
3	Strong
0	Structureless

Table E.17. *Grade codes.*

Compound structure occurs when smaller units may be held together to form larger units. Grade, size, and shape are given for both and the relationship of one set to the other is indicated: “strong medium blocks within moderate coarse prisms,” or “moderate coarse prismatic structure parting to strong medium blocky.”

Consistence

Field Name	Description and Action To Be Taken
Consistence	Soil consistence (USDA NRCS 1993, 172-183) refers to “attributes of soil material as expressed in degree of cohesion and adhesion or in resistance to deformation on rupture.” As employed here, consistence includes: (1) resistance of soil material to rupture, (2) resistance to penetration, (3) plasticity, toughness and stickiness of puddled soil material, and (4) the manner in which the soil material behaves when subject to compression. Consistency is highly dependent on the soil-water state and the description has little meaning unless the water state class is specified or is implied by the test. Previously class sets were given for “dry” and “moist” consistence of the soil material as observed in the field. “Wet” consistence was evaluated for puddled soil material. Here the terms used for “moist” consistence previously are applied to the wet state as well. Stickiness, plasticity, and toughness of the puddled soil material are independent tests.

Classes			Test Description
Moderately dry and very dry	Slightly dry and wetter	Air dried, submerged	Operation.
Loose	Loose	Not applicable	Specimen not obtainable.
Soft	Very friable	Noncemented	Fails under very slight force applied slowly between thumb and forefinger.
Slightly hard	Friable	Extremely weakly Cemented	Fails under slight force applied slowly between thumb and forefinger.
Moderately hard	Firm	Very weakly cemented	Fails under moderate force applied slowly between thumb and forefinger.
Hard	Very firm	Weakly cemented	Fails under strong force applied slowly between thumb and forefinger.
Very hard	Extremely firm	Moderately cemented	Cannot be failed between thumb and forefinger but can be between both hands or by placing on a nonresilient surface and applying gentle force underfoot.

Classes			Test Description
Extremely hard	Slightly rigid	Strongly cemented	Cannot be failed in hands but can be underfoot by full body weight applied slowly.
Rigid	Rigid	Very strongly cemented	Cannot be failed underfoot by full body weight but can be by < 3 Joules blow.*
Very rigid	Very rigid	Indurated	Cannot be failed by a blow > 3 Joules.

Table E.18. *Rupture resistance for blocklike specimens.*

*One joule is the energy delivered by dropping a 1 kg weight 10 cm.

Code	Description	Code	Description	Code	Description
EH	Extremely hard	MH	Moderately hard	S	Soft
HA	Hard	R	Rigid	VH	Very hard
L	Loose	SH	Slightly hard	VR	Very rigid

Table E.19. *Moderately dry and very dry blocklike specimens.*

Code	Description	Code	Description	Code	Description
EFI	Extremely firm	L	Loose	VFI	Very firm
FI	Firm	R	Rigid	VFR	Very friable
FR	Friable	SR	Slightly rigid	VR	Very rigid

Table E.20. *Slightly dry and wetter blocklike specimens.*

Code	Description	Code	Description
EW	Extremely weakly cemented	S	Strongly cemented
I	Indurated	VS	Very strongly cemented
M	Moderately cemented	VW	Very weakly cemented
NA	Nonapplicable	W	Weakly cemented
N	Noncemented		

Table E.21. *Air dried, submerged blocklike specimens.*

Stickiness

Stickiness refers to the capacity of a soil to adhere to other objects. The determination is made on puddled < 2 mm soil material at the water content at which the material is most sticky. The sample is crushed in the hand; water is applied while manipulation is contained between thumb and forefinger until maximum stickiness is reached. The classes in the table below are used to describe stickiness.

Code	Classes	Test Description
SO	Nonsticky	After release of pressure, practically no soil material adheres to thumb or forefinger.
SS	Slightly sticky	After release of pressure, soil material adheres perceptibly to both digits. As the digits are separated, the material tends to come off one or the other rather cleanly. The material does not stretch appreciably on separation of the digits.
MS	Moderately sticky	After release of pressure, soil material adheres to both digits and tends to stretch slightly rather than pull completely free from either digit.
VS	Very sticky	After release of pressure, soil material adheres so strongly to both digits that it stretches decidedly when the digits are separated. Soil material remains on both digits.

Table E.22. *Stickiness codes.*

Plasticity

Plasticity is the degree to which a puddled soil material is permanently deformed without rupturing by force applied continuously in any direction. Plasticity is determined on material smaller than 2 mm.

The determination is made on thoroughly puddled soil material at a water content where maximum plasticity is expressed. This water content is above the plastic limit, but it is less than the water content at which maximum stickiness is expressed. The water content is adjusted by adding water or removing it during manipulation. The closely related plastic limit, used in engineering classifications, is the water content for < 0.4 mm material at which a roll of 3 mm in diameter which had been formed at a higher water content breaks apart.

Code	Classes	Test Description
PO	Nonplastic	A roll 4 cm long and 6 mm thick that supports its own weight held on end cannot be formed.
SP	Slightly plastic	A roll 4 cm long and 6 mm thick can be formed and, if held on end, will support its own weight. A roll 4 mm thick will not support its own weight.
MP	Moderately	A roll 4 cm long and 4 mm thick can be formed and will support plastic its own weight, but a roll 2 mm thick will not support its own weight.
VP	Very plastic	A roll 4 cm long and 2 mm thick can be formed and will support its own weight.

Table E.23. *Plasticity codes.*

Code	Classes	Test Description
Brittleness		Press a 3 cm block between thumb and forefinger).
B	Brittle	Ruptures abruptly (“pops” or shatters).
SD	Semi-deformable	Rupture occurs after compression to > or = to ? original thickness.
D	Deformable	Rupture occurs after compression to > or = to ? original thickness.
Fluidity		Squeeze a palmful of soil in hand.
NF	Nonfluid	No soil flows through fingers with full compression.
SF	Slightly fluid	Some soil flows through fingers, most remains in the palm, after full pressure.
MF	Moderately fluid	Most soil flows through fingers, some remains in palm, after full pressure.
VF	Very fluid	Most soil flows through fingers, very little remains in palm, after gentle pressure.
Smeariness ¹		Press a 3 cm block between thumb and forefinger.
NS	Nonsmeary	At failure, the sample does not change abruptly to fluid, fingers do not skid, no smearing occurs.
WS	Weakly smeary	At failure, the sample changes abruptly to fluid, fingers skid, soil smears, little or no water remains on fingers.
MS	Moderately smeary	At failure, the sample changes abruptly to fluid, fingers skid, soil smears, some water remains on fingers.
SS	Strongly smeary	At failure, the sample changes abruptly to fluid, fingers skid, soil smears and is slippery, water easily seen on fingers.

¹ Smeary failure classes are used dominantly with Andic materials, but may also be used with some spodic materials.

Special Features

Field Name	Description and Action To Be Taken
Special Features	Films. The kinds of special surface features are clay films (or clay skins), clay bridges, sand or silt coats, other coats, stress surfaces (pressure faces), and slickensides. The various surface features may be on some or all structural units, channels, pores, primary particles or grains, soil fragments, rock fragments, nodules, or concretions. The kind and orientation of surface on which features are observed is always given. For example, if clay films are on vertical but not horizontal faces of peds, this fact should be recorded.

Feature	Code	Description
Surface features	BRF	Clay bridging
Surface features	CAF	Carbonate coats
Surface features	CLF	Clay films
Surface features	CT	Coats (undifferentiated)
Surface features	CTOX	Oxide coats
Surface features	FEF	Iron stains
Surface features	GBF	Gibbsite coats
Surface features	MNF	Manganese stains
Surface features	NNS	Nonintersecting slickensides
Surface features	OAF	Organoargillans
Surface features	OSF	Organic stains
Surface features	PRF	Pressure faces
Surface features	SAF	Skeletans on argillans
Surface features	SIF	Silica (silans, opal)
Surface features	SKF	Skeletans (sand or silt)
Surface features	SLF	Silt coats
Surface features	SNF	Sand coats
Surface features	SS	Slickensides (pedogenic)
Surface features	SSG	Slickensides (geogenic)
Surface features	STIR	Iron-manganese stains
Surface features	STSB	Black stains

Table E.24. *Ped surface feature kinds.*

Amount

The amount, or percentage, of the total surface area of the kind of surface considered occupied by a particular surface feature over the extent of the horizon or layer is described.

Code	Meaning	Description
VF	Very few	Occupies < 5 percent
F	Few	Occupies 5 to 25 percent
C	Common	Occupies 25 to 50 percent
M	Many	Occupies > 50 percent

Table E.25. *Surface features abundance codes.*

Distinctness

Distinctness refers to the ease and degree of certainty with which a surface feature can be identified.

Code	Meaning	Description
F	Faint	Evident only on close examination with 10X magnification and cannot be identified positively in all places without greater magnification. The contrast with the adjacent material in color, texture, and other properties is small.
D	Distinct	Can be detected without magnification, although magnification or tests may be needed for positive identification. The feature contrasts enough with the adjacent material to make a difference in color, texture, or other properties evident.
P	Prominent	Conspicuous without magnification when compared with a surface broken through the soil. Color, texture, or some other property or combination of properties contrasts sharply with properties of the adjacent material or the feature is thick enough to be conspicuous.

Table E.26. *Distinctness class codes.*

Location of Surface Features

Type of feature	Code	Meaning
Surface features	SC	Root channels
Surface features	PLB	Plate bottoms
Surface features	BG	Between sand grains
Surface features	VF	Ped vertical faces
Surface features	CC	Concretions
Surface features	PF	All ped faces
Surface features	PEPO	Peds and pores
Surface features	HF	Ped horizontal faces
Surface features	BF	Ped lower surface (bottom faces)
Surface features	BR	Rock lower surface
Surface features	NO	Nodules
Surface features	RF	Rock fragments
Surface features	SGR	Sand and gravel
Surface features	TC	Column tops
Surface features	TF	On top faces of peds
Surface features	TR	Rock upper surface
Surface features	SP	On surfaces along pores

Table E.27. *Surface feature location codes.*

The order of the description of surface features is usually amount, distinctness, color, kind, and location. For example: “few distinct grayish brown (10YR 5/2) clay films/clay skins on vertical faces of peds”; “many distinct brown clay bridges between mineral grains.”

Rock Fragments and Roots

Field Name	Description and Action To Be Taken
Rock Fragments	Using the ocular method and/or line intercept method, determine the percent of gravels (GR), cobbles (CB), stones (ST), and boulders (BY) for each horizon.
Roots	Quantity, size, and location of roots in each layer are recorded (USDA NRCS 1993, 184-188). Using features of the roots (length, flattening, nodulation and lesions), the relationships to special soil attributes or to structure may be recorded as notes. Quantity of roots is described in terms of numbers of each size per unit area. The class placement for quantity of roots pertains to an area in a horizontal plane unless otherwise stated. This unit area changes with root size as follows: 1 cm² for very fine and fine, 1 dm² for medium and coarse and 1 m² for very coarse. The quantity classes given in table E.28.

Code	Meaning	Description
F	Few	< 1 per unit area
C	Common	1–5 per unit area
M	Many	> 5 per unit area

Table E.28. *Quantity of roots codes.*

Roots are described in terms of a specified diameter size.

Code	Meaning	Description
VF	Very fine	< 1 mm
F	Fine	1–2 mm
M	Medium	2–5 mm
C	Coarse	5–10 mm
VC	Very coarse	> 10 mm

Table E.29. *Size of roots codes.*

Pores

Field Name	Description and Action To Be Taken
Pores	Pore space is a general term for voids in the soil material (USDA NRCS 1993, 186-190). The term includes matrix, nonmatrix, and interstructural pore space. Matrix pores are formed by the agencies that control the packing of the primary soil particles. These pores are usually smaller than nonmatrix pores. In addition, their aggregate volume and size would change markedly with water state for soil horizons or layers with high extensibility. Nonmatrix pores are relatively large voids that are expected to be present when the soil is moderately moist or wetter, as well as under drier states. The voids are not bounded by the planes that delimit structural units. Interstructural pores, in turn, are delimited by structural units. Inferences as to the interstructural porosity may be obtained from the structure description. Commonly, interstructural pores are at least crudely planar. Nonmatrix pores may be formed by roots, animals, action of compressed air, and other agents. Most nonmatrix pores are either vesicular (approximately spherical or elliptical) or tubular (approximately cylindrical and elongated). Some are irregularly shaped. Nonmatrix pores are described by quantity, size, shape, and vertical continuity—generally in that order. Some examples of descriptions of pores are “many fine tubular pores,” “few fine tubular pores and many medium tubular pores with moderate vertical continuity,” and “many medium vesicular pores in a horizontal band about 1-cm wide at the bottom of the horizon.”

Quantity classes pertain to numbers per unit area: 1 cm² for very fine and fine pores, 1 dm² for medium and coarse pores, and 1 m² for very coarse.

Code	Meaning	Description
F	Few	< 1 per unit area
C	Common	1–5 per unit area
M	Many	> 5 per unit area

Table E.30. *Quantity of pores codes.*

Pores are described in five classes relative to a specified diameter size.

Code	Meaning	Description
VF	Very fine	< 0.5 mm
F	Fine	0.5–2.0 mm
M	Medium	2.0–5.0 mm
C	Coarse	5.0–10.0 mm
VC	Very coarse	> 10.0 mm

Table E.31. *Size of pores codes.*

Pores are described in five classes relative to their shape.

Code	Meaning	Description
VE	Vesicular	Approximately spherical or elliptical
DT	Dendritic Tubular	Cylindrical, elongated, branching voids
TU	Tubular	Approximately cylindrical and elongated
IR	Interstitial	Irregularly shaped
IG	Irregular	Nonconnected cavities, chambers

Table E.32. *Shape of pores codes.*

Effervescence

Field Name	Description and Action To Be Taken
Effervescence Class	Cold 2.87N (about 1:10 dilution of concentrated HCL) hydrochloric acid is used to test for carbonates in the field. The amount and expression of effervescence is affected by size distribution and mineralogy as well as the amount of carbonates. Consequently, effervescence cannot be used to estimate the amount of carbonate.

Code	Meaning	Description
NE	Noneffervescent	No reaction.
VS	Very slightly effervescent	Few bubbles seen.
SL	Slightly effervescent	Bubbles readily seen.
ST	Strongly effervescent	Bubbles form low foam.
VE	Violently effervescent	Thick foam forms quickly.

Table E.33. *Effervescence class codes.*

Water State

Field Name	Description and Action To Be Taken
PH	Enter the pH value. List reagent or method used in notes section.
Water State Class	Three classes defined below are used in this field. See discussion on pages 90 to 98 of the <i>Soil Survey Manual</i> (USDA NRCS 1993) for further definitions of classes.

Code	Meaning
D	Dry
M	Moist
W	Wet

Table E.34. *Water state class codes.*

Accessory Properties

Masses, plinthite, nodules, concretions, crystals, ironstone, pressure faces, and slickensides (USDA NRCS 1993, 169-172) are accessory properties of soils. These features are identifiable bodies within the soil that were formed by pedogenesis. Some of these bodies are thin and sheetlike, some are nearly equidimensional, and others have irregular shapes. They may contrast sharply with the surrounding material in strength, composition, or internal organization. Alternatively, the differences from the surrounding material may be slight. Soft rock fragments, which have rock structure but are weakly cemented or noncemented, are not considered concentrations. They are excluded based on inference as to a geological as opposed to pedological origin.

Masses are noncemented concentrations of substances that commonly cannot be removed from the soil as a discrete unit. Most accumulations consist of calcium carbonate, fine crystals of gypsum or more soluble salts, or iron and manganese oxides. Except for very unusual conditions, masses have formed in place.

Plinthite consists of reddish, iron-enriched bodies that are low in organic matter and are coherent enough to be separated readily from the surrounding soil. Plinthite commonly occurs within and above reticulately mottled horizons. Soil layers that contain plinthite rarely become dry in the natural setting. The bodies are commonly about 5 to 20 mm across their smallest dimension. Plinthite bodies are firm or very firm when moist, hard, or very hard when air dry, and become moderately cemented on repetitive wetting and drying.

Nodules and concretions are cemented bodies that can be removed from the soil intact. Composition ranges from material dominantly like that of the surrounding soil to nearly pure chemical substances entirely different from the surrounding material. Their form is apparently not governed by crystal forms based on examination at a magnification of 10X, as is the case for crystals and clusters of crystals. It is impossible to be sure if some nodules and concretions formed where they are observed or were transported.

Type of feature	Code	Meaning
Concentrations	BAM	Barite masses
Concentrations	BAX	Barite crystals
Concentrations	BC	Biological concentrations (undifferentiated)
Concentrations	CAC	Carbonate concretions
Concentrations	CAM	Carbonate masses
Concentrations	CAN	Carbonate nodules
Concentrations	CAX	Calcite crystals
Concentrations	CBM	Clay bodies
Concentrations	CCD	Dark concretions

Type of feature	Code	Meaning
Concentrations	CCIM	Iron-manganese concretions
Concentrations	CCIR	Iron concretions
Concentrations	CCMN	Manganese concretions
Concentrations	CO	Concentrations (undifferentiated)
Concentrations	COLI	Lime concretions
Concentrations	CR	Crystals (undifferentiated)
Concentrations	DIB	Diatoms
Concentrations	DM	Finely disseminated materials (undifferentiated)
Concentrations	DNN	Durinodes
Concentrations	DPC	Clay depletions
Concentrations	DPIR	Iron depletions
Concentrations	FDC	Finely disseminated carbonates
Concentrations	FDS	Finely disseminated salts
Concentrations	FPB	Fecal pellets
Concentrations	GBC	Gibbsite concretions
Concentrations	GBN	Gibbsite nodules
Concentrations	GLI	Glauconite pellets
Concentrations	GNM	Nests of gypsum
Concentrations	GYM	Masses of gypsum
Concentrations	GYX	Gypsum crystals
Concentrations	HACR	Halite crystals
Concentrations	ICB	Insect casts
Concentrations	MA	Masses (undifferentiated)
Concentrations	MIC	Mica flakes
Concentrations	MSD	Masses of dark accumulations
Concentrations	MSIM	Masses of iron-manganese
Concentrations	MSIR	Masses of iron
Concentrations	MSL	Masses of lime
Concentrations	MSMN	Masses of manganese
Concentrations	MSOX	Masses of oxides
Concentrations	NO	Nodules (undifferentiated)
Concentrations	NOD	Dark nodules
Concentrations	NOIM	Iron-manganese nodules
Concentrations	NOIR	Ironstone nodules
Concentrations	NOLI	Lime nodules
Concentrations	NOMN	Manganese nodules
Concentrations	OPN	Opal
Concentrations	PPB	Plant phytoliths
Concentrations	RSB	Root sheaths
Concentrations	SAM	Masses of salt

Type of feature	Code	Meaning
Concentrations	SAX	Salt crystals
Concentrations	SFB	Shell fragments
Concentrations	SGPT	Plinthite segregations
Concentrations	SHMG	Magnetic shot
Concentrations	SHNMG	Nonmagnetic shot
Concentrations	SIC	Silica concretions
Concentrations	SIM	Masses of silica
Concentrations	SSB	Sponge spicules
Concentrations	THCB	Carbonate threads
Concentrations	THGP	Gypsum threads
Concentrations	TIC	Titanium oxide
Concentrations	WCB	Worm casts
Concentrations	WNO	Worm nodules

Table E.35. *Concentration kind codes.*

Soft Masses and Concretions

Code	Meaning	Description
F	Few	Less than 2 percent of the surface area
C	Common	2 to 20 percent of the surface area
M	Many	More than 20 percent of the surface area

Table E.36. *Abundance codes.*

Code	Meaning	Description
F	Fine	< 2 mm
M	Medium	2–5 mm
C	Coarse	5–20 mm
VC	Very coarse	20–76 mm
EC	Extremely coarse	> 76 mm

Table E.37. *Size codes.*

Code	Meaning	Description
R	Rounded	Generally rounded or slightly oblong.
C	Cylindrical	Cylindrical or tubular; one dimension is much greater than the other two.
P	Platelike	Shaped crudely like a plate; one dimension is very much smaller than the other two.
I	Irregular	Characterized by branching, convoluted, or mycelial form.

Table E.38. *Shape codes.*

Type of feature	Code	Meaning
Concentrations	ARF	Around rock fragments
Concentrations	TOH	Top of horizon
Concentrations	CRK	Cracks
Concentrations	MPF	Matrix
Concentrations	DIA	Diatoms
Concentrations	MAT	Matrix adjacent to pores
Concentrations	ALS	Along lamina or strata surfaces
Concentrations	RPO	On surfaces along root channels
Concentrations	SSS	On slickensides
Concentrations	MAC	Matrix surrounding concentrations
Concentrations	MAD	Matrix surrounding depletions
Concentrations	LPO	Pore lining
Concentrations	APF	Ped faces
Concentrations	HPF	Ped horizontal faces
Concentrations	PFPO	Ped faces and pores
Concentrations	VPF	Ped vertical faces
Concentrations	TOT	Throughout
Concentrations	BPF	Between peds
Concentrations	BRF	On bottom of rock fragments
Concentrations	SPO	On surface along pores
Concentrations	MPO	Infused into the matrix adjacent to pores (hypocoats)

Table E.39. *Concentration location codes.*

Excavation Difficulty

Field Name	Description and Action To Be Taken
Excavation Difficulty	Enter the appropriate code from table E.40 for excavation difficulty.

Code	Classes	Test Description
LO	Low	Can be excavated with a spade using arm-applied pressure only. Neither application of impact energy nor application of pressure with the foot to a spade is necessary.
MO	Moderate	Arm-applied pressure to a spade is insufficient. Excavation can be accomplished quite easily by application of impact energy with a spade or by foot pressure on a spade.
HI	High	Excavation with a spade can be accomplished, but with difficulty. Excavation is easily possible with a full length pick using an over-the-head swing.

Code	Classes	Test Description
VH	Very high	Excavation with a full-length pick using an over-the-head swing is moderately to markedly difficult. Excavation is possible in a reasonable period of time with a backhoe mounted on a 40 to 60 kW (50 to 80 hp) tractor.
EH	Extremely high	Excavation is nearly impossible with a full-length pick using an over-the-head arm swing. Excavation cannot be accomplished in a reasonable time period with a backhoe mounted on a 40 to 60 kW (50 to 80 hp) tractor.

Table E.40. *Excavation difficulty codes.*

Appendix F. TEUI Documentation

The following examples were adapted from the *Bridger-East Ecological Unit Inventory* (Svalberg et al. 1997).

Ecological Type Description

PIAL/VASC, Ivywild Family Ecological Type

Whitebark pine/grouse whortleberry, Ivywild Family Ecological Type

Concept and Distribution

This ecological type (ET) consists of the PIAL/VASC Plant Association (p.a.) on soils of the Ivywild Family. The PIAL/VASC p.a. includes plant communities in which white-bark pine is the projected climax dominant tree and the understory is characterized by grouse whortleberry. Soils of the Ivywild Family are 20 to 40 inches deep, well drained, and have a loamy-skeletal subsoil layer.

This ET occurs dominantly from Doubletop Mountain south to Big Sandy Opening within the Subsummit Uplands Subsection. It is a component of map units 2345, 2601, and 2602. The geographic extent of this ET is approximately 53,480 acres. Within this area, it occupies about 9,590 acres.

Geomorphology

Landscape: Mountains.

Landforms: Roche Mountonee-Alpine Glaciation – Ice Erosion-Glacial.

Common Landforms: Bench and Freeface.

Landscape Position: Backslopes and sideslopes.

Surficial/Parent Materials

Primary Lithology: Unconsolidated.

Secondary Lithology: Glacial till desposit, colluvium, and residuum. Colluvium, residuum, and glacial till are derived from Early to Late Archean granite, granite gneiss, and granodiorite.

Colluvium occurs predominantly as slopewash, with some areas of talus and scree deposits. Glacial till is dominantly Late Wisconsin (Pinedale) age. Higher elevations may have Holocene (Neoglacial) till present.

Parent/Surficial Material Size Class: Bouldery.

Bedrock

Primary Lithology: Igneous Intrusive, Metamorphic.

Secondary Lithology: Granite, granodiorite, gneiss. Bedrock includes some areas of diorite, quartz diorite, amphibolite, and/or quartzite.

Climate: Cryic temperature regime and ustic moisture regime. Estimated mean annual precipitation ranges from 21 to 46 inches.

Elevation: Full Range: 9,000 to 10,800 feet. Typical Range: 9,000 to 10,500 feet.

Slope: 5 to 50 percent, on all aspects.

Potential Natural Vegetation: The potential natural vegetation of this ET is the PIAL/VASC p.a. (Steele et al. 1983).

In mature stands, total tree canopy cover ranges from 10 to 30 percent. Whitebark pine is the projected climax dominant tree. Lodgepole pine is the major early seral species. At lower elevations, lodgepole pine may persist for long periods of time and act as a codominant (Steele et al. 1983).

Shrub cover ranges from 10 to 30 percent. Grouse whortleberry is the climax dominant. It forms a low, somewhat open mat approximately 6 inches high. Planeleaf willow may be found on sites transitional to wetter areas.

Herbaceous cover is usually sparse and ranges from 5 to 30 percent. The most common graminoids are Wheeler's bluegrass, Ross' sedge, and spike trisetum. Common forbs include pussytoes, heartleaf arnica, and varileaf cinquefoil. Herbs that increase with disturbance are fireweed, pussytoes, western yarrow, and common dandelion.

Soil Description: Soils of this ET are 20 to 40 inches deep, well drained, and have a permeability of 2.0 to 6.0 inches per hour. Available water capacity to a depth of bedrock ranges from 1.5 to 2.4 inches.

Soil Name: Ivywild Family.

Taxonomic Classification: Loamy-skeletal, mixed, superactive Typic Dystrocryepts.

Location of Typical Pedon: Horseshoe Lake quadrangle, SW 1/4 of NW 1/4 Section 03, T. 34 N., R. 107 W., 1 mile east of Belford Lake, Pinedale Ranger District, Sublette County, Wyoming. Latitude 42 56' 39" N., Longitude 109 37' 16" W. Map unit 2602. Reference pedon: L1804B.

Horizon Description

- A 0 to 5 inches; dark grayish brown (10YR 4/2) very bouldery sandy loam, very dark grayish brown (10YR 3/2) moist; weak fine granular structure; soft, very friable, nonsticky and nonplastic; 5 percent gravel, 5 percent cobbles, 5 percent stones, 20 percent boulders; many very fine, few fine, many medium, few coarse roots; many very fine and fine, common medium interstitial pores; pH 6.0; clear smooth boundary.
- Bw1 5 to 12 inches; yellowish brown (10YR 5/4) very bouldery sandy loam, dark yellowish brown (10YR 4/4) moist; weak fine and medium subangular blocky structure; soft, very friable, nonsticky and nonplastic; 20 percent gravel, 15 percent cobbles, 10 percent stones, 10 percent boulders; many very fine, few fine, many medium roots; common very fine, few fine interstitial pores; pH 6.0; gradual smooth boundary.
- Bw2 12 to 30 inches; yellowish brown (10YR 5/4) very stony sandy loam, dark yellowish brown (10YR 4/4) moist; weak fine subangular blocky structure; soft, friable, nonsticky and nonplastic; 20 percent gravel, 15 percent cobbles, 10 percent stones, 5 percent boulders; few very fine roots; common very fine and fine interstitial pores; pH 6.0; abrupt wavy boundary.
- R 30 inches; granitic bedrock.

Observed Characteristics: Depth to hard bedrock ranges from 22 to 36 inches. Rooting depth ranges from 12 to 31 inches. Texture of the A horizon is very bouldery sandy loam, very stony sandy loam, or cobbly loam. The A horizon is 5 to 10 percent gravel, 2 to 15 percent cobbles, 3 to 20 percent stones, and 5 to 20 percent boulders. The pH of the A horizon ranges from 5.0 to 6.0. Texture of the Bw horizons is very bouldery sandy loam, very stony sandy loam, or very cobbly sandy loam. The Bw horizons are 15 to 20 percent gravel, 10 to 15 percent cobbles, 5 to 20 percent stones, and 5 to 10 percent boulders. The pH of the Bw horizons ranges from 4.5 to 6.0. A C horizon with a texture of very stony sandy loam, extremely bouldery sandy loam, or very gravelly sandy loam is present in some pedons.

Plant Community Composition (n=5)

Common Name	Code	Const.	Cover	Const.	Cover	Ecological Role
<u>Overstory</u>						
Trees						
Whitebark pine	PIAL	100	6	100	18	Major climax dominant
Tall lodgepole pine	PICOL	20	2	20	8	Incidental to minor seral
<u>Understory</u>						
Shrubs:						
Grouse whortleberry	VASC	80	18			Major climax increaser, resprouts after fire
Alpine prickly currant	RIMO2	20	3			Minor climax increaser
Perennial grasses						
Wheeler's bluegrass	PONE	100	5			Minor climax decreaser, rhizomatous
Spike trisetum	TRSP2	60	2			Minor climax decreaser
Slender bluegrass	POGR	20	1			Minor climax
Sandberg bluegrass	POSEI	20	1			Minor climax
Sedges and rushes						
Ross' sedge	CARO5	40	4			Minor climax, increases fire, grazing, or mechanical disturbance
Parry's rush	JUPA	40	3			Minor climax increaser
Sedge	CAREX	20	1			Minor climax
Rush	JUNCU	20	1			Minor climax
Perennial forbs						
Pussytoes	ANTEN	100	1			Minor climax, increases on bared soil
Heartleaf arnica	ARCO9	80	2			Minor climax increaser, rhizomatous
Varileaf cinquefoil	PODI2	60	1			Minor climax increaser
Aster	ASTER	40	2			Minor climax increaser, often rhizomatous
Western yarrow	ACMIL3	40	1			Minor climax increaser
Fireweed	EPAN2	40	1			Seral, increases after fire
Lupine	LUPIN	20	6			Seral increaser

Common Name	Code	Const.	Cover	Const.	Cover	Ecological Role
Pale agoseris	AGGL	20	3			Minor climax decreaser
Rydberg's arnica	ARRY	20	3			Minor climax increaser, rhizomatous
Manyray goldenrod	SOMUS	20	2			Minor climax increaser
Sulphur buckwheat	ERUM	20	1			Minor climax, increases on bared soil
Fleabane	ERIGE2	20	1			Minor climax increaser
Ballhead sandwort	ARCO5	20	1			Minor climax, increases on bared soil

Const. = Constancy, the percentage of plots in which a species is present.

Cover = The mean cover of a species for the plots in which it is present.

Similar Ecological Types

The PIAL/VASC, Ivywild Family ET is similar to other ETs on Ivywild Family soils.

No other ETs have been defined with the PIAL/VASC p.a. Other ETs on Ivywild

Family soils differ from the PIAL/VASC, Ivywild Family ET as follows:

The ABLA-PIEN/VASC, Ivywild Family has (1) Subalpine fir or Engelmann spruce as the climax dominant tree, and (2) no lodgepole pine.

The ABLA/ARCO9, Ivywild Family has (1) Subalpine fir as the climax dominant tree, (2) lower elevations, and (3) an understory represented by heartleag arnica.

The ABLA/VASC, Ivywild Family has (1) subalpine fir as the climax dominant tree, and (2) lower elevations.

Associated Ecological Types

The PIAL/VASC, Ivywild Family ET is associated primarily with ETs within the ABLA/VASC p.a. and the ABLA/PIEN/VASC group with well drained, loamy-skeletal soils. It is also an association with rock outcrop. The table below lists the ETs that occur as map unit components within the geographic extent of this ET and the area in which each is associated with this ET.

Associated Ecological Types	Acres	Percent Co-occurrence
Rock Outcrop	44,696	84%
ABLA/VASC, Jeru Family ET	30,820	58%
ABLA-PIEN/VASC, Ivywild Family ET	13,876	26%
ABLA-PIEN/VASC, Boze Family ET	8,784	16%
DECE, Oxyaquic Cryumbrepts, C-L Family, D, MW ET	8,784	16%

Map Unit Description

MAP UNIT: 2345

Subsummit Moraines, Spruce/Fir – Whitebark Pine – Meadow Complex

MAP UNIT COMPOSITION

This map unit is a mosaic of coniferous forests and meadows on benches, roche moutonnées, ground moraines, and benches. The ABLA-PIEN/VASC, Boze Family ET occurs on benches and roche moutonnées and mountain slopes. The PIAL/VASC, Ivywild Family ET occurs on similar landforms with southerly aspects. The DECE, Oxyaquic Dystrocryepts, C-L Family, D, MW ET occurs on lower backslopes, footslopes, and toeslopes of ground moraines.

35 Percent – ABLA-PIEN/VASC (subalpine fir – Engelmann spruce/grouse whortleberry), Boze Family ET

25 Percent – PIAL/VASC (whitebark pine/grouse whortleberry), Ivywild Family ET

25 Percent – DECE (tufted hairgrass), Oxyaquic Dystrocryepts, C-L Family, D, MW ET

15 Percent – Minor Components

SETTING

Hierarchy of Ecological Units: The Subsummit Uplands Subsection.

General Location: Sandpoint Lake south to Poston Lake.

Elevation: Full Range: 9,500 to 10,800 feet
80 Percent Range: 9,600 to 10,400 feet
Annual Precipitation: 29 to 36 inches
Areal Extent: 8,800 acres

Slope: 0 to 25 percent

Aspect: Dominantly southwest, minor east, northwest, and flat

COMPONENT DESCRIPTIONS

ABLA-PIEN/VASC, Boze Family ET Component

Potential Natural Vegetation: ABLA-PIEN/VASC group. This includes plant communities in which either subalpine fir or Engelmann spruce dominate at climax and the understory is dominated by grouse whortleberry. The ABLA-PIEN/VASC group is not expected to occur below 9,700 feet. Below this elevation, the ABLA/VASC.p.a. is expected to occur.

Landform: Roche moutonnées, benches, and ground moraines on glacial mountain slopes.

Primary Lithology: Unconsolidated.

Secondary Lithology: Glacial till desposit, colluvium, and residuum. Colluvium, residuum, and glacial till are derived from Early to Late Archean granite, granite gneiss, and granodiorite.

Colluvium occurs predominantly as slopewash, with some areas of talus and scree deposits. Glacial till is dominantly Late Wisconsin (Pinedale) age. Higher elevations may have Holocene (Neoglacial) till present.

Parent/Surficial Material Size Class: Bouldery.

Bedrock

Primary Lithology: Igneous Intrusive, Metamorphic

Secondary Lithology: Granite, granodiorite, gneiss. Bedrock includes some areas of diorite, quartz diorite, amphibolite, and/or quartzite.

Soil Name: Boze Family.

Classification: Coarse-loamy, mixed, superactive Oxyaquic Dystrocryepts.

Landform Position: bench.

Depth: 28 inches to a dense layer, and more than 40 inches to bedrock.

Drainage Class: Well drained.

Permeability: 0.6 to 2.0 inches per hour.

Available Water Capacity (AWC): 2.6 inches to dense layer.

Reference Pedon: O2302B.

PIAL/VASC, Ivywild Family ET Component

Potential Natural Vegetation: PIAL/VASC p.a. This includes plant communities in which whitebark pine is the climax dominant tree and the understory is dominated by grouse whortleberry.

Landform: Roche moutonnées, benches, and ground moraines on glacial mountain slopes.

Primary Lithology: Unconsolidated.

Secondary Lithology: Glacial till desposit, colluvium, and residuum. Colluvium, residuum, and glacial till are derived from Early to Late Archean granite, granite gneiss, and granodiorite.

Colluvium occurs predominantly as slopewash, with some areas of talus and scree deposits. Glacial till is dominantly Late Wisconsin (Pinedale) age. Higher elevations may have Holocene (Neoglacial) till present.

Parent/Surficial Material Size Class: Bouldery

Bedrock

Primary Lithology: Igneous Intrusive, Metamorphic.

Secondary Lithology: Granite, granodiorite, gneiss. Bedrock includes some areas of diorite, quartz diorite, amphibolite, and/or quartzite.

Soil Name: Ivywild Family.

Classification: Loamy-skeletal, mixed, superactive Typic Dystrocryepts.

Landscape Position: Narrow bench.

Depth: 31 inches.

Drainage Class: Well drained.

Permeability: 2.0 to 6.0 inches per hour.

Available Water Capacity (AWC): 1.6 inches.

Reference Pedon: O2109B.

DECE, Oxyaquic Dystrocryepts, C-L Family, D, MW ET Component

Potential Natural Vegetation: DECE community type (c.t.) This includes herbaceous riparian communities characterized by tufted hairgrass.

Landform: Roche moutonnées, benches, and ground moraines on glacial mountain slopes.

Primary Lithology: Unconsolidated.

Secondary Lithology: Glacial till desposit, colluvium, and residuum. Colluvium, residuum, and glacial till are derived from Early to Late Archean granite, granite gneiss, and granodiorite.

Colluvium occurs predominantly as slopewash, with some areas of talus and scree deposits. Glacial till is dominantly Late Wisconsin (Pinedale) age. Higher elevations may have Holocene (Neoglacial) till present.

Parent/Surficial Material Size Class: Bouldery.

Bedrock

Primary Lithology: Igneous Intrusive, Metamorphic.

Secondary Lithology: Granite, granodiorite, gneiss. Bedrock includes some areas of diorite, quartz diorite, amphibolite, and/or quartzite.

Soil Name: Oxyaquic Dystrocryepts, C-L Family, D, MW.

Classification: Coarse-loamy, mixed, superactive Oxyaquic Cryumbrepts.

Landscape Position: Toeslope.

Depth: More than 40 inches.

Drainage Class: Moderately well drained.

Permeability: 2.0 to 6.0 inches per hour.

Available Water Capacity (AWC): 3.3 inches.

Depth to Seasonal High Water Table: 21 inches.

Reference Pedon: Q2309B.

Minor Components

Rock outcrop.

The ABLA-PIEN/VASC (subalpine fir-Engelmann spruce/grouse whortleberry) group on soils similar to the Boze Family, except with a greater percentage of rock fragments in the subsoil.

The PIAL/VASC (whitebark pine/grouse whortleberry) p.a. on soils similar to the Ivywild Family, except with a thicker and/or darker surface layer.

The DECE (tufted hairgrass) c.t. on soils that are less than 40 inches deep to bedrock or a dense layer.

Areas of sedges on wet soils.

Appendix G. List of Reviewers

The following individuals contributed significant comments and edits:

Region 1

John Lane, Soil Scientist, Custer National Forest (NF), Billings, MT
Jeff Dibenedetto, Ecologist, Custer NF, Billings, MT
Mary Manning, Regional Ecologist, Missoula, MT
John Nesser, Regional Soil Scientist (retired), Missoula, MT
Henry Shovic, Soil Scientist, Gallatin NF, Bozeman, MT
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Angela Parker, Zone Silviculturist, Pike and San Isabel NF, Salida, CO

Region 3

Wayne Robbie, Supervisory Soil Scientist, Albuquerque, NM
Steve Strenger, Soil Scientist, Albuquerque, NM
George Robertson, Supervisory Soil Scientist, Phoenix, AZ

Region 4

Don Fallon, NRIS Terra Module Coordinator, Ogden, UT
Dave Tart, Ecologist, Ogden, UT
Clint Williams, Timber Planning Analyst, Ogden, UT
Jeff Bruggink, Regional Soil Scientist, Ogden, UT
Darlene Koerner, Ashley NF Soil Scientist, Vernal, UT
Sherel Goodrich, Ashley NF Ecologist, Vernal, UT

Region 5

Alan Gallegos, Assistant Province Geologist, Clovis, CA
John Chatoian, Regional Geologist, Vallejo, CA
Sydney Smith, Ecologist, Modoc/Lassen/Plumas NFs, Sonora, CA
Don Potter, Ecologist, Stanislaus NF, Sonoma, CA
Denise Downie, Soil Scientist/Operations Hydrologist, Region 5, Lake Tahoe Basin Management Unit, Lake Tahoe, CA
Max Creasy, Ecologist, Happy Camp R.D., Klamath NF, Yreka, CA

Region 6

Tom DeMeo, Ecologist, Portland, OR
Duane Lammers, Assistant Regional Soil Scientists, Corvallis, OR
Jim Dorr, Soil Scientist, Winema NF, Lakeview, OR
Carl Davis, Soil Scientist, Okanogan and Wenatchee NF, Wenatchee, WA

Region 8

Tom Arnold, Soil Scientist (retired), Atlanta, GA
Wayne Owen, Regional Plant Ecologist, Atlanta, GA
David Meriwether, Ecosystem Management Coordinator, Atlanta, GA
James D. Brown, Forester, Francis Marion & Sumter NFs, Columbia, SC

Region 9

Greg Nowacki, Regional Ecologist, Milwaukee, WI
Larry Laing, Regional Soil Scientist, Milwaukee, WI
Eunice Padley, Regional Ecologist, Milwaukee, WI

Region 10

Terry Brock, Regional Soil Scientist (retired)
Patti Krosse, Tongass Ecology and Botany Program Manager, Ketchikan, AK

Washington Office

John Haglund, Ecologist, NRIS Terra, Sandy, OR
Martin Ferwerda, Soil Scientist, NRIS Terra, Sandy, OR
Andy Rorick, Geologist, NRIS Terra, Sandy, OR
Sheila Logan, NRIS Terra Resource Group Leader, Sandy, OR
Don Haskins, NRIS Terra Technical User Support Group Leader, Sandy, OR
Paul Maus, Remote Sensing Specialist, Remote Sensing Applications Center,
Salt Lake City, UT
Michael Williamson, Remote Sensing Specialist, Remote Sensing Applications
Center, Salt Lake City, UT
Haans Fisk, Remote Sensing Specialist, Remote Sensing Applications Center,
Salt Lake City, UT

Davis, Randy L., Soil Scientist, Watershed, Fish, and Wildlife Staff, Washington, DC

Keys, Jim, National Coordinator for Integrated Inventories, Ecosystem Management
Coordination Staff, Washington, DC

Research

Dave Cleland, Ecologist, North Central Research Station, Rhinelander, WI

Agencies

The National Soil Survey Center, Natural Resources Conservation Service, Lincoln,
NE

Appendix H. Field Equipment

Equipment List

Clinometer	Spade
Compass	Camera
Diameter tape	Backpack
Hand lense	Global Positioning System
Increment bore	Densitometer
Munsell soil color chart	First Aid kit
Notebook (write in rain)	Flagging
PH kit	Auger
Plant press	Soil thermometer
Prisim	Hard hat
Sieve	Tatums (clipboards)
Soil boxes	Stereoscope
Soil knife	Shovel
Soil sample bags	Field vest

Supply Sources

Suppliers

Forestry Suppliers, Inc.
Box 8397
205 West Rankin St.
Jackson, MS 39284–8397

Ben Meadows Company
<http://www.benmeadows.com>
A Division of Lab Safety Supply Inc.
P.O. Box 5277
Janesville WI 53547–5277
1–800–241–6401

Soiltest Products Division
ELE International
P.O. Box 8004
86 Albrecht Drive
Lake Bluff, IL 60044-8004

Magellan Systems Corporation
260 East Huntington Drive
Monrovia, CA 91016
John Michaels 818-358-2363

Trimble Navigation, Ltd.
645 North Mary Avenue
P.O. Box 3642
Sunnyvale, CA 94088-3642
408-730-2900

The sources indicated herein are in no way endorsed by the Government as being the preferred vendor of choice. Proposed acquisitions by the Government shall be in accordance with the applicable Federal Acquisition Regulations and in full compliance with the Competition and Contracting Act and Procurement Integrity Act.

Appendix I. Personnel Requirements

Terrestrial Ecological Unit Inventory Specialist Job Description

Ecologist, GS-408-11

Soil Scientist, GS-470-11

Geologist, GS-880-11

Introduction

This position is located at a Terrestrial Ecological Unit Inventory (TEUI) Center. The incumbent serves as a technical expert in soils, ecology, geology, and related disciplines for the Inventory Center, and develops the TEUI on one to four national forests.

Incumbent will also ensure that the development of the TEUI is consistent with the *TEUI Technical Guide*. Incumbent works with the forest(s) in developing management interpretations and applications for the TEUI information.

Major Duties

1. Supplies all land surface (soils, geology, potential natural vegetation, and landform) information to the TEUI, including both photo interpreting and field verifying information on landform, soil, potential natural vegetation, and geology/parent material.
2. Conducts ecological inventory of soil, vegetation, and other environmental components of TEUI from which an ecological classification and mapping system is developed to produce useful land management and planning information. This activity requires intensive field sampling, mapping, and computerized analysis. The classifications of the TEUI and mapping information are used for indexing ecological information, inventory, data storage, and retrieval. Provides technical expertise in managing and analyzing this information, including entering and managing digital data in a Geographic Information System (GIS) environment.
3. Keeps abreast of the latest information relative to soil taxonomy, ecological classifications (including plant associations and integrated landform classifications), models, and evaluation methods to ensure adoption and application of new technology and theories.
4. Ensures consistency and quality of the TEUI. Focuses on the timeline of the inventory, ensuring completion of the workplan. Takes corrective action to ensure that policies,

plans, and prescribed budget are followed within predetermined flexibility limitations. Participates in quality control reviews as well as general management reviews of the inventory.

5. Works to integrate aquatic information and existing vegetation into inventory design and, where possible, polygon structure or appropriate modeling techniques. Establishes and maintains an atmosphere of complete cooperation with forest and District soil, ecology, and geology specialists. Cooperates with the Regional Office in the further refinement of inventory procedures. Formulates and recommends changes to the *TEUI Technical Guide*. Coordinates with other Inventory Centers around the Region to assure consistency and quality be maintained on a Regionwide basis.
6. Responsible for working with forest and District specialists to develop interpretations and applications of the TEUI information for land management planning and ecosystem management.

Factor 1. Knowledge Required by the Position

Professional knowledge and experience in soil classification, soil mapping, soil correlation, development of report interpretations, and report writing, which are used in completing soil resource inventories.

Professional knowledge and experience in plant association classification, and potential natural vegetation mapping and modeling. Development of report interpretations and report writing, which are used in completing plant association classification and resource inventories.

Mastery of advance concepts, principles, and practices of natural resources, databases, and the GIS environment sufficient to conduct an inventory based on the integration of ecosystem elements. Good working knowledge of related fields, such as hydrology, forestry, engineering, wildlife, fisheries, and ecology to coordinate ecological relationships.

Initiative and creativity in developing new approaches, methodologies, and techniques to meet target demands with limited funding and personnel ceilings.

Factor 2. Supervisory Controls

The Inventory Center leader will be the immediate supervisor and will provide administrative leadership and guidance in significant policy matters and coordination on a Regionwide basis. Functions with independence in reaching decisions. The incumbent clears with the supervisor approaches that have potential policy impacts. Results are

reviewed by the supervisor and the Regional Office TEUI Coordinator. Performance is determined by these results.

Factor 3. Guidelines

The basic guides are the broad policies and objectives of the Forest Service and the broad policies of the National Cooperative Soil Survey as contained in the *National Soil Survey Handbook* (USDA NRCS 2003b) and the *Soil Survey Manual* (USDA NRCS 1993). Regional Guides, forest plans, applicable regulations, recognized standards, and administrative knowledge and training act as day-to-day guidelines.

Sound professional judgment, ingenuity, and resourcefulness are required. The incumbent will follow the *TEUI Technical Guide*. Many different situations will be encountered. Incumbent is expected to assist in developing new methods and procedures, to identify the latest technical concepts and practices, and to incorporate them in the inventory procedures.

Factor 4. Complexity

The assignment requires sound professional knowledge of plant and soil interactions, soil series, and plant associations. Must have a basic understanding of geology, geomorphology, climate, and vegetative characteristics. The assignment includes analysis of an extremely complex interaction of abiotic factors and flora along with cooperating with the Districts, forests, Regional Office, and other Inventory Centers.

The work assignment will require the incumbent to relate new work situations to precedent situations, to extend or modify existing techniques, and to adequately solve problems. Incumbent will work with the forests to develop management interpretations and applications for the information. Occasionally, the assignments require substantial effort to overcome resistance to change when it is necessary to modify an accepted method or approach.

Factor 5. Scope and Effect

The work associated with this position is primarily to carry out the complete classification and inventory of landforms, soils, potential natural vegetation, and geology/parent material on one to four national forests. The results of this work will have a significant effect on preparing the forests for a GIS and ecosystem management.

Factor 6. Personal Contacts

Contacts help develop new ideas and procedures, validate existing procedures, and complete the development, testing, and implementation of the TEUI on one to four forests and within the Region.

Factor 7. Purpose of Contacts

Contacts help develop new ideas and procedures, validate existing procedures, and complete the development, testing, and implementation of the TEUI on one to four forests and within the Region.

Factor 8. Physical Demands

Demands range from sedentary work seated in an office using stereoscopes to the rigorous physical exertion of walking in rugged terrain and streams. Physical exertion will include hiking, climbing, riding horses, and driving all-wheel vehicles over unimproved roads.

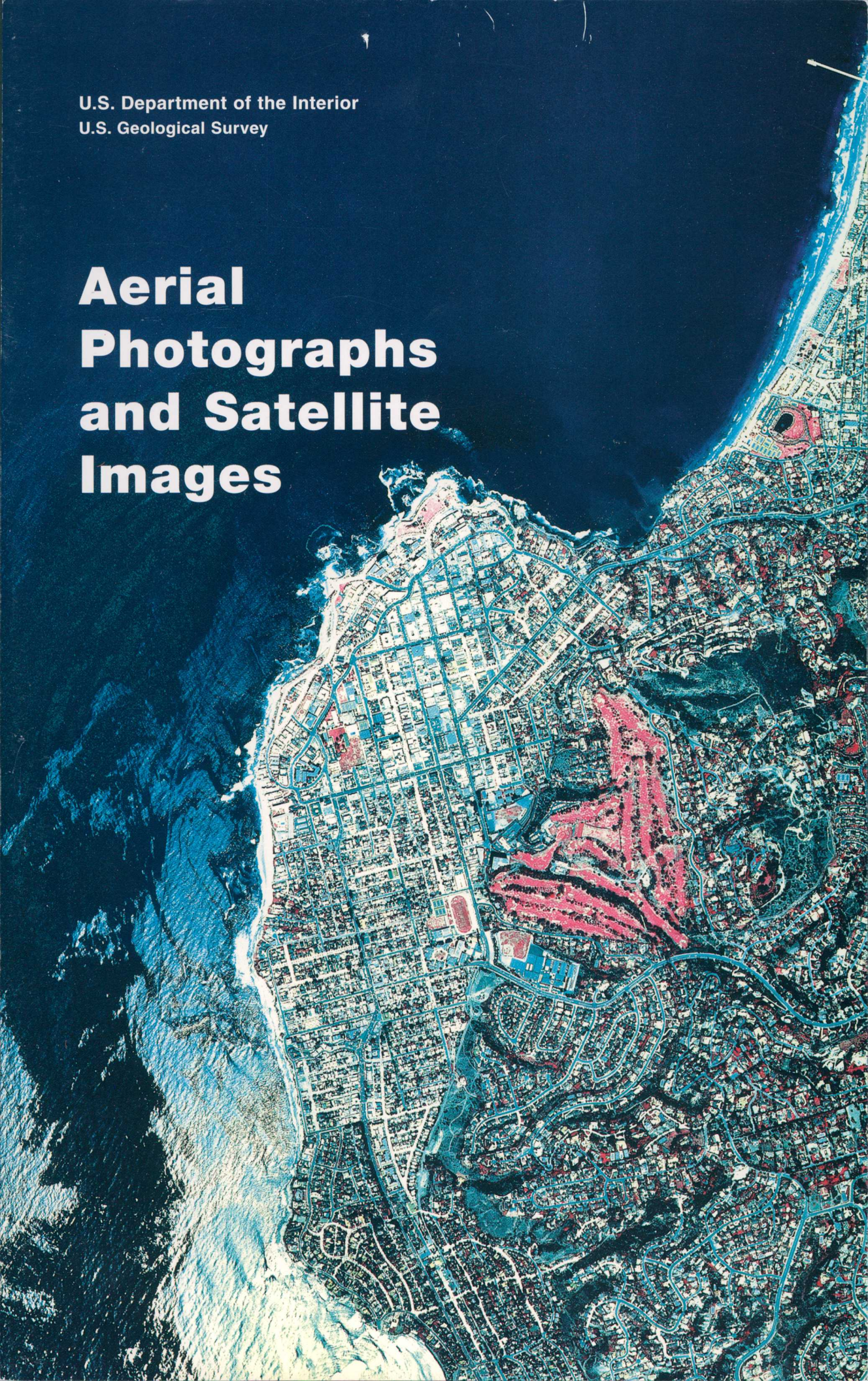
Factor 9. Work Environment

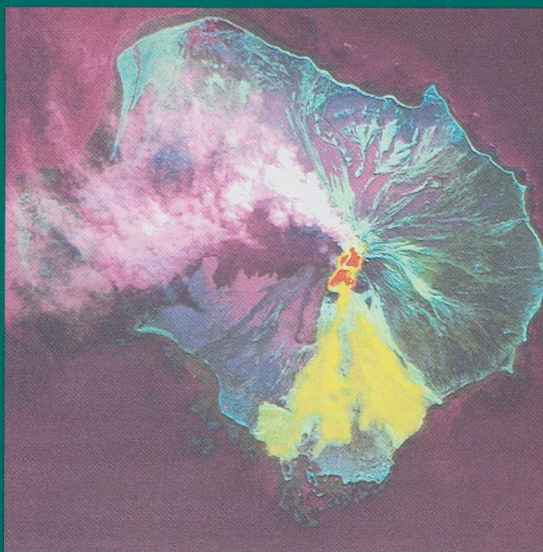
Routine office work is performed in a normal office setting. Work requires exposure to some risks involved in logging operations, firefighting, and walking or riding in isolated country, sometimes in adverse weather conditions. Safety precautions are required and the employee must wear protective equipment while making on-the-ground inspections.

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U.S. Department of the Interior
U.S. Geological Survey

Aerial Photographs and Satellite Images





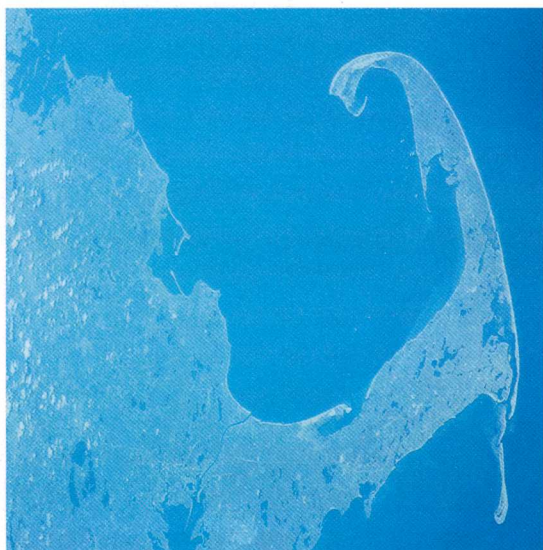
E-1708-99CT

Augustine Volcano, Alaska, Landsat 5 TM,
April 1986. (Reduced to 75 percent)

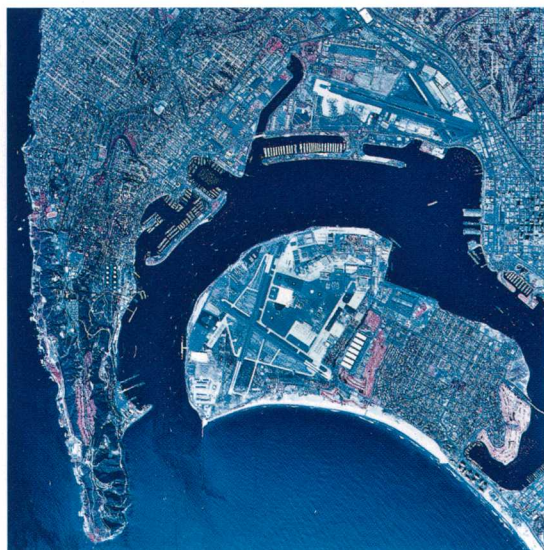
Cover: La Jolla, Calif., NAPP color infrared,
original scale:1:40,000, September 1990.
NAPP Roll 1854, Frame 40

Unless otherwise noted, all images in this
booklet have been reduced 50 percent.

E-1337-99CT



Cape Cod, Mass., space shuttle photograph, April 1981.



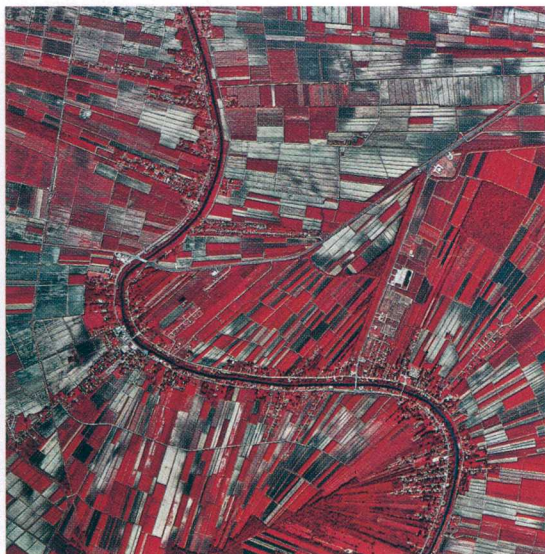
NHAP 84 Roll 305, Frame 32

San Diego, Calif., NHAP color infrared, original scale: 1:58,000, February 1985.

Aerial Photographs and Satellite Images

Photographs and other images of the Earth taken from the air or from space afford valuable information about the planet; its landforms, vegetation, and resources. Aerial and satellite images permit researchers to see and accurately map patterns of land use that otherwise are not readily visible from the ground. Transient phenomena such as ocean currents or pollution discharges can be studied. The aerial perspective allows us to see landscape features on regional, continental, or even global scale.





Bayou Laforche, La., NAPP, color infrared, original scale: 1:40,000, October 1990.

The U.S. Geological Survey and Remote Sensing

Because photographs and images taken from the air or from space are acquired without direct contact with the ground, they are referred to as remotely sensed images. The U.S. Geological Survey (USGS) has used remote sensing from the early years of the 20th century to support earth science studies and for mapping purposes.

The USGS began using aerial photographs for mapping in the 1930's. Successive aerial photographs can be overlapped, and using a



Horseshoe Falls (Niagara Falls), N.Y. and Canada, looking South, low oblique (scale will vary), EPA, July 1989.

stereoscope, can be made into contour maps. Although aerial photographs from earlier decades are scarce, the USGS archives photographs from its mapping projects and from national programs.

Photographs and some images from U.S. space programs such as the Landsat program, begun in 1972, are also held by the USGS. Most Landsat scenes can only be obtained in digital form for use in computer-based image processing and geographic information systems or as film positives or negatives.

This booklet discusses some characteristics of aerial photographs and satellite images and the types of images that are available from the USGS.

How Images Are Classified

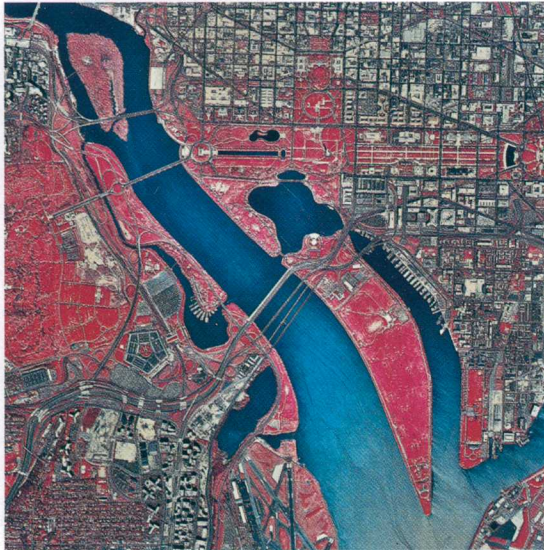
Images taken from above the Earth are usually categorized according to the altitude of the aircraft or spacecraft, the type of image medium, and the type and characteristics of the sensor.

Altitude

Manned or unmanned spacecraft usually collect images from altitudes greater than 150 miles. Aircraft commonly operate at altitudes from 5,000 to 60,000 feet. The height from which a photograph or image is taken and the physical characteristics of the sensor, including the focal length, largely determine the area covered and the amount of detail shown in a remotely sensed image. In general, the level of detail is the greatest in low-altitude photographs that cover relatively small areas. Satellite images cover larger areas but show less detail.

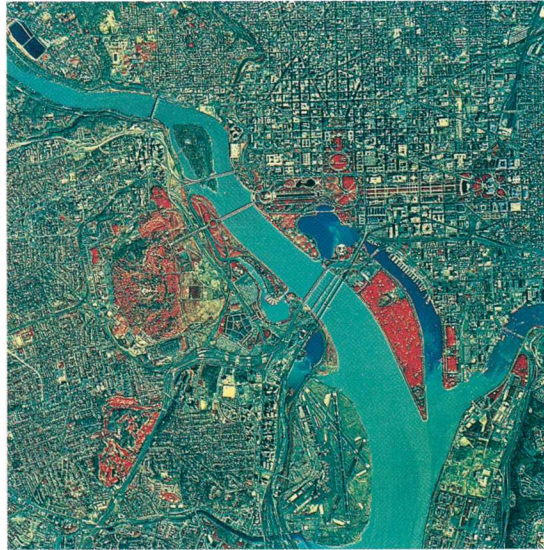
Views of the same area from progressively higher altitudes

NAPP Roll 4, Frame 78



Medium altitude aerial photograph of Washington, D.C., NAPP, color infrared, original scale: 1:40,000, April 1988.

NHAP 80 Roll 581, Roll 27



High altitude aerial photograph of Washington, D.C., NHAP, color infrared, original scale: 1:58,000, March 1982.

E-1488-99CT



Washington, D.C. and vicinity, Landsat 5 TM, January 1984.

LM85205115114X0



Washington, D.C. and vicinity, Landsat MSS, October 1989.

Comparison of four types of image media of the same area

NAPP Roll 1840, Frame 170



Los Angeles, Calif., NAPP, black and white, original scale: 1:40,000, August 1989.

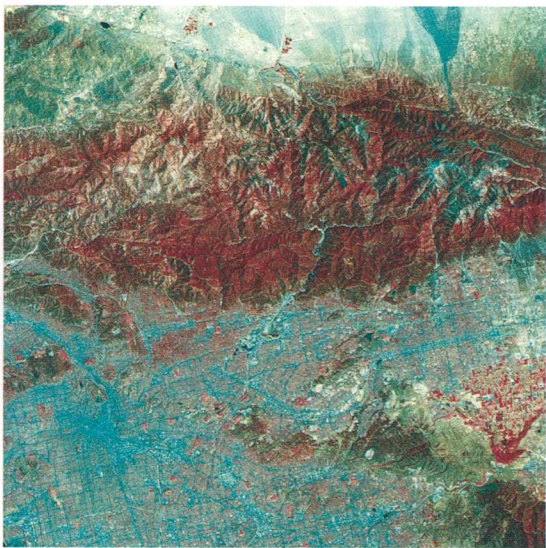


Los Angeles, NASA Ames U-2, natural color, scale: 1:128,000, January 1988.

NAPP Roll 1840, Frame 170



Los Angeles, NAPP, color infrared, original scale: 1:40,000, August 1989.



Los Angeles, Landsat TM, November 1987.

AB58800369 ROLL Frame 1265

E-1702-99CT

Image media

Aerial photographs are produced by exposing film, an image medium, directly to solar energy reflected from the Earth. Photographic film has been used for aerial reconnaissance, for both military and civilian purposes, since the middle of the 1860's. Black-and-white film was used at first; color film became widely used in the 1950's.

Color-infrared film, which records energy from portions of the electromagnetic spectrum invisible to the human eye, was developed to detect camouflaged military installations in the 1940's. In a color-infrared (also known as a false-color) photograph, near-infrared light reflected from the scene will show as red, red will show as green, green as blue, and blue as black. Color-infrared film is useful for distinguishing between healthy and diseased vegetation, for delineating bodies of water, and for penetrating atmospheric haze.

Black-and-white and color-infrared films are used today in both high- and low-altitude aerial photography. Natural-color film is used more rarely.

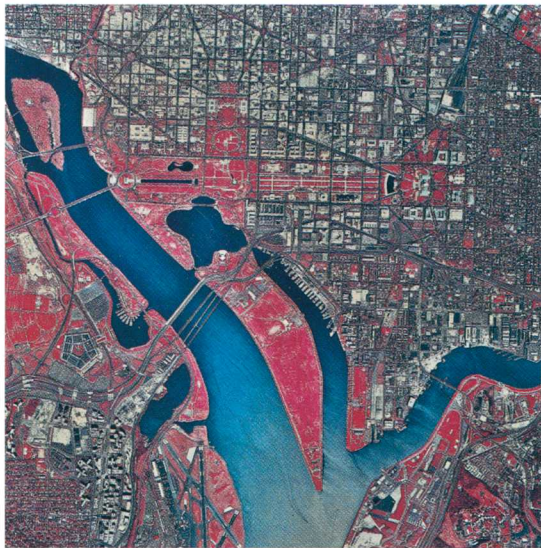
Sensors

Cameras of various types are used to take aerial photographs. Cameras can be carried on aircraft or on such spacecraft as the space shuttle. Satellites commonly use electronic scanners to record ground scenes in digital, or computer-readable, form. Aircraft can also carry electronic scanners. Sensors can be passive; that is, recording radiation reflected from the Earth, or active, generating their own energy. A camera is passive; so are the sensors used aboard the Landsat satellites. These sensors record reflected energy in the visible, infrared, and thermal portions of the spectrum. Satellite data are displayed as images whose colors resemble color-infrared aerial photographs, but the colors of a given image can be manipulated by computer to enhance landscape features.

Side-looking airborne radar (SLAR) instruments on aircraft or satellites generate their own energy and record the amount of energy reflected back to them from the ground.



Original scale



2x enlargement

Overall size

These images represent the three standard paper print sizes for aerial photographs available from the USGS. The standard contact print size is 9 by 9 inches. Enlargements to 18 by 18 inches (2x), and 36 by 36 inches (4x) can also be ordered. In this scene of Washington, D.C., the 9-inch contact print (upper left) represents the original scale of 1:40,000, where 1 inch on the image represents approximately 3,333 feet on the ground. The 18-inch print (above) represents a 2x enlargement with a scale of 1:20,000, where 1 inch on the image represents approximately 1,666 feet on the ground. The 36-inch print (right) represents a 4x enlargement with a scale of 1:10,000, where 1 inch on the image represents approximately 833 feet.

NAPP Roll 4, Frame 78



4x enlargement

NAPP Roll 511, Frame 159



Golden Gate Bridge, San Francisco, Calif., NAPP color infrared, original scale: 1:40,000, June 1987.

NAPPW Roll 6365, Frame 36



Golden Gate Bridge, NAPP black and white, original scale: 1:40,000, August 1993.

Aerial Photographs

Various types of aerial photographs are archived by the USGS. Although the USGS has used aerial photographs for many decades, the availability of photographs from the earliest years is limited. Most recent photographs are from national programs and were taken at relatively high altitudes with predominately black-and-white or color-infrared film.

NHAP 82 Roll 261, Frame 130

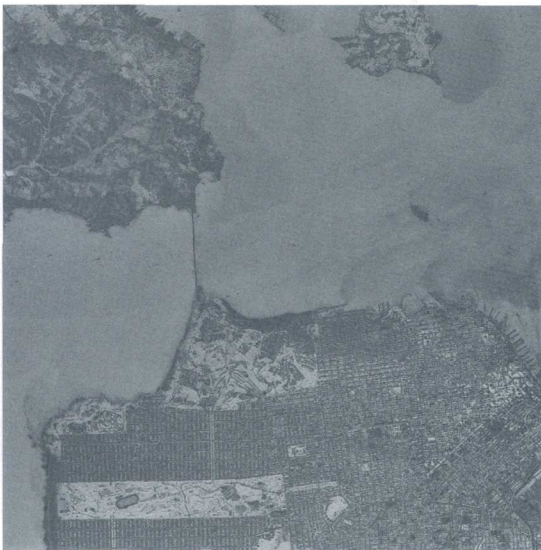


Golden Gate Bridge, NHAP color infrared, original scale: 1:58,000, August 1982.

National Aerial Photography Program

The National Aerial Photography Program (NAPP) was established in 1987 to coordinate the acquisition of aerial photographs for the United States among Federal and State agencies. NAPP photographs are used for mapping, resource planning, land management, and agricultural monitoring. Taken from aircraft flying nominally at 20,000 feet above the terrain, each NAPP photograph covers about 32 square miles of ground. Black-and-white and color-infrared photographs are available from the NAPP program.

NHAP 82 Roll 252, Frame 58



Golden Gate Bridge, NHAP black and white, original scale: 1:80,000, August 1982.

National High Altitude Photography Program

The National High Altitude Photography Program (NHAP) was a Federal project that preceded NAPP, running from 1978 to 1988. NHAP photographs were taken simultaneously with two cameras, one containing black-and-white film, the other color infrared. The NHAP aircraft flew at 40,000 feet above the terrain. These photographs cover more area, but show less detail, than NAPP photographs. An NHAP black-and-white photograph covers about 129 square miles, and because of the longer focal length in the second camera, an NHAP color-infrared photograph covers about 68 square miles.



Washington, D.C., section of a 1-m resolution, quarter-quadrangle digital orthophoto, date of photography-April 1988. (Reduced 30 percent)

Orthophotos and digital orthophotos

Orthophotos are prepared from perspective aerial photographs or digital representations of these photographs in which the displacements caused by differences in terrain elevations and camera tilt have been removed, giving the orthophoto the geometric characteristics of a map. That is, measurements of distances between points on an orthorectified aerial photograph can be made accurately because of the common scale of the new image. Because aerial photographs show the entire texture of the ground in much greater detail than do conventional line maps, orthophotos are useful for updating maps and in land studies. The USGS produces digital versions of orthophotos for map revision and for computer analysis using geographic information systems.

Aerial photographs from mapping programs

The USGS archives photographs used for making maps that are not associated with national programs. The mapping photographs of some other Federal agencies are also available. Some of these photographs date back to the 1950's. Most show more detail than NAPP and NHAP photographs. These mapping photographs may be in black and white or, in a few cases, in natural color.

Aerial photographs from the National Aeronautics and Space Administration (NASA)

NASA uses aerial photographs for research and to test remote sensing techniques and instruments. These photographs are available in various formats and were taken from altitudes of a few thousand feet up to 60,000 feet, although the majority were collected at the higher altitude. NASA aerial photographs are available in black and white, natural color, or color infrared, but only for certain areas. Digital multispectral scanner data are also available.

Manned spacecraft photographs

Photographs were acquired over limited areas of the Earth on NASA's Gemini (1965-66) and Apollo (1968-1969) missions. Three Skylab missions in 1973 and 1974 provided more than 35,000 photographs.

Astronauts aboard the space shuttle, which began flying in 1981, have taken many photographs of the Earth with hand-held cameras. The photographs from these missions document sites of scientific interest around the world and depict temporary phenomena such as hurricanes and erupting volcanoes. Most of these photographs are in natural color.

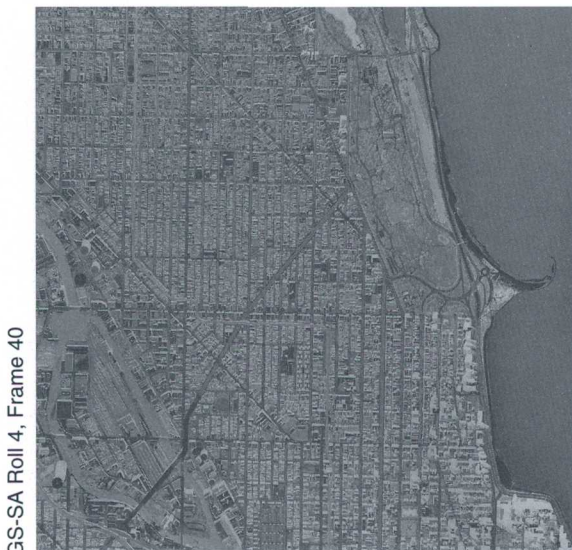
Aerial photographs from Government agencies

The Earth Resources Observation Systems (EROS) Data Center of the USGS stores negatives of aerial photographs from other

Federal agencies, including the Bureau of Land Management, the Bureau of Reclamation, the Bureau of Indian Affairs, NASA, and the former Departments of the Army, Navy, and Air Force. Copies of these photographs can be ordered directly from the USGS's Earth Science Information Centers.

Major metropolitan areas of the United States

Color-infrared aerial photographs of the central business districts of more than 100 cities in the United States are available. The photographs are selected largely from the NHAP program, prior to 1987, and were chosen for their high quality. Most of these photographs were taken with color-infrared film at a scale of 1:58,000 (1 inch equals about 0.9 miles or 1 centimeter equals about 0.6 kilometers).



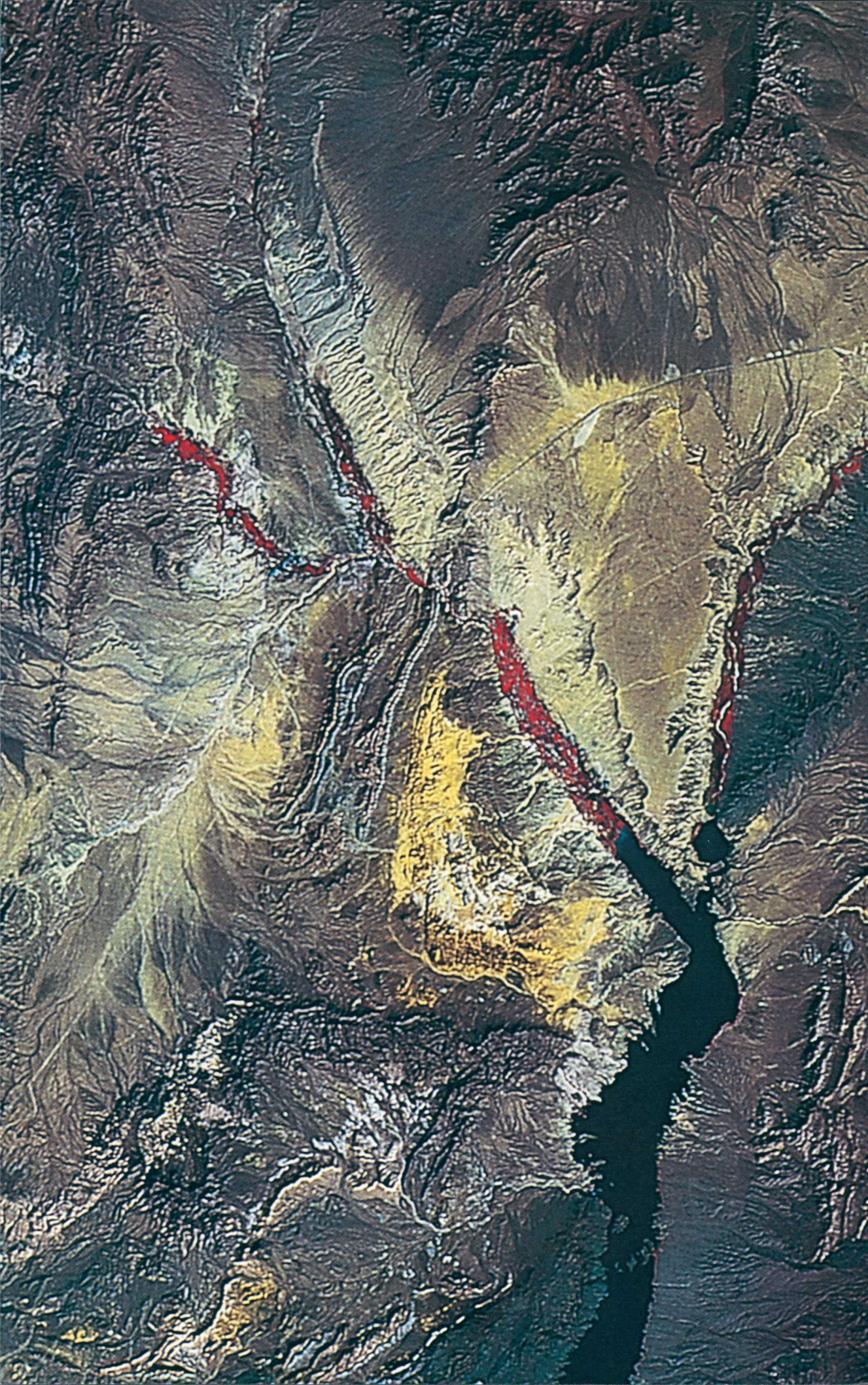
GS-SA Roll 4, Frame 40

Chicago, Ill. and Lake Michigan shoreline, USGS project, black and white, original scale: 1:23,600, March 1952.



E-1804-99CT

Hurricane Elena, space shuttle photograph over the Gulf of Mexico, September 1985.



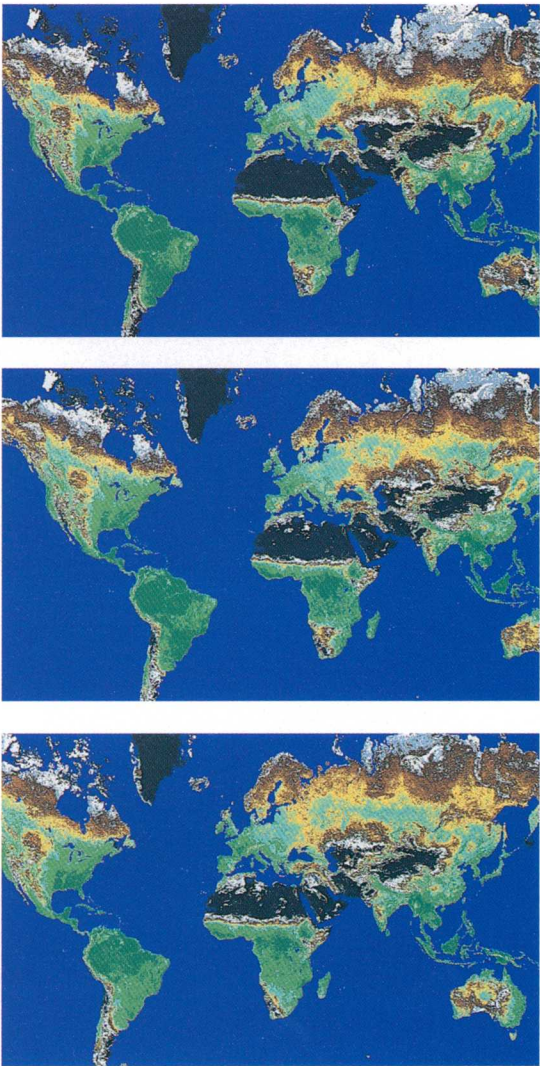
Satellite Images

The EROS Data Center processes and stores satellite data from several different types of satellites. The major types are described below.

The Landsat Program

In 1972, the United States launched its first Earth Resources Technology Satellite, ERTS-1, later renamed Landsat 1, for experimental global coverage of the Earth's land masses. Landsats, serially numbered, were launched in 1972, 1975, 1978, 1982, and 1984.

Data are collected by sensors that measure a range of wavelengths of electromagnetic energy reflected or emitted from the Earth. The broad wavelength bands are often from those parts of the electromagnetic spectrum outside the range of human eyesight, showing normally invisible land characteristics. The Landsat data are transmitted to Earth where they are processed by computers and archived.



Global summation of vegetation greenness index for calendar years 1986-1988 (black = low greenness, dark green = high greenness), from AVHRR data, source - NOAA. (Reduced to 87 percent)

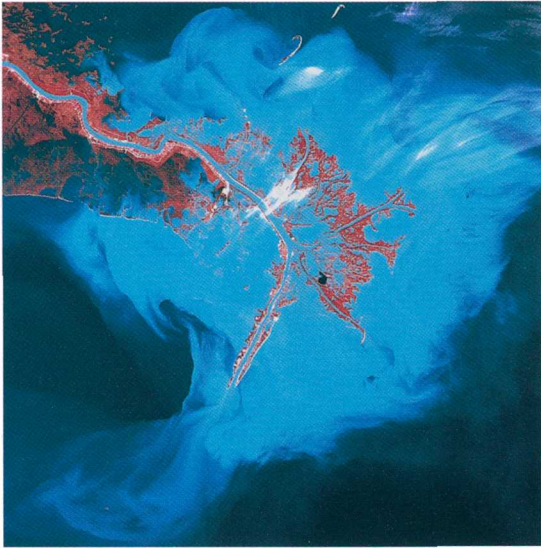
Background: Las Vegas, Nev., Landsat 4 TM, April 1983. (Enlarged 420 percent)
E-1469-99CT

E-1884-99CT

Landsats 1-5 have carried versions of a sensor called the multispectral scanner (MSS), which collects data simultaneously from four broad bands of the electromagnetic spectrum, from visible green through near-infrared wavelengths. The MSS images in this booklet have a picture element (pixel) resolution of 79 meters—that is, the height and width of each pixel correspond to 79 meters or about 259 feet on the ground. Landsats 1 and 2 also carried a sensor called the return beam videcon, or RBV, with high geometric accuracy but lower spectral detail than the MSS. Because of technical problems, RBV operations were limited and the sensors were not used on later spacecraft.

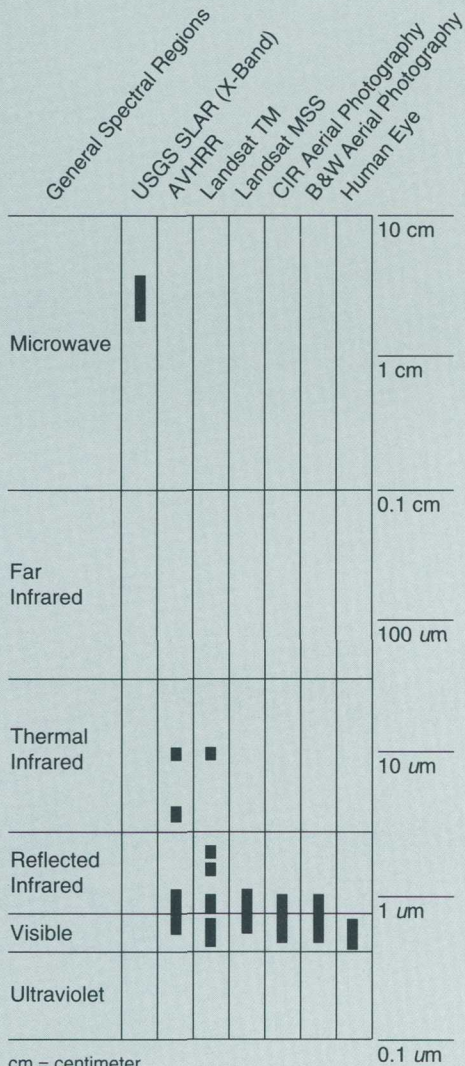
The thematic mapper (TM) sensor carried on Landsats 4 and 5, in addition to the MSS, gives higher resolution than the MSS, each pixel corresponding to 30 meters, or about 98 feet on the ground. The TM sensor also records a greater number of bands than the MSS, yielding more detailed spectral information. Landsat images can be processed to emphasize different features of the land, making such data especially useful for scientific studies.

Landsats 4 and 5 pass from north to south over the Equator at an altitude of 705 kilometers (438 miles) each day at about 10 a.m., and their orbits provide repeat coverage of the Earth, allowing the detection of changes. Cloud cover and the need to transmit data directly to a ground station affect the amount of acceptable continuous repeat coverage.



Comparison of Landsat MSS scenes of the Mississippi River Delta, January 16, 1973, and March 3, 1989. (Reduced to 68 percent)

Spectral Sensitivity of Remote Sensing Systems



cm = centimeter
 um = micrometer
 (1 um = 10⁻⁴ cm)
 (1000 um = 0.1 cm)



E-1879-88CT

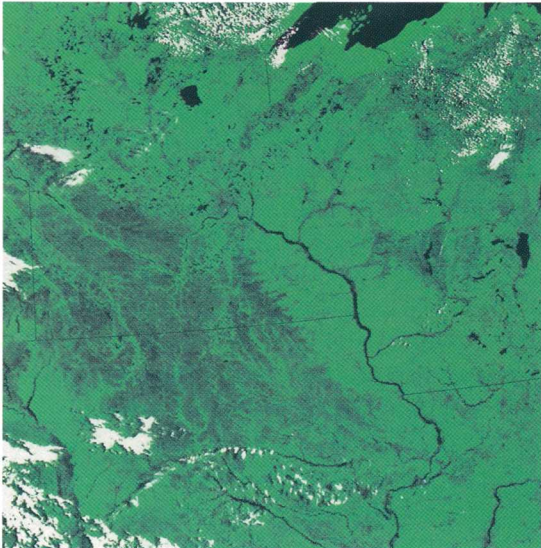
Greenness map, AVHRR, August 11-20, 1990.

Advanced very high resolution radiometer

The advanced very high resolution radiometer (AVHRR) is one of several sensors aboard meteorological satellites operated by the National Oceanic and Atmospheric Administration. AVHRR data are collected in the visible, near-infrared, and thermal-infrared portions of the electromagnetic spectrum at a resolution of 1.1 kilometer (about 0.68 of a mile). Two satellites each make about 14 passes over the Earth in a 24-hour period, one in the morning and one in the afternoon. Thus, data are collected more frequently than Landsat data, but with much coarser resolution and for much larger areas.

The EROS Data Center has been receiving and processing 1-kilometer resolution data from the AVHRR system since 1987 and using them for a variety of land applications, such as drought monitoring, fire fuel assessment, and land surface characterization. The use of these data for management purposes complements the traditional use of 4- and 16-kilometer resolution AVHRR data for meteorological applications. Some AVHRR data are available on CD-ROM.

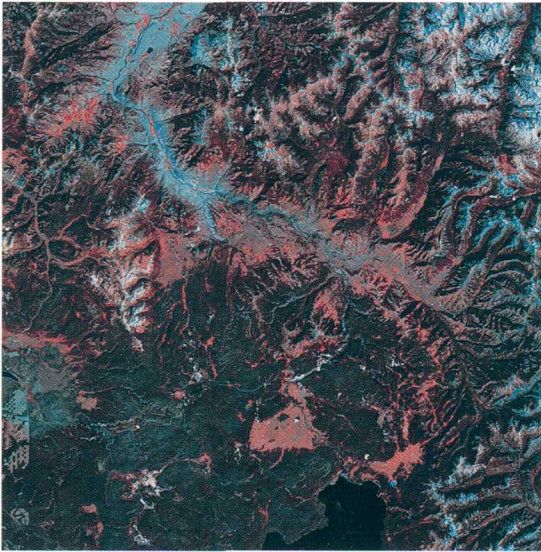
E-1911-99CT



E-1917-99CT

Effects of flooding on the Mississippi River Basin, AVHRR, July 17, 1992, and July 12, 1993.

E-1853-810CT



E-1853-810CT

Comparison of Landsat sensors: Yellowstone National Park, Wyo., Landsat MSS, August 1972, and Landsat TM, August 1989. (Reduced to 68 percent)



SI1SSPA00820805

Los Angeles, Calif., SLAR mosaic compiled in April 1986 from radar strips flown in November 1985. (Reduced to 25 percent)

Side-looking airborne radar

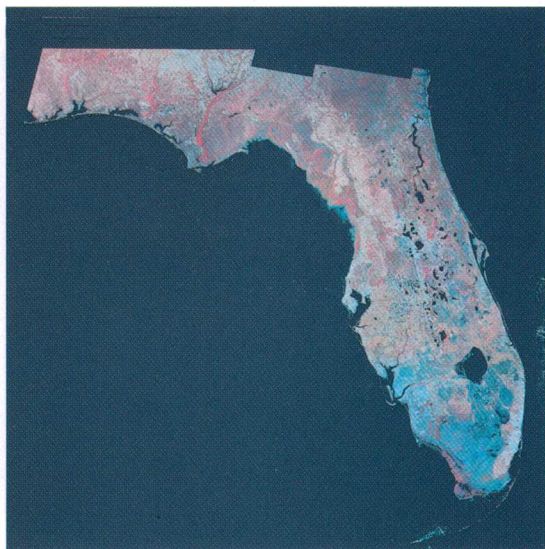
Because SLAR systems provide their own energy to illuminate the ground, these images can be collected regardless of the weather or time of day, making such data valuable for mapping parts of the world that are perpetually cloud covered, such as the Amazon Basin. SLAR systems transmit microwave energy to the ground from aircraft. The signal strikes the ground and is reflected and scattered. The portion of the signal that returns to the sensor is recorded as digital values that can be represented on photographic film. The side-looking geometry of the system produces

shadows of varying lengths depending on the angle of illumination and the surface relief. Although these shadows enhance subtle terrain features, such as faults and folds, they also obscure land surface detail in the shadow area. SLAR images are useful to scientists studying geologic structures. SLAR images most often consist of image strips and 1:250,000-scale mosaics prepared from these strips. Some SLAR data are available on CD-ROM.

E-1373-99CT



Earthrise from Moon, Apollo 11, July 1969.
(Reduced to 40 percent)



Florida, Landsat 5 TM mosaic, April 1979
and May 1985. (Reduced to 43 percent)

E-1721-99CT

Display Images

The USGS has available aerial photographs and images suitable for framing that can be ordered without custom research. In this category are satellite images and aircraft photographs of selected States, cities, regions, and features within the United States; and of such natural phenomena as fires and volcanic eruptions. Some areas outside the United States are also covered. Some photographs taken on space missions by NASA astronauts are also available in this format.

Ordering Information

USGS aerial photographs covering the United States and worldwide satellite data from the early 1970's to the present can be ordered directly from the USGS. The USGS also has information about images available from other Government agencies and commercial sources. Indexes of aerial photographs and online information about satellite data are also available. For more information or to order any of the products in this booklet, call 1-800-USA-MAPS.

Boston, Mass. metropolitan area, NHAP color
infrared, original scale: 1:58,000, April 1985.
(Enlarged 130 percent)
NHAP 85 Roll 53, Frame 236





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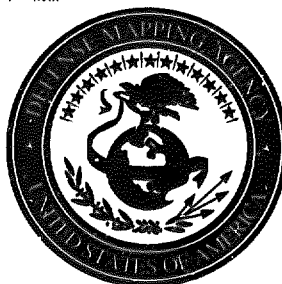
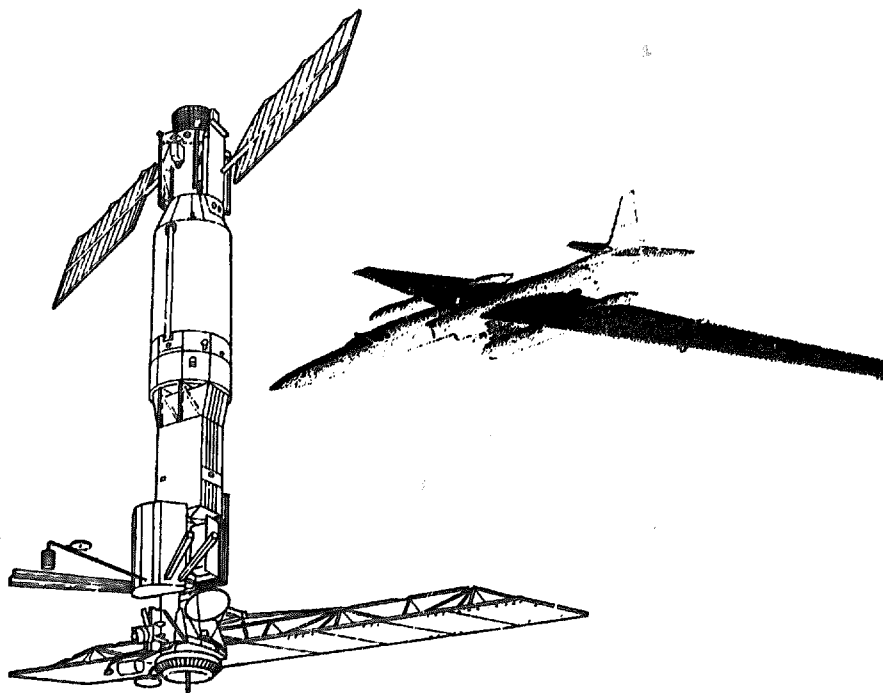


Photo Interpretation Student Handbook

UNCLASSIFIED



MODULE 1: PHOTO INTERPRETATION
PRINCIPLES

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MARCH 1996

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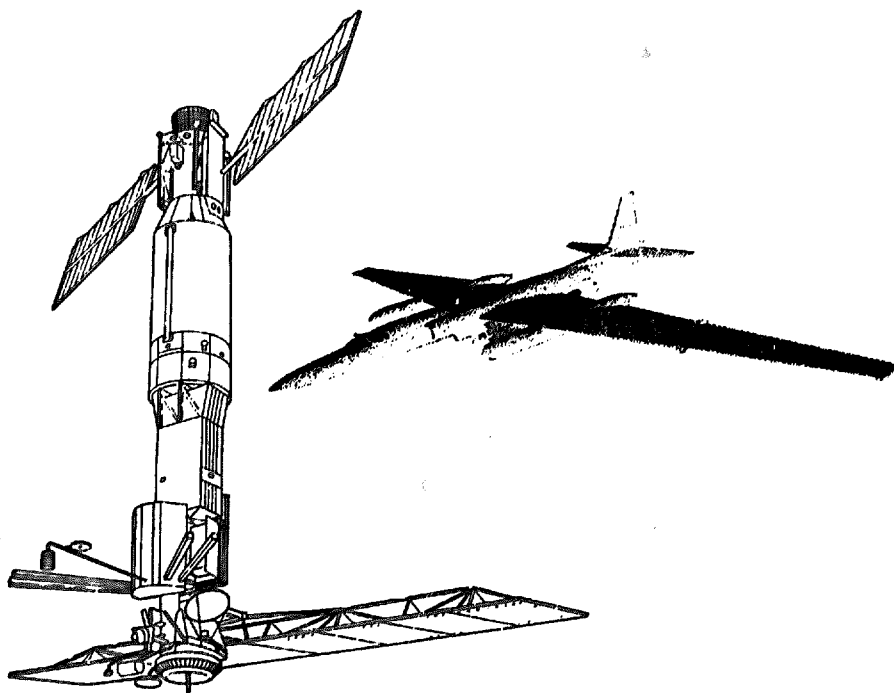
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Photo Interpretation Student Handbook

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MODULE 1: PHOTO INTERPRETATION
PRINCIPLES

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**Photo Interpretation
Student Handbook
Photo Interpretation
Principles**

UNCLASSIFIED
MARCH 1996

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C-2

FOREWORD

The history of cartography comprises many technological breakthroughs that stand as milestones of our profession. The use of aerial imagery as a source for mapping represented a tremendous breakthrough for cartography. The use and introduction of airborne sensors for photogrammetric exploitation and feature identification continues to affect the production of geo-spatial information.

More recently, the introduction of Geographic Information Systems (GIS) has enabled cartographers to selectively portray various aspects of the earth and its surface by querying a data base populated with spatial and feature information. The fidelity of the resulting product is directly related to the quality of the information resident in the data base from which the query was drawn.

The Image Interpretation Course was produced under the auspices of the Integrated Training Working Group (ITWG) and approved by the Activation Control Team (ACT). The Photo Interpretation Training Working Group (PITWG) performed extensive research in the planning and development stages of the course. The PITWG was composed of representatives from Defense Mapping Agency-Aerospace Center, Hydrographic/Topographic Center, and Reston Center. The PITWG determined both course format and content.

The information contained in the Imagery Interpretation Course and the Student Handbooks will assist the trained image analyst in the accurate identification of physical and cultural features viewed on aerial imagery. The Imagery Interpretation Course Student Handbooks are part of a training course that was developed by the Defense Mapping Agency in recognition of the need to maintain a highly skilled and proficient cartographic work force.

The course developer staff at the Defense Mapping Agency includes:

George Szigeti, Cartographer. Mr. Szigeti produced Module 1, 2, and edited Module 3, 4, and 5. His expertise is based on a MS in Geological Engineering, 4 years experience as a topographic and terrain intelligence officer in the US Army Corps of Engineers, and at DMA on the AS-11 and FE systems for 11 years. His knowledge of physical and cultural geography and his knowledge of application software helped make the document a valued training resource.

Gregory J. Bushur, Cartographer. Mr. Bushur produced the majority of Module 2 and the Supplemental Handbook. His expertise is based on a B.S. in Geophysics, 3 years cryptographic and electronic engineering experience with the U.S. Marine Corps, 8 years engineering experience in private industry, and 6 years of experience on the Feature Extraction system. Without his knowledge of industrial processes, electronics, and surface transportation the cultural handbook would not have been possible.

II Photo Interpretation Principles

Stephen L. Wheat, Cartographer. Mr. Wheat produced the Airfield module. His expertise is based on a BS in Geography, 18 years experience as an Intelligence Officer, 2 years as an Imagery Intel. instructor for the USAF, and 12 years experience at DMA. His knowledge of airfields and experience as an Imagery Interpretation instructor has enabled him to produce the Airfield Module and assist in designing the overall structure of the course.

Chris Riopelle, Cartographer. Mr. Riopelle produced the Coastal Hydrography Module and the Climate Section of the Vegetation Module. His expertise is based on a BS in Meteorology and Earth Science, 2 years with the National Weather Service and 7 years experience at DMA. He has worked in Manual DTED compilation, Terrain Analysis, DE cartography and is now a DE Segment Production Engineer.

Debra L. Hinrichs, Cartographer. Ms. Hinrichs produced the Physiography and Inland Waterway Modules. Her expertise is based on a BS in Geology, and 8 years experience at DMA in Terrain Analysis and the Automatic Graphic Digitization System. Her contribution to the course made a significant difference.

Sandra Fleming, Computer Operator. Ms. Fleming assisted in the editing and formatting of the final documents. Her expertise is based on 15 years experience in DMA and she is nearing completion of undergraduate work in Geography. Her contributions helped make the document usable and understandable.

ACKNOWLEDGMENTS

The compilation and preparation of materials for the DMA Photo Interpretation Course involved much more than just the authoring of this student handbook. The other components of the photo interpretation library include the Photo Interpretation Illustrated Glossary, the teaching images, instructor image viewgraphs and templates, lesson plans and other instructional materials. The timely completion of this project would not have been possible without the assistance of our co-workers. We thank the following individuals for their assistance with the development of the Photo Interpretation Course:

A large number of images were required to cover the many cultural features discussed in Module 2. Mr. Paul Burrows used his experience as an image interpreter in the US Marine Corps and as an analyst on the FE and DE systems to locate and identify features on source imagery for inclusion in the teaching imagery set. He also assisted with the compilation of the instructor templates and maintenance of the feature/image database.

A substantial part of the image scanning for the teaching images and instructor viewgraphs was done via the Point Graphics Production System at St. Louis. Kerry Antoniewicz, Robyn Burris, Luther Claus, Laurence Englehard, David Nelson and Garth Sutton performed the scanning and formatting, volunteering to work second shift.

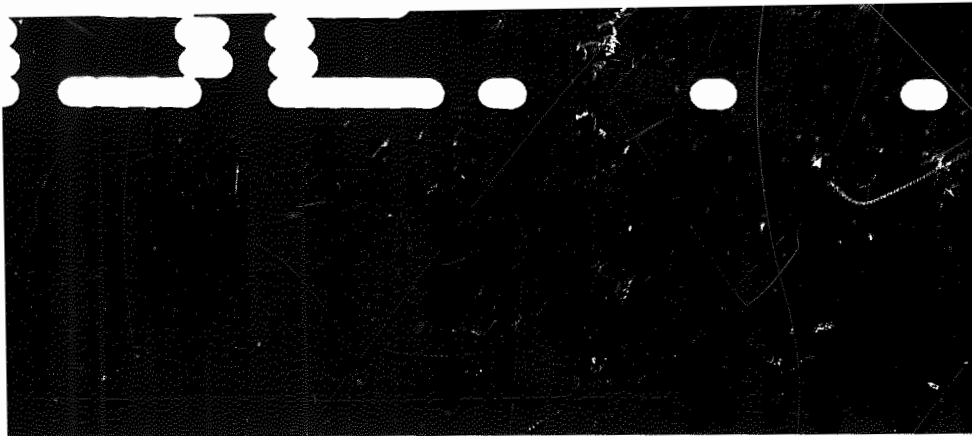
Technical expertise, proofreading and editorial support were provided by Sam Adamczyk, Cliff Hardin, Debbie Knox, Patti May, Tom Obelenus, Victoria Sanders, James Sarcinello, Todd Stovall, and Glen Tewkesbury. Brian Fleming and Tamara Warden assisted with text development and illustrations were prepared by Tobi Bordihn and Ellen Krafcsin. Terrance Moore played a significant part in the development of lesson plans.

Many more of our co-workers provided significant support to this effort, but it would be impractical to name them all. Nevertheless, their assistance is appreciated.

Finally, we wish to thank Steve Handwerk, Phyllis Farris, Rose Pangborn and Pat Hart for their roles in the administration of the project. They provided guidance and direction through the sometimes tumultuous history of this team.

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CHAPTER 1 – INTRODUCTION

Photo interpretation, or more properly **image interpretation**, is something which we practice every day. We see images in books, newspapers and magazines, or on TV. Unconsciously, we interpret the information conveyed by these images in order to identify and gain information about the objects portrayed. The degree of success depends on a number of factors, including the type, scale and resolution of the image, and our familiarity with the subject.

As cartographers, we deal with that aspect of image interpretation known as **remote sensing**. Remote sensing is defined as the gathering of information about an object by means of a sensor at some distance from that object. For our purposes, this refers to an airborne or spaceborne sensor. This means that we are viewing objects from a vertical or a near-vertical perspective. Since we are used to looking at objects from a ground level, or horizontal, perspective, many familiar objects may become difficult to recognize.

The term **photo interpretation** has been handed down from the days when all remotely sensed imagery was in the form of black and white photographs. Since then, other types of sensors, both photographic and digital, have been developed to utilize the visible and invisible portions of the electromagnetic spectrum. The term **image interpretation** was adopted to cover all aspects of remote sensing. Since we will be dealing with black and white, panchromatic (representing only the visible part of the spectrum) imagery, we will label the process as photo interpretation, whether the source material is photographic or digital. We will reserve the term image interpretation for other sources, such as multi-spectral, infrared, and radar imagery.

Aerial Photo Examples

Aerial photo examples for many of these features are contained within the teaching imagery set. A data base (FileMaker Pro, for Macintosh) referencing the features to the imagery is included with the teaching materials.

Changes and Additions

The contents of this course are as complete and as current as the best sources available. Any corrections or information about new features, new configurations, or better image examples should be forwarded to:

Defense Mapping Agency
Process Improvement Office (ODGI)
Attn: Image Interpretation Training Team, Mail Stop L-54
3200 South Second Street
St. Louis MO 63118-3399
(314) 263-4547

CHAPTER 2 – PHOTO INTERPRETATION PROCESS

The type, quantity and quality of information that can be obtained by analyzing aerial photography is dependent on the background, knowledge, skill and interest of the photo interpreter. Those individuals with a broader range of experience find photo interpretation to be less difficult. The purpose of this course is to build on the individual cartographers' background by giving them instruction and practice in applying photo interpretation skills. As each individual becomes more skilled at photo interpretation, it is natural that their interest level will increase as their task becomes less frustrating.

There are several activities, or processes, that the photo interpreter performs during examination of the aerial photograph. These processes, in the order in which they are performed, are: detection, identification, and evaluation. In other words, photo interpretation is:

1. The art of knowing what you are looking for;
2. Identifying it when you find it; and
3. Knowing the significance of it in that location.

Measurement is also a part of the interpretation process, but is done at two different times and for different purposes; first, as an estimation of relative size to aid in identification, and second, as detailed measurements during the evaluation process.

Detection is the easiest part of photo-interpretation, in that it only requires the realization that there is something on the photo that is different from its surroundings. Local changes in the characteristics of the photo (tone, texture, pattern, etc.) distinguish objects from each other. The changes could be sharp and distinctive, allowing rapid visual discrimination. Other features are harder to detect because of their small size or because they are not distinct from their surroundings. In these cases, their presence must be inferred from more subtle visual clues, and a knowledge of what features should be found in a particular area. Other features may not be visible at all, but their presence is inferred through the identification of related features. The use of stereo models greatly enhances the photo interpreter's ability to detect features.

Identification of the feature is the next step in the interpretation process. Part of identification is a judgment of the feature's size, relative to the surrounding features. Knowing the relative size of an object determines what it may or may not be. Identification requires not only the use of clues provided by the imagery, but also a working knowledge of the types of features likely to be found in the area, and how they would look from the vertical perspective.

Some features are distinctive and readily identified. For other features, identification is an exercise in problem solving, using the different elements of photo

interpretation to identify features, or to identify object-complexes from their components. The problem solving process will be discussed in more detail in the section on Convergence of Evidence.

The evaluation process is the most difficult, and requires an in depth knowledge of both the features being considered, and the geographic area in which the features are located. For many DMA products, information on the size, construction, composition and function of a feature are required. Detailed measurements are easily made using modern stereoplotters. However, the rest of the information must often be inferred from scant visual clues, supplementary source materials and the background knowledge of the cartographer. Again, the analyst must resort to problem solving skills to provide the needed information. For cartographic purposes, detailed evaluations on the economic or political significance of most features is not needed. However, the military significance of features is a key consideration on some products.

This module will concentrate on using the clues provided by the imagery to locate, identify and evaluate features. Detailed information about the different classes of features depicted on cartographic products will be covered in the following modules.

CHAPTER 3 – ELEMENTS OF PHOTO INTERPRETATION

The visual clues provided by the aerial photograph can be grouped into eight categories: Size, Shape, Shadow, Tone, Texture, Pattern, Location and Associations. When we look at a photograph we use these elements in our interpretation. Some features can be quickly identified using only one of these elements; others require the use of several elements.

Size

One of the first judgments we make about an object we have located on a photograph is its size in relation to other nearby objects. Trees are larger than bushes, reservoirs are larger than swimming pools, and an apartment building is larger than a single family house. Most of the time there are readily recognizable objects on the photo for us to compare an unknown object to. In some cases, especially when dealing with aerial photos, we may need to make a judgment as to the scale of the image before we can identify anything. Whether we use a comparison, or a measurement, the relative size of an object is our first clue as to its identity.

Shape

The shape of an object is an important factor in its identification. The shape delimits the class of features to which the unknown object belongs. Sometimes the shape alone will conclusively identify the feature. The shape also yields information as to the structure, function and significance of the object being studied.

Regular shapes and patterns, straight edges, and square corners are almost always indicative of man-made (or man-modified) objects. The opposite normally indicate natural features. Many industries can be identified by the characteristic shapes of the buildings or equipment associated with that activity.

Although the shape of an object is an important clue to its identification, the shape when viewed from the vertical perspective (plan view) can be quite different than when viewed from the horizontal (profile or oblique views). The ability to visualize and identify objects in the plan view is an important skill for the cartographer to develop. Wherever possible in this course, plan view illustrations are provided to help familiarize the students with the shapes of objects from the vertical perspective.

Stereo viewing enhances our ability to recognize the features by revealing their three-dimensional shape. This is especially important when high sun angles minimize shadows.

Shadow

Shadows reveal information about the shape, size, and construction of features, and in some cases can yield an immediate identification.

The shape of some objects is difficult to determine, either because they are not distinct from their background, or because their size in plan view is very small (e.g., towers and pylons). In these cases, a good shadow will reveal the shape of the object, usually providing a silhouette similar to the familiar profile view. In some cases, the shadow is the best indicator of the feature's presence and identity.

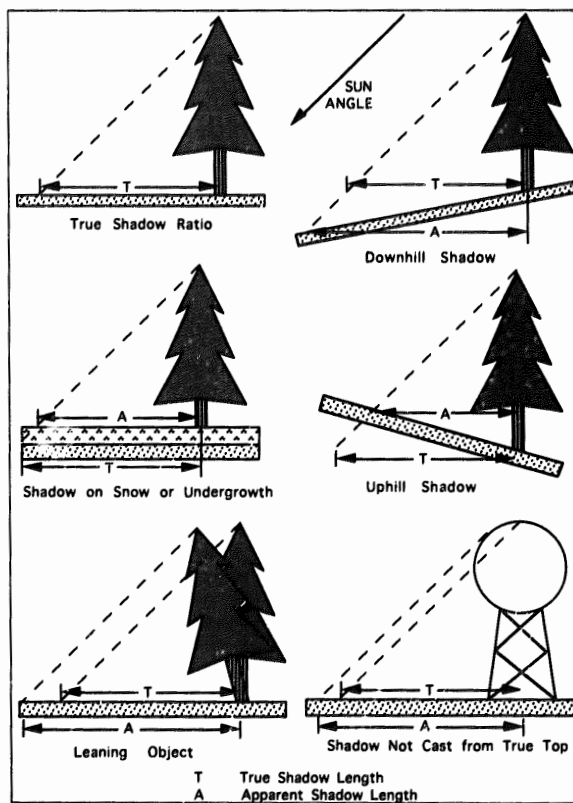


Figure 1: Effect of slope and other factors on shadow length.

The shadow also provides an indication of the height of an object. This is especially important when viewing imagery monoscopically. Relative heights of objects can be quickly determined by comparing the length of their shadows. You must be careful when using shadows, however, as the slope of the ground and other factors, will affect the length of the shadow (Figure 1). The careful use of mensuration techniques will yield accurate values of height.

Shadows will also work against the analyst, hiding smaller features or the character of the ground's surface. Shadow areas should be studied carefully so that no significant feature is missed.

Tone

Tone is a measure of the amount of light reflected by an object. On a black and white image, this appears as shades of gray. The edges created by differences in tone allow us to distinguish between adjacent features, and define the shape and boundaries of these objects. The tone of an object is influenced by its composition, the angle at which the sun strikes the surface of the object, and the position of the sensor.

Smooth surfaces, such as water and glass, are excellent reflectors. They can be either light or dark in tone, depending whether they are reflecting the light toward or away from the sensor. Because stereo photographs are taken from different angles, such surfaces may appear very light on one image and almost black on the other.

On the other hand, rough surfaces reflect light in all directions, and will appear as intermediate gray tones, depending upon their composition. Those surfaces oriented toward the sun will appear lighter on both images, than surfaces oriented away from the sun.

Composition and color also affect the tone. Light colored materials, or objects painted in light colors, will have a lighter tone on the imagery than those with dark colors.

Tone is often used in analysis of vegetation. Coniferous trees are usually darker than deciduous trees. Differences in tone are used to distinguish between types of crops. Tone may also be an indication of soil types or soil moisture.

Areas of bare ground, or paved surfaces, will frequently show up as lighter than the surrounding ground surface. The smooth surfaces of pavements in particular will show up as light-toned areas. Fresh asphalt will appear darker in tone, but becomes lighter with age.

Areas of shallow water can often be detected by their lighter tones, particularly when the bottom material is a light colored sand or mud. When describing water bodies, they should be examined carefully for variations in tone.

Texture

Texture is the frequency of tonal changes across the image of a feature. Smooth texture is where the feature has a constant even tone. Fine texture represents rapid tone changes over short distances. Coarse textured features have a lesser frequency of tonal changes. Mottled texture refers to a blotchy appearance, with irregular blobs of different tones. Other terms used to describe texture include stippled, rippled and lumpy.

The texture of a given surface will vary with the scale and resolution of the imagery. As scale or resolution decrease, the apparent texture of a feature becomes finer. For example, large scale imagery of a forest has a mottled or coarse texture, with variations caused by individual leaves and branches. At a smaller scale, the forest would display a finer texture, where the variations are caused by the individual trees and their shadows. At a still smaller scale, where the resolution does not allow the distinguishing of individual trees, the forest may have a smooth texture.

Pattern

Pattern refers to the spatial arrangement of features in an area. Patterns may be regular, such as trees in orchards or urban street patterns, or irregular, such as the arrangement and alignment of streams. Patterns can be used to identify features (such as orchards) or to determine functions (military installations normally have a distinctive pattern in the arrangement of buildings). Drainage patterns often yield information about the nature of the underlying rocks and soil.

One of the advantages of aerial photography is that many patterns and associations not visible from the ground are readily visible in the plan view. The patterns are related to the function and/or origin of the feature. As with shape, regular, geometric patterns indicate the influence of man, while irregular patterns are frequently natural.

Associations

As mentioned before, vertical aerial photography reveals spatial relationships between objects in a manner that may not be obvious when viewed from the ground. This viewpoint also allows us to see a large area around the feature being examined, and use the information to help identify it.

Features, both natural and manmade, arrive on the earth's surface via an orderly set of processes. Their arrangement reflects the processes that placed them there, and, for manmade objects, often reflects their function as well. An appreciation of these orderly arrangements is developed through a thorough knowledge of the features in question.

When the identity of a feature is not obvious, we look at those features immediately surrounding the object we wish to identify. For instance, a large, single

story building's purpose may not be obvious when examined by itself. A large parking lot full of cars would indicate that it is a shopping center, while the presence of many trucks and a railroad siding could identify it as a warehouse, or the presence of raw materials would indicate a light fabrication facility. Aluminum processing requires large amounts of electric power, and a large transformer substation is always associated with these facilities. Military facilities and prisons will have security facilities such as fences, guard shacks and sometimes guard towers.

Location

Location is the regional aspect of associations. The appearance and occurrence of many features will vary in different parts of the world. Before starting their analysis, cartographers should be aware of the region they are working in, and how climate, availability of materials, local customs and economics affect the appearance of the features they are to identify. For example, schools in Asian countries look significantly different from schools in western countries. The type of vegetation you would expect to find depends upon what part of the world you are looking at.

In a local context, the area being studied can be broken down into subregions. The identity of features can then be judged on the basis of the subregion in which they occur. Cylindrical objects in an agricultural area are likely to be grain silos, but if they were located at a refinery or power plant they would probably be oil or gas tanks. A large building in a military base could be an administration building, but if it were in a residential area it could be a school.

Factors such as topography, soils and geology, vegetation, and cultural effects must be considered. Radar sites are normally located on high ground to minimize terrain interference, thermal power plants must be located near supplies of water for cooling, and vegetation types may vary depending on the direction the slope is facing.

Seasonal Effects

When performing photo interpretation, it is also important to consider the time of year the imagery was recorded. The date of the imagery should be determined before any interpretation is started. Seasonal changes can have a substantial effect on the appearance of objects, particularly natural features. Information about the climate and seasonal changes in the area being studied is needed.

In areas of deciduous vegetation, the loss of leaves from the trees in the winter (or dry season) can lead to erroneous estimations of tree height or canopy closure, but estimates of tree spacing and trunk diameter are easier to obtain. In addition, features normally concealed by the canopy are readily visible. Contours or ground elevation data can be collected more accurately when the canopy does not hide the ground.

Elements of Photo Interpretation

Photo Interpretation Principles 9

Characteristics of drainage features will vary with the seasons. Intermittent streams and ponds may be filled with water during the wet seasons, leading to their erroneous classification as perennial. Water levels in lakes, ponds and rivers may vary considerably during the year. Ancillary sources must be consulted to insure that the predominant conditions are portrayed properly.

Snow cover can conceal many important features. Small streams may be frozen and covered in snow. Roads may be plowed, but accurate road widths, and often road surface type, cannot be determined. Snow remains longer on shaded slopes, and thus may decrease the contrast. A reversed effect can result, with the shadow side of hills and ridges appearing lighter than the sunlit sides.

CHAPTER 4 – PROBLEM SOLVING

Responsibilities of the Photo Interpreter

No one is an expert in all the fields of knowledge that a modern cartographer has to deal with, but that should not lead to complacency. The best photo interpreters are those that continually educate themselves, seeking to improve their ability to perform their job. There are certain key traits and skills that a photo interpreter should strive to develop:

1. An awareness of the characteristics and limitations of the source imagery.
2. A thorough knowledge of the characteristics of agriculture, industry, transportation, living customs, civic planning, military organizations and equipment, hydrography, vegetation and natural terrain features.
3. A positive attitude. Photo interpretation requires a scientific approach. Common sense, disciplined study, research and experience are prerequisites for proficiency. Solutions to all questions are not easily obtained; but with a positive attitude and knowledge of the subject material, the qualified photo interpreter can produce a detailed and accurate analysis.
4. Communication with fellow cartographers. The individual analyst must keep in contact with others working in the same area to insure consistency in their interpretation and representation of features. One individual may have access to a particular source of information, or may have experience in a particular field or geographic area, or may have a particularly good example of a feature on his imagery, which would give other analysts the insight they need to identify problematical features.

The quality of the product generated by the cartographer is dependent on four factors: the quality and resolution of the imagery; the facilities and equipment available to the analyst; the amount of time available; and, most important of all, the ability of the interpreter. The first three factors are generally out of our control, but the fourth is entirely within our influence.

Ancillary Materials

Maps are graphic representations of the aerial view of the earth's surface. They provide a guide to what features are present, and their spatial relationship to each other. Studying maps will give you experience in the visualization of features from the vertical perspective. During photo analysis, a map, even one which is out-dated, is an excellent guide to the area being studied. It may help you identify features unfamiliar features, and helps you to remain properly oriented within your area.

As mentioned above, texts and other sources that document the local climate and seasonal changes should be consulted whenever working in a new area. Local cultural factors also must be considered. The skilled analyst knows when to seek additional information from ancillary sources. Magazine articles and travel brochures can be as helpful as texts and intelligence documents.

No single cartographer can hope to know everything about all the different types of features he may encounter. This emphasizes the need for an adequate library of reference materials to which the cartographer can turn. Each individual can contribute by collecting items that they find helpful. The pooled resources and experience of a team of analysts will usually be enough to solve even the most difficult interpretation problems.

Convergence of Evidence

Although many features can be readily identified using one or two of the previously mentioned factors, some features require the use of several lines of evidence to make an identification. Further analysis of features, to include determination of composition, structure and function, also usually require reference to different sources of information. The analyst uses these different sources and lines of reasoning to converge at the correct answer.

A methodical approach is required to most efficiently analyze an area. The cartographer should start with generalities and go on to details. Always evaluate the known features before attempting to identify the unknown.

The first step in the analysis of an aerial photograph is to orient the photo to the best available map source. Once the analyst has determined what area on the map is covered by the particular image, he has established a framework of features upon which to build his interpretation. A quick check is made at this point to insure that all prominent features are in their correct locations.

The area being studied is then scanned and the general character of the area is noted. The area is divided into subregions if appropriate (e.g., mountains vs. plains, forests vs. prairies, urban areas vs. agricultural areas, etc.). The classification of the subregions helps to determine the kind of features liable to occur in those areas.

Large area features and major lines of communication are defined to help orient the analyst, and to form a framework for the detailed evaluation. The analyst works across the image evaluating known features. Then unknown features are identified through their associations with those previously identified. The elements of photo interpretation described earlier are used to generate probable answers to questions, and a critical evaluation of the evidence indicates the choice with the highest probability of being correct.

Estimations of Density and Composition

Many cartographic applications require an estimation of feature density or percent composition. Some common problems are: canopy closure in forested areas; determining percentages to discern between deciduous, coniferous or mixed tree areas; percentage roof cover in built-up areas; and density of scrub or brush. There are several techniques for deriving this information, ranging from quick, visual approximations to more time consuming sampling techniques. Several of these methods are described here. The analyst can choose the best method for the product being compiled.

Visual estimation is the quickest method for determining densities and composition. However, it is also the most difficult for the inexperienced analyst. The best way to perform a visual estimation is with a comparison chart. Comparison charts can be constructed illustrating the critical percentage breakouts for the particular application.

Figure 2 shows breakouts at 10%, 25%, 50% and 75%, values used for defining canopy closure in tree areas. Different products may use different values, and another chart may be needed.

Sampling techniques involve measuring small portions of an area and extrapolating the results to the entire area. Sampling methods assume an approximately uniform distribution of the item in question, so that the area being measured is representative of the entire area. If the density changes across an area, it should either be separated into two areas, or the density estimates for the parts should be averaged together. The product specifications would decide which method to use.

The most common method used for determining percentages is the point count method. To determine the percentage by the point count method, an evenly spaced grid is placed over the area to be sampled. The grid intersections are used as sampling points. For simplicity in calculation, a 10 by 10 grid is used, yielding 100 sampling points (see Figure 3). To determine a percentage, just count the number of points that fall on the item being measured (tree canopy in Figure 3), and this number equals the percentage of that item in the given

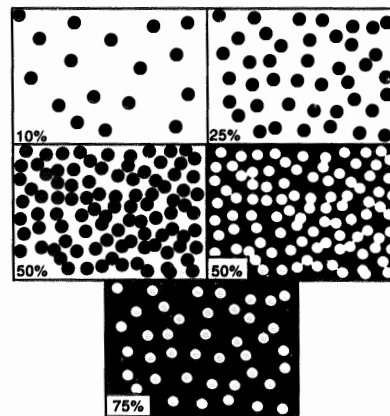


Figure 2: Density Comparison Chart
(Percentage represents black area).

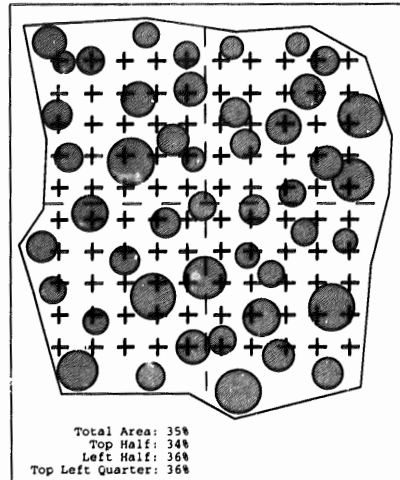


Figure 3: Density by Point Count

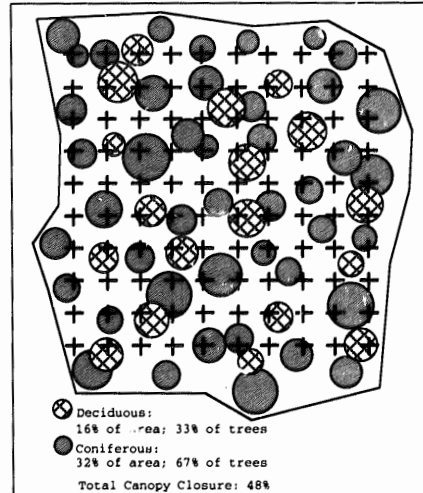


Figure 4: Composition by Point Count

area, in this case, 35% tree canopy cover. As demonstrated in Figure 3, using half of the grid (50 points) and multiplying by 2, or one fourth of the grid (25 points) and multiplying by 4 will also give an acceptable approximation of percentages.

Figure 4 illustrates how the point count method can be used to determine percentage composition. In this area there are two types of trees. Thirty two percent

of the area is coniferous, and sixteen percent is deciduous for a total canopy closure of forty eight percent. Fifty two percent is open ground. Two thirds (67%) of the trees are coniferous and one third (33%) are deciduous.

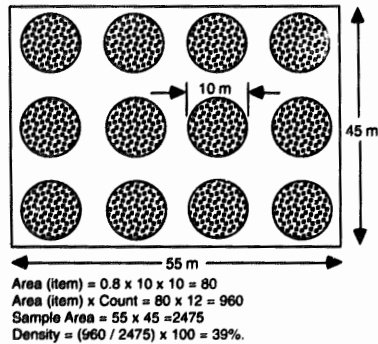


Figure 5: Sample Area Density Calculation

When the items being measured are more or less uniform in size (e.g., tanks, houses, orchard trees, etc.), measuring a small area and counting the number of items in that area can quickly yield a percentage. Just multiply the area of one item by the number of items in the sample area, and divide the product by the area of the sample (see Figure 5). For quicker computation, an accurate approximation of the area of a circle is given by the formula:

$$\text{Area} = 0.8 \times \text{Diameter}^2$$

CHAPTER 5 – LIMITATIONS OF PANCHROMATIC IMAGERY

The resolution of the imagery affects the ability of the analyst to identify and analyze features. The resolving power of an imaging system depends on two factors, the minimum size of an object that can be detected, and the ability of the system to detect tonal differences. There are many variables that affect the resolution of imagery, depending on the type of sensor (digital versus photographic), optical configuration, film or sensor sensitivity, the wavelength of radiation used, etc.

The minimum size of objects detected is described by the Ground Resolved Distance (GRD) for photographic systems, and Ground Sample Distance (GSD) for digital sensors. Both are an indication of the smallest object that can be separated from a neighboring object. When comparing photographic to digital sources, the values for GRD and GSD are interchangeable.

Another method for describing the spatial resolution of imagery is the National Imagery Interpretability Rating Scale (NIIRS), developed by the CIA's National Photographic Interpretation Center (NPIC). This method rates imagery on a scale of 1 to 9, with larger numbers signifying a greater resolution.

Although an object may be smaller than the resolution of the imagery, its presence can sometimes be inferred. The power transmission lines or telephone lines stretched between pylons may not be visible, but their presence can be inferred because of the presence of the pylons. At a smaller scale, the pylons themselves may not be visible, but a cleared way through a forest with no associated road or railroad would imply the presence of the power line and pylons.

The ability to detect tonal differences varies with the sensitivity of the sensor, and the wavelengths of radiation being used. Near infrared wavelengths, for instance, are much better for discerning between different types of vegetation. Wavelengths near the blue end of the spectrum are better for detecting areas of shallow water and underwater hazards.

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MODULE 2 – BIBLIOGRAPHY

BOOKS

- Allen, Geoffrey Freeman, Editor, *Jane's World Railways, 33rd Edition*, 1991, Jane's Information Group
- Alth, Max and Alth, Charlotte, *Constructing & Maintaining Your Well & Septic System*, 1984, TAB Books
- American Association of State Highway and Transportation Officials, *A Policy on Design of Urban Highways and Arterial Streets*, 1973, American Association of State Highway and Transportation Officials
- Amin, Mohamel and Eames, John, Editors, *Insight Guides: Kenya, 1st Edition*, 1985, Prentice-Hall, Inc.
- Anderson, John Gottberg, Editor, *Insight Guides: Burma, 7th Edition*, 1989, Höfer Press, Pte, Ltd.
- Anderson, John Gottberg, Editor, *Insight Guides: Nepal, 7th Edition*, 1989, APA Press, Pte., Ltd
- Appleyard, S.F., *Marine Electronic Navigation*, 1980, Routledge & Kegan Paul
- Avery, Thomas Eugene, *Interpretation of Aerial Photographs, 3rd Edition*, 1977, Burgess Publishing Company
- Baedeker, Gisela Bockcamp, Editor, *Baedeker's Austria, 2nd Edition*, 1992, Prentice-Hall
- Baedeker, Stuttgart, Editor, *Baedeker's France, 1st Edition*, 1991, Prentice-Hall
- Baedeker, Stuttgart, Editor, *Baedeker's Italy, 1st Edition*, 1991, Prentice-Hall
- Baker, Ron, *A Primer of Oil-Well Drilling, Fourth Edition*, 1979, Petroleum Extension Service, The University of Texas at Austin and International Association of Drilling Contractors
- Bamford, James, *The Puzzle Palace*, 1982, Houghton
- Barrett, E.C. and Curtis, L.F., *Environmental Remote Sensing*, 1976, Halstead Press (John Wiley & Sons Inc.), London
- Barrett, E.C. and Curtis, L.F., *Introduction to Environmental Remote Sensing*, 1976, Chapman and Hall
- Bath, Dierdre, Editor, *Insight Guides: Argentina, 2nd Edition*, 1990, Höfer Press, Pte, Ltd.
- Baass, W., Editor, *Radio Navigation Systems*, 1963, Pergamon Press, The MacMillan Company

- Bayard, Edwin, *Kyoto*, 1978, Newsweek Book Division
- Beard, R.B. and Rotherham, A.C., *Space Flight and Satellite Vehicles*, 1958, Pitman Publishing Corporation
- Bell, Brian, Editor, *Insight Guides: Eastern Europe, 1st Edition*, 1993, Höfer Press, Pte, Ltd.
- Bellamy, John, *Digital Telephony*, 1982, John Wiley and Sons
- Benton, William Publisher, *The New Encyclopædia Britannica*, 1983, Encyclopædia Britannica, Inc.
- Bhartia, P. and Bahl, I.J., *Millimeter Wave Engineering and Applications*, 1984, John Wiley & Sons
- Binkowski, Edward S., *Satellite Information Systems*, 1988, Hall
- Blake, Bernard, Editor, *Jane's Radar and Electronic Warfare Systems 1994-95*, 1994, Jane's Information Group
- Blake, Bernard, Editor, *Jane's Radar and EWS Systems*, 1992, Jane's Information Group
- Bleassard, G.B., *Introducing Satellite Communications*, 1985, NCC Publications
- Borthwick, John and McGonigal, David, Editors, *Insight Guides: Melbourne, 1st Edition*, 1989, Höfer Press, Pte, Ltd.
- Borthwick, John and McGonigal, David, Editors, *Insight Guides: The Great Barrier Reef and Queensland Coast*, 1991, Höfer Press, Pte, Ltd.
- Brinkman, David, Editor, *Jane's Avionics*, 1992, Jane's Information Group
- Brookner, Eli, *Radar Technology*, 1978, Artech
- Burrows, William E., *Deep Black*, 1988, Berkley Books
- Butterworth, Sue, Editor, *Air Forces of the World*, 1983, Chartwell Books Inc.
- Carpentier, Michel H., *Principles of Modern Radar Systems*, 1988, Artech House
- Carr, Joseph J., *The Complete Handbook of Radio Receivers*, 1982, TAB Books
- Catling, Christopher, Editor, *Insight Guides: The Netherlands*, 1st Edition, 1991, Höfer Press, Pte, Ltd.
- Ching, Francis D.K., *Building Construction Illustrated*, 1975, Van Nostrand Reinhold Company
- Chwaszcza, Joachim, Editor, *Insight Guides: Prague, 1st Edition*, 1989, Höfer Press, Pte, Ltd.
- Chwaszcza, Joachim, Editor, *Insight Guides: Sardinia, 1st Edition*, 1991, Höfer Press, Pte, Ltd.

- Communications and Education Service Department, American Iron and Steel Institute, *Steelmaking Flowlines*, August 1978, American Iron and Steel Institute
- Considine, Douglas M., *Van Nostrand's Scientific Encyclopedia*, 5th Edition, 1976, Van Nostrand Reinhold Company
- Considine, Douglas M., Editor, *Van Nostrand's Scientific Encyclopedia*, 7th Edition, 1983, Van Nostrand Reinhold
- Cook, Nigel P., *Microwave Principles and Systems*, 1986, Prentice-Hall
- Cracknell, Arthur P. and Hayes, Ladson, *Introduction to Remote Sensing*, 1991, Taylor and Francis
- Cunningham, Hillary, Editor, *Insight Guides: Canada*, 4th Edition, 1992, Höfer Press, Pte, Ltd.
- Danforth, Kenneth C., Ed., *Journey Into China*, 1982, The National Geographic Society
- Dobrin, Milton B., *Introduction to Geophysical Prospecting*, 1976, McGraw-Hill, Inc.
- Donze, Marie-Ange and Sauvageot, Claude, *China Today*, 1979, Editions, J.A.
- Dubey, Manjulika, Editor, *Insight Guides: Delhi Japur Agra*, 1st Edition, 1991, Höfer Press, Pte, Ltd.
- Eames, Andrew, Editor, *Insight Guides: Southern Spain*, 1st Edition, 1990, Höfer Press, Pte, Ltd.
- Eames, Andrew, Editor, *Insight Guides: Tenerife and the Western Canary Islands*, 1st Edition, 1989, Höfer Press, Pte, Ltd.
- Ebner, D.; Fritsch, D.; and Heipke, C., Editors, *Digital Photogrammetric Systems*, 1991, Karlsruhe Wichmann
- Encyclopædia Britannica, Inc., *The New Encyclopædia Britannica*, 1994, Encyclopædia Britannica, Inc.
- Eu, Geoffrey, Editor, *Insight Guides: East African Wildlife*, 1st Edition, 1989, Höfer Press, Pte, Ltd.
- Eu, Geoffrey, Editor, *Insight Guides: Java*, 1st Edition, 1993, Höfer Press, Pte, Ltd.
- Eu, Geoffrey, Editor, *Insight Guides: Myanmar Burma*, 1st Edition, 1992, Höfer Press, Pte, Ltd.
- Eu, Geoffrey, Editor, *Insight Guides: Vietnam*, 1st Edition, 1991, Höfer Press, Pte, Ltd.
- Ewell, George W., *Radar Transmitters*, 1981, McGraw-Hill Book Company
- Feynman, Richard P.; Leighton, Robert B.; and Sands, Matthew, *The Feynman Lectures on Physics: Vol. I*, 1977, Addison-Wesley Publishing Company

- Feynman, Richard P.; Leighton, Robert B.; and Sands, Matthew, *The Feynman Lectures on Physics: Vol. II*, 1977, Addison-Wesley Publishing Company
- Feynman, Richard P.; Leighton, Robert B.; and Sands, Matthew, *The Feynman Lectures on Physics: Vol. III*, 1977, Addison-Wesley Publishing Company
- Fintel, Mark, Editor, *Handbook of Concrete Engineering*, 1985, Van Nostrand Reinhold Company
- Flüeler-Grauwer, Marianne, Editor, *Insight Guides: Switzerland. 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Folberg, Neil, *In a Desert*, 1987, Cross River Press, Ltd.
- Forsell, Börje, *Radionavigation Systems*, 1991, Prentice Hall
- Foss, Christopher and Hogg, Ian, Editors, *Battlefield The Weapons of Modern Land Warfare*, 1986, Longmeadow Press
- Freeman, Roger L., *Reference Manual for Telecommunications Engineering*, 1985, John Wiley and Sons
- Freeman, Roger L., *Telecommunication Transmission Handbook*, 1981, John Wiley and Sons
- Gardiol, Fred E., *Introduction to Microwaves*, 1984, Artech House
- Gartenhaus, Simon, *Physics: Basic Principles: Vol. I*, 1975, Holt, Rinehart and Winston, Inc.
- Gartenhaus, Simon, *Physics: Basic Principles: Vol. II*, 1975, Holt, Rinehart and Winston, Inc.
- Gervasi, Tom, *Arsenal of Democracy II*, 1981, Grove Press, Inc.
- Giebel, Wieland, Editor, *Insight Guides: The New Germany, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Goltz, Thomas, Editor, *Insight Guides: Turkey, 3rd Edition*, 1991, Höfer Press, Pte, Ltd.
- Green, James Harry, *The Dow Jones-Irwin Handbook of Telecommunications*, 1986, Dow Jones-Irwin
- Gunston, Bill and Spick, Mike, *Modern Air Combat*, 1983, Crescent Books
- Haape, Johannes, Editor, *Insight Guides: South Africa, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Haggett, Peter, Editor, *Encyclopedia of World Geography*, 1994, Andromeda
- Halliday, David and Resnick, Robert, *Physics, Parts I and II*, 1966, John Wiley & Sons, Inc.
- Halliday, Tony, Editor, *Insight Guides: Pakistan, 1st Edition*, 1990, Höfer Press, Pte, Ltd.

- Hallion, Richard P., *Storm Over Iraq: Air Power and the Gulf War*, 1992, Smithsonian Institution Press
- Held, Gilbert, *Understanding Data Communications, 3rd Edition*, 1991, Sam's Information Group
- Hertzberg, Robert, *So You Want To Be A Ham*, 1979, Howard W. Sams & Company, Inc.
- Hill, Alison Friesinger, Editor, *Insight Guides: Portugal, 1st Edition*, 1991, Höfer Press, Pte, Ltd.
- Hobbs, Richard R., *Marine Navigation 2: Celestial and Electronic*, 1974, United States Naval Institute
- Hoefer, Haas, Editor, *Insight Guides: Bali, 14th Edition*, 1989, APA Press, Pte, Ltd.
- Hoefer, Haas, Editor, *Insight Guides: Malaysia, 13th Edition*, 1990, Höfer Press, Pte, Ltd.
- Hoefer, Haas, Editor, *Insight Guides: Thailand, 9th Edition*, 1989, Höfer Press, Pte, Ltd.
- Hoefer, Hans Johannes, Editor, *Insight Guides: Philippines, 7th Edition*, 1989, APA Press, Pte., Ltd.
- Horn, Alfred and Pietras, Bozena, Editors, *Insight Guides: Poland, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Hunt, V. Daniel, *Handbook of Energy Technology: Trends and Perspectives*, 1982, Van Nostrand Reinhold Company
- Hunter, William A., *Modern Amateur Radio License Study Guide For Novice, Technician & General Class*, 1978, TAB Books
- Inglis, David Rittenhouse, *Windpower and Other Energy Options*, 1978, University of Michigan Press
- International Hydrographic Organization, *Chart Specifications of the IHO and Regulations of the IHO for International (INT) Charts*, 750-VI-1988 Mp-004, 1988, International Hydrographic Bureau
- Jackson, Donald C., *Great American Bridges and Dams*, 1988, Great American Press, The Preservation Press
- Jeppesen Sanderson, Inc., *Jeppesen Airway Manual*, 1992, Jeppesen Sanderson, Inc.
- Kayton, Myron, Editor, *Navigation: Land, Sea, Air, & Space*, 1989, IEEE Press
- Keiser, Bernhard E. and Strange, Eugene, *Digital Telephony and Network Integration*, 1985, Van Nostrand Reinhold Company
- Killen, Harold B., *Digital Communication with Fiber Optics and Satellite Applications*, 1988, Prentice-Hall

- Klein, Wilhelm, Editor, *Insight Guides: St. Petersburg Leningrad, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Korb, Edward L., Editor, *The World's Missile Systems, Eighth Edition*, 1988, General Dynamics
- Kyle, James; Sessions, Ken; and Carr, Joseph J., *Amateur Radio General Class License Study Guide, 3rd Edition*, 1981, TAB Books
- Lambert, Mark, Editor, *Jane's All the World's Aircraft*, 1992, Jane's Information Group
- Legault, Adrian R., *Highway and Airport Engineering*, 1960, Prentice-Hall, Inc.
- Lenfestey, Thompson and Capt. Lenfestey, Thompson, Jr., *The Facts on File Dictionary of Nautical Terms*, 1994, Facts on File, Inc.
- Leverenz, Jon M., Ed., *Photographic World Atlas*, 1989, Rand McNally
- Lockhard, Saul, Editor, *Insight Guides: Hong Kong, 6th Edition*, 1989, APA Press, Pte., Ltd
- Lukers, Thomas B., *Dictionary of Electronic Terms*, 1984, Master Publishing Company
- MacFarquhar, Roderick, *The Forbidden City*, 1972, Newsweek Book Division
- Marshall, Bruce Editor, *The Real World*, 1991, Marshall editions Development Ltd.
- Marshall, John, *The Guinness Railway Book*, 1990, Guinness Books
- Mayerchak, Patrick M., *East Asia and the Western Pacific, 27th Edition*, 1994, Stryker-Post Publications
- Melrod, George, Editor, *Insight Guides: Israel, 2nd Edition*, 1989, APA Press, Pte., Ltd.
- Melton, Luke, *Complete Loran-C Handbook*, 1986, International Marine Publishing Company
- Meyers, Robert, Editor, *Encyclopedia of Telecommunications*, 1989, Academic Press
- Miller, David and Foss, Christopher F., *Modern Land Combat*, 1987, Portland House
- Miller, David and Miller, Chris, *Modern Naval Combat*, 1986, Crescent Books
- Mims, Forrest M., *Engineer's Mini-Notebook: Communications Projects*, 1987, Siliconcepts
- Mims, Forrest M., *Engineer's Mini-Notebook: Formulas, Tables and Basic Circuits*, 1988, Siliconcepts
- Mooney, Michael M., *The Hindenburg*, 1972, Cornwall Press
- Morgenstern, Manfred, Editor, *Insight Guides: China, 1st Edition*, 1990, Höfer Press, Pte, Ltd.

- Morland, Howard, *The Secret That Exploded*, 1981, Random House
- Morris, Christopher, Editor, *Dictionary of Science and Technology*, 1992, Academic Press
- Moctezuma, Julio Rodolfo, Lic Cid, Director General, *La Nueva Política Petrolera*, 1983, PEMEX
- Müller, Kristiane, Editor, *Insight Guides: Belgium, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Müller, Kristiane, Editor, *Insight Guides: The Rhine, 1st Edition*, 1991, Höfer Press, Pte, Ltd.
- Munro, Lloyd A., *Chemistry in Engineering*, 1964, Prentice-Hall, Inc.
- Naar, Jon, *The New Wind Power*, 1982, Penguin Books
- Naeim, Farzad, Editor, *The Seismic Design Handbook*, 1989, Van Nostrand Reinhold
- Nickey, J.M., *The Stoneworker's Bible*, 1979, TAB Books
- Nolan, Michael S., *Fundamentals of Air Traffic Control*, 1990, Wadsworth Publishing Company
- Oey, Eric, Editor, *Insight Guides: Indonesia, 1st Edition*, 1985, Prentice-Hall, Inc.
- Parker, Sybil P., Editor, *McGraw-Hill Dictionary of Scientific and Technical Terms, 3rd Edition*, 1984, McGraw-Hill
- Parker, Sybil P., Editor, *McGraw-Hill Encyclopedia of Science and Technology, 6th Edition*, 1987, McGraw-Hill Book Company
- Peeples, Walter P., Jr., *Radiation Safety Training Manual for Well Loggers*, Gulf Nuclear, Inc.
- PennWell Publishing Company, *International Petroleum Encyclopedia 1993*, 1993, PennWell Publishing Company
- Perrottet, Tony, Editor, *Insight Guides: Chile, 1st Edition*, 1991, Höfer Press, Pte, Ltd.
- Perrottet, Tony, Editor, *Insight Guides: Ecuador and Galápagos, 1st Edition*, 1991, Höfer Press, Pte, Ltd.
- Perrottet, Tony, Editor, *Insight Guides: South America, 1st Edition*, 1990, Höfer Press, Pte, Ltd.
- Pretty, Ronald T., Editor, *Jane's Weapon Systems*, 1988, Jane's Information Group
- Radkai, Marton, Editor, *Insight Guides: Hungary, 1st Edition*, 1989, Höfer Press, Pte, Ltd.
- Ramsey, Dan, *Fences, Decks, and Other Backyard Projects, 2nd Edition*, 1988, TAB Books

- Reeves, Robert G., Editor, *Manual of Remote Sensing Volume I: Theory, Instruments, and Techniques*, 1975, American Society of Photogrammetry, Keuffel and Esser Company
- Reeves, Robert G., Editor, *Manual of Remote Sensing Volume II: Interpretation and Applications*, 1975, American Society of Photogrammetry, Keuffel and Esser Company
- Rhodes, Richard, *The Making of the Atomic Bomb*, 1986, Simon and Schuster
- Richelson, Jeffrey T., *America's Secret Eyes in Space*, 1990, Harper & Row, Publishers, Inc.
- Rider, David F., Editor, *Jane's Airport Equipment 1989-1990*, 1990, Jane's Information Group
- Rives-Micoud, Miquel; Zanghi, Joseph; and Hirokawa, Megumi, Editors, *Insight Guides: Tokyo 1st Edition*, 1991, Höfer Press, Pte, Ltd.
- Ross, Norman P. Ed., *The Life Pictorial Atlas of the World*, 1961, Time, Inc.
- Roston, Anne Sanders, Editor, *Insight Guides: Provence, 1st Edition*, 1989, Höfer Press, Pte, Ltd.
- Sandretto, Peter C., *Electronic Avigation Engineering*, 1958, International Telephone and Telegraph Corporation
- Sabins Jr., Floyd F., *Remote Sensing Principles and Interpretation, 2nd Edition*, 1987, W.H. Freeman and Compant
- Schwab, David, Editor, *Insight Guides: Caribbean, The Lesser Antilles, 1st Edition*, 1989, APA Press, Pte., Ltd.
- Selby, Samuel M., Editor, *Standard Mathematical Tables, 22nd Edition*, 1974, CRC Press
- Skolnik, Merrill, Editor, *Radar Handbook*, Second Edition, 1990, McGraw-Hill Publishing Company
- Skolnik, Merrill I., *Introduction to Radar Systems*, 1980, McGraw-Hill, Inc.
- Slama, Chester C., Editor, *Manual of Photogrammetry, 4th Edition*, 1980, American Society of Photogrammetry
- Smith, John T., *Manual of Color Aerial Photography, First Edition*, 1968, American Society of Photogrammetry
- Smoot, Robert C.; Price, Jack; and Barrett, Richard L., *Chemistry: A Modern Course*, 1965, Charles E. Merrill Books, Inc.
- Stannard, Dorothy, Editor, *Insight Guides: Morocco, 1st Edition*, 1989, Höfer Press, Pte, Ltd.
- Stannard, Dorothy, Editor, *Insight Guides: Tunisia, 1st Edition*, 1991, Höfer Press, Pte, Ltd.

- Stephens, John H., *Towers, Bridges and Other Structures*, 1976, Sterling Publishing Co., Inc.
- Stoner, Carol Hopping, Editor, *Producing Your Own Power*, 1974, Rodale Press
- Storry, Richard, *The Way of the Samurai*, 1978, Galley Press
- Sweeney, Philip, Editor, *Insight Guides: Gambia & Senegal, 1st Edition*, 1990, Höfer Press, Pte, Ltd.
- Taylor, Edwin, Editor, *Insight Guides: Brazil, 1st Edition*, 1989, APA Press, Pte., Ltd.
- Taylor-Wilkie, Doreen, Editor, *Insight Guides: Finland, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Taylor-Wilkie, Doreen, Editor, *Insight Guides: Norway, 1st Edition*, 1991, Höfer Press, Pte, Ltd.
- Tetley, L. and Calcutt, D., *Electronic Aids to Navigation: Position Fixing*, 1991, Edward Arnold
- Thorne, T.K., Editor, *Navigation Systems for Aircraft and Space Vehicles*, 1962, Pergamon Press, The MacMillan Company
- Toomay, J.C., *Radar Principles for the Non-Specialist, Second Edition*, 1989, Van Nostrand Reinhold
- Turnbull, Stephen R., *The Book of the Samurai: The Warrior Class of Japan*, 1982, Area Publishing, Inc.
- Waters, Kenneth H., *Reflection Seismology*, 1978, John Wiley and Sons
- Way, Douglas S., *Terrain Analysts*, 2nd Edition, 1985
- Weast, Robert C., Editor, *Handbook of Chemistry and Physics 55th Edition*, 1974, CRC Press
- Wexler, Merin, Editor, *Insight Guides: Great Britain, 3rd Edition*, 1989, APA Press
- Wexler, Merin, Editor, *Insight Guides: Wales, 1st Edition*, 1989, Höfer Press, Pte, Ltd.
- Wilson, J. and Hawkes J.F.B., *Optoelectronics: An Introduction*, 1983, Prentice-Hall International, Inc.
- Winter, Frank H., Editor, *Rockets Into Space*, 1990, Harvard University Press
- Yogerst, Joseph R., Editor, *Insight Guides: Southeast Asia, 1st Edition*, 1992, Höfer Press, Pte, Ltd.
- Yost, Graham, *Spy-Tech*, 1985, Facts on File
- Zenfell, Martha Ellen, Editor, *Insight Guides: Greek Islands, 1st Edition*, 1990, Höfer Press, Pte, Ltd.

U.S. Government Publications

- 3400th Technical Training Wing, 3420th Technical Training Group, Air Training Command, U.S. Air Force, *Technical Training: Imagery Intelligence Officer and Imagery Interpreter Specialist, Free World Defensive Missile Systems*, AFAITC-055, February 1984, 3400th Technical Training Wing
- 3400th Technical Training Wing, 3420th Technical Training Group, Air Training Command, U.S. Air Force, *Technical Training: Imagery Intelligence Officer and Imagery Interpreter Specialist, Ground Forces Installations*, AFAITC-141, March 1984, 3400th Technical Training Wing
- 3400th Technical Training Wing, 3420th Technical Training Group, Air Training Command, U.S. Air Force, *Technical Training: Imagery Intelligence Officer and Imagery Interpreter Specialist, Introduction to Military Support Subjects*, AFAITC-0101, June 1984, 3400th Technical Training Wing
- 3400th Technical Training Wing, 3420th Technical Training Group, Air Training Command, U.S. Air Force, *Technical Training: Imagery Intelligence Officer and Imagery Interpreter Specialist, Transportation*, AFAITC-103, June 1984, 3400th Technical Training Wing
- Air Force Intelligence Center, Photo Analysis Branch, Department of the Air Force, *Photographic Interpretation Keys: China*, AFM 200-113, TM 30 267, NAVAER 10-35-642, 1 May 1959, Department of the Air Force
- Baker, Simon and Dill, Henry W., Jr., *The Look of Our Land, An Airphoto Atlas of the Rural United States: The Far West*, Agricultural Handbook No. 372, U.S. Department of Agriculture, Economic Research Service, January 1970, U.S. Government Printing Office
- Baker, Simon and Dill, Henry W., Jr., *The Look of Our Land, An Airphoto Atlas of the Rural United States: The Mountains and Deserts*, Agricultural Handbook No. 409, U.S. Department of Agriculture, Economic Research Service, May 1971, U.S. Government Printing Office
- Banks, Donald D. and Corliss, William R., *Wind Tunnels of NASA*, National Aeronautics and Space Administration, Scientific and Technical Information Branch, 1981, Government Printing Office NASA SP-400
- Bowditch, Nathaniel, LL.D., *American Practical Navigator, Publication No. 9*, 1984, Defense Mapping Agency Hydrographic/Topographic Center
- Bureau of Aeronautics, U.S. Naval Photographic Intelligence, Department of the Navy, *Photographic Interpretation Keys: Inland Transportation and Wire Communications*, NAVAER 10-35-632, AFM 200-48, 1 December 1958, Department of the Navy

- Bushur Gregory J.; Szigeti, George J.; and Wheat, Stephen L, Photo Interpretation Training Working Group, Defense Mapping Agency Aerospace Center, *MK 90 Illustrated Glossary Photo Interpretation Keys, Section 1, Cultural Features*, January 1994, DMA
- Bushur Gregory J.; Szigeti, George J.; and Wheat, Stephen L, Photo Interpretation Training Working Group, Defense Mapping Agency Aerospace Center, *MK 90 Illustrated Glossary Photo Interpretation Keys, Section 8, Aeronautical Database Management*, January 1994, DMA
- Cartographic Department, Defense Mapping Agency Aerospace Center, *M C & G Imagery Interpretation Course Handbook*, Defense Mapping Agency Aerospace Center
- Central Intelligence Agency, *USSR Energy Atlas*, 1985, Government Printing Office
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XIII (TM 30-324), Submarines*, April 1983, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XII (TM 30-281), Military Aircraft of the World*, April 1984, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXXIII (TM 30-663), Crates, Containers and Coverings*, February 1984, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXXI (TM 30-254), Electric Power*, January 1979, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXXIV (TM 30-305), Interpretation of Infrared*, January 1984, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume V (TM 30-317), World Tactical Vehicles*, January 1985, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume IX (TM 30-604), General Transport Equipment*, July 1982, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume VII (TM 30-315), World Mobile Gap and River Crossing Equipment*, July 1983, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume X (TM 30-322), World Electronics*, July 1983, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume II (TM 30-308), World Tanks and Self-Propelled Artillery*, July 1984, DIA

- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXIV (TM 30-330), Airfield Installations*, June 1976, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XV (TM 30-331), Patrol Type Combatants*, June 1979, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXVIII (TM 30-265), Petroleum Industries*, June 1980, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XI (TM 30-316), World Missiles and Rockets*, June 1984, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume VI (TM 30-320), Combat Engineer Equipment*, March 1978, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXVI (TM 30-256), Inland Transportation*, May 1980, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume VIII (TM 30-600), Coke, Iron and Steel Industries*, May 1981, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXIII (TM 30-601), Camouflage, Concealment, and Deception*, May 1982, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XIV (TM 30-328), Major Surface Combatants*, May 1983, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXV (TM 30-285), Consolidated JIIS*, May 1983, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXIX (TM 30-274), Nonferrous Metals Industries*, May 1984, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXXII (TM 30-260), Fabrication Industries*, October 1984, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume XXVII (TM 30-264), Military Installations*, September 1977, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume IV (TM 30-321), General Transport Equipment*, September 1979, DIA
- Defense Intelligence Agency, *Joint Imagery Interpretation Keys Structure, DIAM 57-7, Volume III (TM 30-312), World Towed Artillery*, September 1983, DIA

- Defense Intelligence Agency, *Point Reference Guide Book*, DDM-2600-725-81, February 1982, Defense Intelligence Agency
- Defense Mapping Agency, *Digital Production System Illustrated Glossary Photo Interpretation Keys*, Section 2 January 1994, DMA
- Defense Mapping Agency, *DMA Standard Supporting Mark 90: Section 100 Glossary of Feature/Attribute Definitions*, 3rd Edition, December 1988, Defense Mapping Agency
- Defense Mapping Agency, *Military Specification: Planning Terrain Analysis Data Base* (PTADB) MIL-P-89305, 30 October 1990, Defense Mapping Agency
- Defense Mapping Agency Aerospace Center, *Photo Interpretation Keys*, Defense Mapping Agency Aerospace Center, May 1977, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency, Production and Operations Directorate, U.S. Naval Observatory, *DMA Technical Manual: DMA Vertical Obstruction File (DVOF)* DMA TM 8321.1, March 1986, Headquarters, Defense Mapping Agency
- Defense Mapping Agency Aerospace Center, *Defense Mapping Agency Product Specifications for Digital Feature Analysis Data (DFAD) Level 1 and Level 2*, 2nd Edition, PS/ICE/200 and PS/ICG/200, April 1986, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency Aerospace Center, *Defense Mapping Agency Product Specifications for Joint Operations Graphic (Radar) Series 1501 Radar Scale 1:250,000*, 2nd Edition, PS/4AC/390, November 1989, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency Aerospace Center, *Defense Mapping Agency Product Specifications for US Air Target Chart Series 200 Scale 1:200,000*, 2nd Edition, PS/4AA/380, January 1981, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency Aerospace Center, *Feature Extraction System (FE/S) Production Supplement to Defense Mapping Agency Digital Feature Analysis Data (DFAD)*, 2nd Edition, SUPP2DFAD, March 1989, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency Aerospace Center, *Optics, Cameras, Photometrics, and Image Identification*, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency Aerospace Center, *Photo Interpretation Keys*, Defense Mapping Agency Aerospace Center, May 1977, Defense Mapping Agency Aerospace Center

- Defense Mapping Agency Aerospace Center, *Supplemental Guidance to Defense Mapping Agency Product Specifications for US Air Target Chart Series 200 PS/4AA/380, 2nd Edition*, 1 September 1988, Defense Mapping Agency Aerospace Center
- Defense Mapping Agency Hydrographic/ Topographic Center, *Defense Mapping Agency Product Specifications for Harbor, Approach and Coastal Charts Supporting Mark 90 Systems*, PS/2AA/000 and PS/2AB/000, 3rd Edition, DMA, Washington, D.C., December 1988.
- Defense Mapping Agency Hydrographic/ Topographic Center, *Nautical Charting with Remotely Sensed Imagery, Volumes I*, TITAN Systems Incorporated, Vienna, Virginia, 1984.
- Defense Mapping Agency Hydrographic/ Topographic Center, *Nautical Charting with Remotely Sensed Imagery, Volumes II*, TITAN Systems Incorporated, Vienna, Virginia, 1984.
- Defense Mapping Agency Hydrographic/ Topographic Center, *Defense Mapping Agency Product Specifications for 1:50,000 Scale Topographic Maps of Foreign Areas, 1st Edition*, PS/3AA/101, July 1980, DMA Hydrographic/Topographic Center
- Defense Mapping Agency Topographic Center, *Defense Mapping Agency Product Specifications for Joint Operations Graphics Series 1501 and Series 1501 Air Scale 1:250,000, 4th Edition*, PS/1AE/201 and PS/3BB/201, November 1976, Defense Mapping Agency Topographic Center
- Defense Mapping Agency Hydrographic/ Topographic Center, *Defense Mapping Agency Product Specifications for Topographic Maps 1:100,000 Scale, 2nd Edition*, PS/3AG/201, March 1990, DMA Hydrographic/Topographic Center
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Chemical Industries* (DMS No. ST 543), January 1978, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Coke, Iron, and Steel Industries* (DMS No. ST 555), April 1983, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Industrial Handouts* (DMS No. ST 556), April 1983, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Nonferrous Industries* (DMS No. ST 549), April 1983, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Petroleum Industries* (DMS No. ST 553), April 1983, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Ports and Port Facilities* (DMS No. ST 554), August 1981, Defense Mapping School

- Defense Mapping School, Defense Mapping Agency, *Student Handout: Power/Water Facility Clue Sheet* (DMS No. ST 527), March 1983, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Handout: Terrain Evaluation for Quarry Site Selection Using Aerial Photography* (DMS No. ST 548), January 1978, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Pamphlet: Airfield Facilities* (DMS No. ST 209), September 1981, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Pamphlet: Highways and Bridges* (DMS No. ST 215), July 1981, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Pamphlet: Inland Waterway Facilities* (DMS No. ST 217), September 1982, Defense Mapping School
- Defense Mapping School, Defense Mapping Agency, *Student Pamphlet: Railroads* (DMS No. ST 216), August 1981, Defense Mapping School
- Defense Mapping Agency, *Defense Mapping Agency Product Specifications for 1:50,000 Scale Topographic Line Map Supporting Mark 90 Systems*, PS/3AA/000, 3rd Edition, DMA, Washington, D.C., December 1988.
- Defense Sensor Interpretation and Application Training Program, *Fundamentals of SAR Interpretation*, HO-ASIAT-3, 3428 Technical Training Squadron, Armed Forces Air Intelligence Training Center, U.S. Air Force, February 1985, 3428 Technical Training Squadron
- Defense Sensor Interpretation and Application Training Program, *Radar Imaging Principles*, HO ASIAT-1, 3428 Technical Training Squadron, Armed Forces Air Intelligence Training Center, U.S. Air Force, December 1984, 3428 Technical Training Squadron
- Department of Defense, *Soviet Military Power 1985, Fourth Edition*, 1985, Government Printing Office
- Department of Defense, *Soviet Military Power 1990, Ninth Edition*, 1990, Government Printing Office
- Department of Intelligence Training, U.S. Air Force School of Applied Aerospace Sciences (ATC), *Imagery Interpreter Technician CDC 20670, Supplementary Material, Volume 1* (AFSC 20670), Extension Course Institute, August 1975, Extension Course Institute
- Department of Intelligence Training, U.S. Air Force School of Applied Aerospace Sciences (ATC), *Imagery Interpreter Technician CDC 20670, Volume 3: Military Installations and Equipment* (AFSC 20670), Extension Course Institute, August 1975, Extension Course Institute

- Department of Intelligence Training, U.S. Air Force School of Applied Aerospace Sciences (ATC), *Imagery Interpreter Technician CDC 20670, Volume 4* (AFSC 20670), Extension Course Institute, Air University, August 1975, Extension Course Institute
- Department of the Army, Department of the Air Force, *Ammunition General*, TM 9-1900, TO 11A-1-20, June 1956, U.S. Government Printing Office
- Department of the Army, U.S. Army Engineer School, *Engineer Field Data*, FM 5-34, 14 September 1987, Government Printing Office
- Department of the Army, U.S. Army Field Artillery School, *The Threat-Organization, Tactics and Equipment* (TC6-4-2), 31 December 1976, U.S. Army Field Artillery School ATSF-TD-TM
- Department of the Army, U.S. Army Intelligence and Security Command, 513th Military Intelligence Group, 203rd Military Intelligence Battalion, *Consolidated Technical Intelligence Bulletins*, 1984, Government Printing Office
- Department of the Navy, *Photographic Interpretation Keys: Shipbuilding Industries*, AFM 200-54, NAVAER 10-35-626, 2 December 1957, Department of the Navy
- The Desert Processes Working Group: USETL & USGS, *Remote Sensing Field Guide, Desert: A Guide to Analyzing Desert Landforms*, (OH 0-52), Commanding General Marine Corps, Combat Development Command, August 1990, Marine Air-Ground Task Force Warfighting Center
- Extension Course Institute, Air Training Command, *Student Study Packet: Imagery Interpreter Specialist, Volume 4* (20650 04 S01 7910), 1982, U. S. Government Print Office
- Farr, Holland H., *Transmission Line Design Manual*, U.S. Department of the Interior, Water and Power Resources Service, 1980, U.S. Government Printing Office
- Frisch, Joel; Thomas, Richard P.; and Peebles, Roger, *Department of Defense Water Resources Data Base: Water Resources Overlays Users Guide*, ETL-TAC MISC 01-91, U.S. Geologic Survey, U.S. Department of the Interior and Terrain Analysis Center, U.S. Army Engineer Topographic Laboratories, U.S. Army Corps of Engineers, December 1990, U.S. Army Engineer Topographic Laboratories
- Frodigh, Roland J., *Terrain Analysis Procedural Guide for Built-Up Areas (Report No. 13 in the ETL Series on Guides for Army Terrain Analysts)* ETL-0354, U.S. Army Engineer Topographic Laboratories, U.S. Corps of Engineers, April 1984, U.S. Army Engineer Topographic Laboratories
- Headquarters, Department of the Army, *The Soviet Army: Troops, Organization and Equipment* (FM 100-2-3), 16 July 1984, U.S. Army Adjutant General Publications Center

Bibliography

63 Photo Interpretation Principles

- Lutz, Charles Editor, *Intelligence: Radar Prediction and Associated Intelligence Support*, TAC Regulation 200-2 (TACR 200-2), Department of the Air Force, Tactical Air Command, 28 February 1986, Headquarters Tactical Air Command
- McCurdy, P.G., *H.O. Pub. No. 592, Manual of Coastal Delineation from Aerial Photographs*, 1947, United States Navy Hydrographic Office
- Narducci, Dr. Henry M. and Smith, SSGT Jerry W. Editors, *From Shark to Peacekeeper: A Pictorial History of Strategic Air Command Missiles*, Office of the Historian, Headquarters Strategic Air Command, U.S. Air Force, Department of Defense, 1 May 1990, Government Printing Office
- National Oceanic and Atmospheric Administration, National Ocean Service and the Defense Mapping Agency Hydrographic/ Topographic Center, *Chart No.1, United States of America, Nautical Chart Symbols and Abbreviations*, DMA Stock No. WOBZC1, 1990, Department of Commerce
- Naval Reconnaissance and Technical Support Center, Naval Reconnaissance and Technical Support Center, Naval Air Systems Command, The Department of the Navy, Department of Defense, *Image Interpretation Handbook, Volume 1* (TM 30-245, NAVAIR 10-35-685, AFM 200-50), December 1967, Government Printing Office
- North Atlantic Treaty Organization (NATO), *Air Reconnaissance Intelligence Reporting Nomenclature*, ATP-26(A), January 1989, North Atlantic Treaty Organization Military Agency for Standardization (MAS)
- Photo Analysis Branch, Air Force Intelligence Center, Department of the Air Force, Department of Defense, *Intelligence Photographic Interpretation Keys: Mechanical Processing Industries*, AFM 200-59, NAVAER 10-35-647, 1 April 1960, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Intelligence Photographic Interpretation Keys: Southeastern Europe*, AFM 200-116, NAVWEPS 10-35-654, 1 January 1961, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: Caucasus*, AFM 200-117, TM 30-266, 1 May 1959, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: Chemical Processing Industries*, AFM 200-60, TM 30-263, NAVAER 10-35-639, 1 June 1959, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: Electric Power*, AFM 200-45, NAVAER 10-35-629, TM 30-254, October 1957, Department of the Air Force

- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: European U.S.S.R.*, AFM 200-111, NAVAER 10-35-625, TM 30-248, January 1957, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: Heat Processing Industries*, ACS/IM 200-57, March 1959, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: Industrial Components*, AFM 200-49, NAVAER 10-35-630, TM 30-260, January 1958, Department of the Air Force
- Reconnaissance Branch, Headquarters U.S. Air Force, Department of the Air Force, *Photographic Interpretation Keys: Public Utilities*, AFM 200-46, TM 30-249, January 1957, Department of the Air Force
- Rinker, J.N. and Corl, P.A., *Air Photo Analysis, Photo Interpretation Logic, and Feature Extraction*, ETL-0329, U.S. Army Engineer Topographic Laboratories, U.S. Corps of Engineers, June 1984, U.S. Army Engineer Topographic Laboratories
- Robinson, Rogers Project Officer, *DMAAC Technical Report: Test and Evaluation of USAF Project 1183, Digital Data Bases (DMAAC TR 79-1)*, Defense Mapping Agency Aerospace Center, February 1979, Defense Mapping Agency Aerospace Center
- Rydstrom, H.O., La Prade, G.L., and Leonardo, E.S., *Thematic Mapping and Map Compilation from Radar Imagery*, U.S. Army Engineers, Topographic Laboratories, July 1980, Goodyear Aerospace, Arizona Division
- Target Intelligence Division, Air Force Intelligence Service, *An Introduction to Air Force Targeting*, AFP 200-17, Department of the Air Force, Department of Defense, 11 October 1978, Target Intelligence Division
- Tazelaar, James, *Synthesis Guide for Lines of Communication (Report No. 7 in the ETL Series on Guides for Army Terrain Analysts)* ETL-0263, U.S. Army Engineer Topographic Laboratories, U.S. Corps of Engineers, June 1981, U.S. Army Engineer Topographic Laboratories
- Tazelaar, James, *Terrain Analysis Procedural Guide for Railroads (Report no. 10 in the ETL Series on Guides for Army Terrain Analysts)* ETL-0311, U.S. Army Engineer Topographic Laboratories, U.S. Corps of Engineers, December 1982, U.S. Army Engineer Topographic Laboratories
- U.S. Army, *Field Manual 5-33 - Terrain Analysis*, 1990, Department of the Army
- U.S. Army, *Field Manual 30-10 - Military Geographic Intelligence (Terrain)*, 1972, Headquarters, Department of the Army
- U.S. Army Engineer School, U.S. Army Corps of Engineers, *ENCOA Student Workbook: Fixed Bridges*, June 1976, U.S. Army Engineer School

- U.S. Army Intelligence Center and School, *Communist Weapons and Equipment Handbook* (SupR 66152), January 1976, U.S. Army Intelligence Center and School
- U.S. Atomic Energy Commission, Division of Technical Information, *Nuclear Terms: A Brief Glossary*, February 1967, U.S. Atomic Energy Commission
- U.S. Department of Transportation, Federal Aviation Administration, Flight Information and Obstructions Branch (ATQ-210), *Airman's Information Manual: Official Guide to Basic Flight Information and ATC Procedures*, August 23, 1990, Government Printing Office
- U.S. Naval Photographic Intelligence Series, Chief of Naval Operations, Bureau of Aeronautics, *Photographic Interpretation Keys: Military Installations* (NAVAER 10-35-640, AFM 200-61, TM 30-264), 1 June 1959, Bureau of Aeronautics
- U.S. Naval Photographic Interpretation Center, *Photographic Interpretation Key, Beach Interpretation*, 1961, NAVWEPS 10-35-658, United States Navy
- Vogel, Theodore C., *Terrain Analysis Procedural Guide for Roads and Related Structures (Report No. 2 in the ETL Series on Guides for Army Terrain Analysts)* ETL-0205, U.S. Army Engineer Topographic Laboratories, U.S. Corps of Engineers, October 1979, U.S. Army Engineer Topographic Laboratories

Journals

- Almquist, Peter, "Defence Industry in the East: The Drive to Survive", *Military Technology*, Vol. XVII Issue 11, 1993, pp 32-41
- ARAMCO World, "Islam's Path East", *ARAMCO World*, Vol. 42 No. 6, November-December 1991, pp 2-67
- Bahnemann, Jörg and Enders, Thomas, "Reconsidering Ballistic Missile Defence", *Military Technology*, Vol. XV Issue 4, 1991, pp 46-52
- Beitzel, Udo, "Concepts and Requirements for Future Air Defence", *Military Technology*, Vol. XVI Issue 10, 1992, pp 76-78
- Blau, Tom, "TMD in the Clinton Era", *Military Technology*, Vol. XVII Issue 7, 1993, pp 16-23
- Boasignore, Ezia, "The FSAF Challenge", *Military Technology*, Vol. XVI Issue 12, 1993, pp 22-32
- Brown, Sandford, "Producing Oil and Gas From Subsea Wells", *The Lamp*, Vol. 74 No. 1, Spring 1992, pp 8-11
- Eshel, David, "The Iraqi Air Force- How Effective Is It?", *Military Technology*, Vol. XV Issue 2, 1991, pp 72-76

- Heckmann, Erhard, "The German TLVS Programme", *Military Technology*, Vol. XVI Issue 4, 1992, pp 79-83
- Heitmann, Helmoed-Romer, "New South African Air Defence Equipment", *Military Technology*, Vol. XV Issue 12, 1991, pp 57-57
- Higgs, Gary Editor, "Geoscience Applications of Imaging Radar Systems", *Remote Sensing of the Electro Magnetic Spectrum*, Volume 3, Number 3, July 1976, pp 1-151
- Lamberton, Lance L., "Developing Oil and Gas Worldwide", *The Lamp*, Vol. 74 No. 3, Fall 1992, pp 1-5
- Liebstone, Marvin, "CORPSAM: From Idea to Reality", *Military Technology*, Vol. XVI Issue 10, 1992, pp 92-94
- Luxner, Larry, "Jabal'Ali Dubai's Gateway to the World", *ARAMCO World*, Vol. 43 No. 2, March-April 1992, pp 32-37
- Martin, Josh, "Preserving a City", *ARAMCO World*, Vol. 44 No.3, May-June 1993, pp 20-27
- Military Technology, "GE and the Air Defence Solution, Interview with Mr. Chuck Meeks", *Military Technology*, Vol. XV Issue 6, 1991, pp 33-35
- Military Technology, "The HVSD/ADAM Air Defence System", *Military Technology*, Vol. XV Issue 12, 1991, pp 38-42
- Military Technology, "Russian Arms Export Policy Detailed: Interview with General S.A. Karaoglanov, Chairman of VO Oboronexport (GED)", *Military Technology*, Vol. XVI Issue 10, 1992, pp 53-56
- Military Technology, "News", *Military Technology*, Vol. XVI Issue 10, 1992, pp 106-112
- Military Technology, "Retro Tech", *Military Technology*, Vol. XVII Issue 8, 1993, pp 82-84
- Nash, Trevor, "Providing the Capability- British Army Procurement Programmes", *Military Technology*, Vol. XVII Issue 9, 1993, pp 19-23
- Nash, Trevor, "The Changing Face of AD in the UK", *Military Technology*, Vol. XVII Issue 7, 1993, pp 24-26
- Oerlikon Aerospace, "ADATS- Tactical Air Defence for the Next Millennium", *Military Technology*, Vol. XVI Issue 3, 1992, pp 72-79
- Oluengin, Nihal and Oluengin, Bülent, "Homes of Old Makkah", *ARAMCO World*, Vol. 44 No. 4, July-August 1993, pp 20-29
- Promé, Jean-Louis, "Towards a French Non-Nuclear Deterrent", *Military Technology*, Vol. XVII Issue 6, 1993, pp 46-50

Bibliography

67 Photo Interpretation Principles

- Roy, Norbert, "Air Defence- The Technological Possibilities", *Military Technology*, Vol. XVI Issue 10, 1992, pp 81-86
- Smith, William D., "Chile and Copper", *The Lamp*, Vol. 75 No. 2, Summer 1993, pp 1-8
- The Lamp, "Panorama", *The Lamp*, Vol. 74 No. 3, Fall 1992, p 20
- The Lamp, "Panorama", *The Lamp*, Vol. 74 No. 4, Winter 1992, pp 20-21
- Thomson CSF Electronic Systems Division, "Thomson-CSF/DSE Air Defence as a Service", *Military Technology*, Vol. XVII Issue 6, 1993, pp 33-40
- Tracy, William, "Stones That Did the Work of Man", *ARAMCO World*, Vol. 44 No. 6, November-December 1993, pp 20-27
- Velocci, Anthony L., Jr., "Creating Liquid Fuels From Natural Gas", *The Lamp*, Vol. 73 No. 3, Fall 1991, pp 14-20
- Velocci, Anthony L., Jr., "Cat Cracking's First 50 Years", *The Lamp*, Vol. 74 No. 2, Summer 1992, pp 12-20
- VO Oboronexport (GED) and Industrial Promotion Group-Moscow, "The S-300PMU-1 Air Defence/ATBM SAM System", *Military Technology*, Vol. XVII Issue 11, 1993, pp 90-92
- VO Oboronexport (GED) and Industrial Promotion Service-Moscow, "BUK: Setting New Standards in Medium-Range Air Defence", *Military Technology*, Vol. XVII Issue 9, 1993, pp 57-60
- VO Oboronexport (GED) and Industrial Promotion Service-Moscow, "S-300V: The ATBM Trendsetter", *Military Technology*, Vol. XVII Issue 8, 1993, pp 78-80
- VO Oboronexport (GED) and Industrial Promotion Service-Moscow, "256M TUNGUSKA: The World's First Gun/Missile SP AA System", *Military Technology*, Vol. XVII Issue 7, 1993, pp 38-42
- Werner, Louis, "Across the High Atlas", *ARAMCO World*, Vol. 44 No. 2, March-April 1993, pp 16-20
- Wilson, Walter K., "First in Norway", *The Lamp*, Vol. 75 No. 3, Fall 1993, pp 21-27
- Zwicker, Denise Allen, "Drilling Sideways", *The Lamp*, Vol. 73 No. 1, Spring 1991, pp 8-11
- Zwicker, Denise Allen, "Unseen But Essential: The Role of Offshore Pipelines", *The Lamp*, Vol. 73 No. 4, Winter 1991, pp 14-19



CHAPTER 1 – INTRODUCTION

Contents

This module deals specifically with man-made features. Features including and relating to buildings and built-up areas, transportation facilities, industries, communications, etc. are included. A few man-made or man-modified features, such as orchards and reservoirs, have been left to other modules where the logical relationship is more appropriate.

An in depth explanation of airfields, facilities and navigational aids is given in Module 6, Aeronautical Data Maintenance.

The explanations of many features go beyond that which is photo-identifiable. This information is included to give the student a better understanding of the subject so that these features can be more readily identified when found in non-standard configurations or unusual locations.

Organization

This module has been organized so that it follows a logical progression. Information on basic features, such as buildings and transportation is presented first, followed by industries, communication, and cultural areas. The sequence within each section proceeds from general to specific information.

Features have been presented, as far as possible, in functional groupings. This results in some repetition between sections, but the relationships within these groups are important clues to the identification of many features.

A list of terms and their definitions is included after some sections. In addition to words used within the handbook, terms which the analyst may encounter in source references are included.

Sometimes, DMA specifications define a term differently than the general usage, or different definitions are used for different products. Notes to this effect are presented in *italics*.

This student handbook is unclassified. A classified supplement to the handbook is available. The supplement contains additional information derived from classified sources. Reference is made to the supplement in those sections of the handbook where additional, classified material is available.

CHAPTER 2 – BUILDINGS

General

Buildings, no matter what their function, have certain characteristics. These characteristics affect the appearance of the building, and often give clues as to its function. In this section, we will examine building structure types, roof types and construction materials. Identification of building functions will be covered in subsequent sections.

Physical considerations dictate the limitations on building construction and structural characteristics. The type of construction used is dependent on the size and purpose of the building, the cost and availability of construction materials, and the cost and availability of labor and technology. Buildings with the same function will usually be of similar appearance, as the function will dictate certain characteristics. However, geographic differences occur due to the availability of, or lack of construction materials, labor and technology. Building ornamentation also varies due to cultural differences, causing superficial differences in appearance. The successful analyst takes all of these factors into consideration when studying a built up area.

Building Structures

Building structures are classified by the way in which the weight of the building is supported. The most common structural types are framed construction, load bearing wall construction and composite construction. Stressed skin construction is used mostly for light framed structures such as storage buildings. Pneumatic buildings are inflatable structures, normally used as temporary or portable facilities.

Structural Supports

Column and Lintel

In column (or post) and lintel construction, support for the structure is provided by columns or load bearing walls. Various types of structures transmit the weight of the roof or upper floors to the supports. The simplest, and most common method is the column and beam structure. A series of horizontal beams, composed of steel, reinforced concrete or wood support the weight of the roof, and in turn are supported by columns. The columns may be composed of steel, masonry, reinforced concrete or wood.

A truss is used where a simple beam is not strong enough to bear the necessary load, especially where increased floor space between columns is needed. Trusses are normally steel, but may be wood (especially in smaller buildings, e.g. the rafters in single family houses) or reinforced concrete. Truss structures also allow

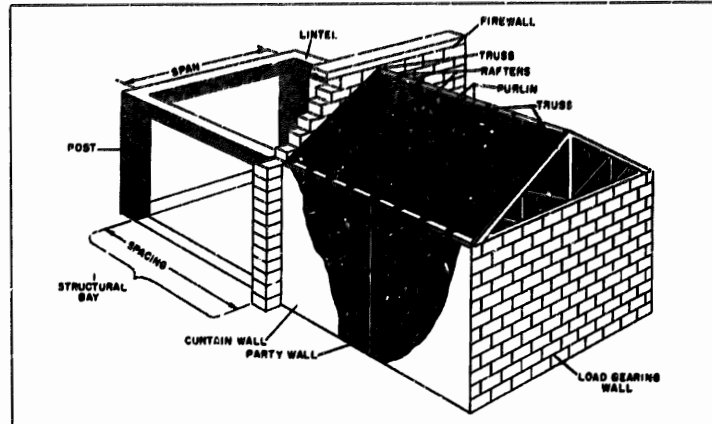


Figure 1: Composite sketch showing basic building structural forms

lighter materials, such as wood, to carry a heavier load. Wood trusses are often used when steel beams are not available, or when steel is considered too expensive.

Arch

An arch is used to support the roof when a truss cannot, either structurally or economically, provide sufficient clear floor space and/or the required vertical clearance. Aircraft hangers frequently use an arch structure.

Masonry arches are occasionally used, but are limited to a span of about 60 feet (18 meters). A braced arch is composed of steel trusses, and can span from 100 to 300 feet (30 to 90 meters). A rigid frame arch can be built with steel, reinforced concrete or wood, and can span from 60 to 200 feet (18 to 60 meters).

Cantilever

Cantilever supports are used primarily in buildings of light construction, and usually for decorative purposes. In industrial applications, they are used for some warehouses and other light buildings. They are more common in commercial and some institutional buildings, where their unique architectural configuration is desired.

A cantilever support consists of a post or column supporting an anchor arm and a cantilever arm. The anchor arm is shorter and more massive, and balances the weight of the longer cantilever arm. In some cases, the mass of the column provides the counter balance to the cantilever. In other systems, a central column supports two opposing cantilever arms. To increase the distance between sup-

ports, a suspended arm may be placed between two cantilevers. Cantilever support systems may be composed of steel beams or trusses, reinforced concrete, or occasionally wood.

Dome

Domes are used primarily as architectural ornaments for public buildings, churches, terminals, etc. They provide a large open space with a high ceiling. The weight of the dome is transmitted evenly around its circumference.

A geodesic dome derives its strength from a geometric lattice of trusses. The pattern of triangles or polygons that comprise the lattice gives it a faceted appearance. This is distinct from the smooth surface of a regular dome.

Structure Types

Load Bearing Walls

Buildings with load bearing walls are substantial structures, composed of stone masonry, concrete or other materials capable of withstanding a compressive load. As the name implies, the weight of the structure is supported entirely by a series

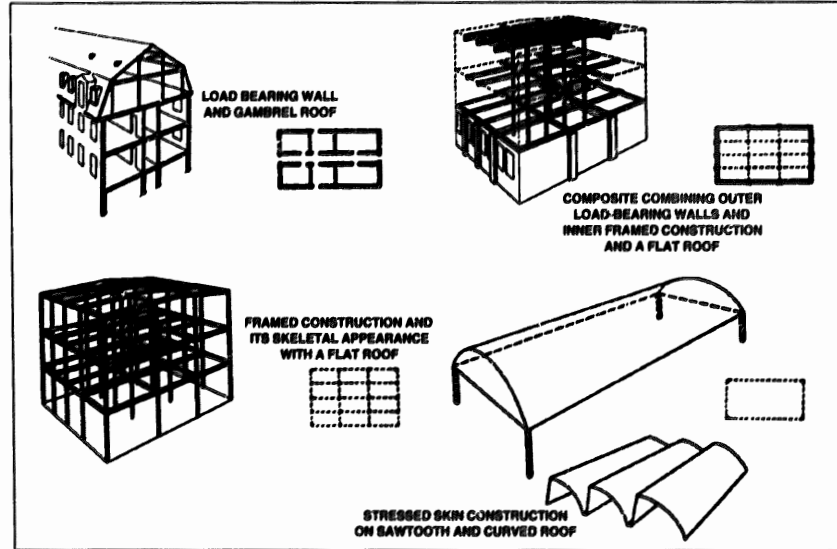


Figure 2: The four basic types of building structures

of walls. The spans between the walls normally will not exceed 20 to 25 feet (< 10 meters). The size and shape of the interior rooms are limited by the arrangement of the bearing walls.

Stone:

Stone is not used frequently in modern buildings because of the high cost. However, its high compressive strength make it an excellent material for construction of larger structures. Classical architecture made extensive use of stone for palaces, churches, government and institutional buildings. The increasing cost of stone construction, and the development of less costly framed structures, is reflected by the low percentage of stone buildings in newer built-up areas. Modern use of stone is, in many places, restricted to government and institutional buildings where the desire to maintain traditional appearances outweighs the cost.

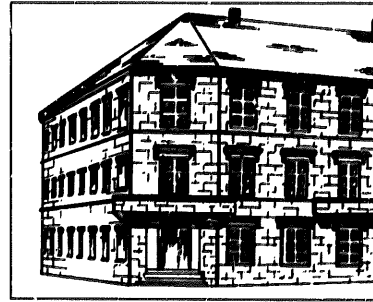


Figure 3: Multi-story, masonry building, bearing wall construction

The principal recognition factors for a load bearing structure built of stone are:

- The structure has a heavy, substantial, massive appearance.
- The walls in stone buildings are, by necessity, thick, causing windows and doors to be recessed. The width of the walls may also be observed if parapets are present on the roof.
- There are relatively few windows and doors. They are normally small, and frequently have arches at the top to maintain structural integrity.
- The color or tone will vary with the type of stone used. If larger blocks are used, the pattern of joints between the blocks may be visible. The surface may be smooth if cut stone is used, or rough if the blocks are of shaped stone.

Note: Framed structures are sometimes faced with stone. The thinner walls and abundance of windows and doors will help to distinguish these. Since stone is expensive, frequently only the front of the building would be faced.

Brick:

Brick, adobe, cement blocks and cinder blocks are man-made substitutes for stone and their collective use is referred to as masonry construction. (Stone construction is also included as a subcategory of masonry.) As such, they are much less expensive, and are frequently used in smaller buildings in areas where the raw materials are available and/or wood is not available. Construction methods are similar, but adobe is restricted geographically, while cement and cinder

blocks are used mainly for industrial or storage buildings, and some small commercial buildings. In addition, cement or cinder block walls are sometimes covered with a decorative facing, such as brick, artificial stone, plaster (stucco) or siding, particularly in small commercial buildings.

The way in which masonry (particularly brick) buildings are constructed gives these buildings a distinctive appearance. Load bearing walls can be distinguished from framed structures faced in brick by the use of these characteristics.

The principal recognition factors for a load bearing structure built of brick are:

- Load bearing walls are characterized by relatively small windows and doors with lintels or brick arches above them to maintain structural integrity.
- Because the walls provide the structural support, windows and doors cannot exceed more than one third of the wall, unless special measures are taken.
- Windows and doors must be aligned vertically to maintain structural integrity. The sections of wall between openings provides the load-bearing strength.
- Load bearing walls must be sufficiently thick to support the cumulative weight of the roof and upper stories. Therefore, the walls on the lower stories are thicker than the walls on the upper stories. Windows and doors are recessed in proportion to the thickness of the walls, with windows on the lower floors being recessed deeper. In some cases, additional glass is placed flush with the exterior of the wall, concealing the recessed interior window.
- Floor joists must be anchored in the side walls, particularly in larger structures, and anchor plates or wedges (often decorated) may be visible.
- Load bearing wall structures rarely exceed 6 stories in height.

Brick load bearing walls are used in all classes of buildings where a nearby source of bricks makes it economical. The increase in the use of concrete because of its strength, versatility and lower labor cost results in fewer new buildings made of brick. However, older brick structures are locally plentiful.

Concrete:

Concrete has high compressive strength, making it an excellent material for load bearing walls. In addition, it can be given substantial tensile strength through the addition of steel reinforcing rods. Thus it can be used for floors, ceilings, roofs, and as beams, as well as for walls. It is easily handled by machinery, reducing labor costs during construction.

Load bearing buildings made of concrete fall into three categories: poured-in-place, tilt-up, and box-wall. The first two are very similar in design, and vary only in the way they are assembled. In the first, forms are assembled where the floors, walls etc. are to be located, and the concrete is poured into the forms.

The concrete structure is formed in place. In tilt-up construction, the walls are laid in slabs on the ground and lifted or tilted into place. The tilt-up method requires a high level of technology, and is used where labor costs are expensive. In either case, the interior walls may be either load bearing or framed. These methods are rarely used in buildings taller than one or two stories, usually for storage buildings, industrial buildings and public buildings such as auditoriums and gymnasiums.

The principal recognition factors for a load bearing structure of poured-in-place or tilt-up construction are:

- They are low structures, usually one or two stories, but they may be 20 feet (6 meters) or more in height.
- There are few window and door openings, which are small. Most structures of this type require little natural light, but may use skylights (often "sawtooth") in the roof.
- The walls must be thick enough to support the weight of the structure. This is reflected by the recessed doors and windows.
- They are usually of a simple box shape. Construction costs are kept down by the simple design, appropriate for industrial and storage structures.
- Roofs will not be high pitched. Normally a low arch or horizontal truss support is used. Sawtooth skylights may be present.

Box-wall construction uses a framework of load bearing walls braced with concrete floor/ceilings, resulting in a structure composed of a series of boxes of uniform size and shape. This type of construction can be used for multi-story buildings, and is commonly used for apartment buildings and hotels. This is a relatively recent form and is found in newer developments.

The principal recognition factors for a load bearing structure built of box-wall construction are:

- The individual cells (boxes) that comprise the building structure can usually be identified from the exterior of the building. Only one wall of each cell, that which faces outward has windows.
- The walls are thick, resulting in recessed windows and doors, but less than on other load bearing walls because of the added support of the concrete floor/ceilings.
- The added support of the concrete floor/ceilings also allows the walls to maintain a constant thickness rather than being more massive on lower floors.

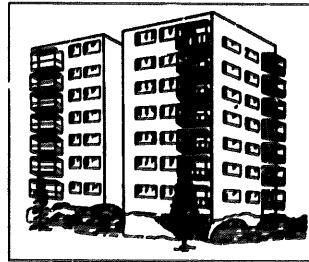


Figure 4: High-rise concrete building, box-wall construction

- There are few windows and doors, especially on end walls. End walls will often have only a single vertical row of windows to provide light to stairwells.
- The roof will normally be flat because of the box-wall construction.

Framed Construction

Framed construction consists of a rigid framework of supporting columns and beams (posts and lintels) over which the walls and roof are constructed. The framing can be composed of wood (for smaller structures) steel, concrete, or a combination. When the columns are made of one material and the beams or trusses of another, it is called a "composite framed structure." Large, multi-story apartment and office buildings, as well as single- and multi-story industrial buildings use reinforced concrete framing.

Framing allows for more flexibility in the layout of rooms. Larger rooms are possible, but columns may be present. Architecturally, framing allows for greater variety in building styles and appearance. The frame structure may be entirely covered, giving the building a more massive appearance (heavy clad), or large windows can be used for a more open appearance (light clad). Framed structures range from single story residential buildings to high-rise apartments, office buildings and skyscrapers.

Frame construction has developed from simple post and beam construction, evolving through several distinctive styles to the modern light clad skyscrapers. Yet all frame structures are based on the same basic framework, horizontal beams or lintels that support the roof and floors, and transmit the load to a series of columns or posts which provide the vertical support for the structure. The terms "post and beam" are commonly used in reference to wood structural members, while "column and lintel" refer to concrete, steel, trusses, and other advanced structural members.

Post and Beam Frames

Basic frame construction is well illustrated by the wood post and beam structures popular in northwestern Europe from the 12th through the mid-19th century. These buildings utilized heavy, fire-resistant timbers of great strength joined into box-like frames. The frame was set on a stone or brick foundation, and diagonal braces were commonly used. Since the frame supported the structural load, the walls could be made of lighter materials, such as boards, panels, mud and straw, stucco, a single layer of brick, or similar materials. In the orient, frame buildings with walls of light screens and paper are common. In newer buildings, these light, non-load bearing walls are referred to as curtain walls.

These older post and beam buildings were frequently partitioned on the inside to provide space for various functions, including retail, light fabrication (hand crafting), and residential areas within the same building.

In Germany and other parts of northwestern Europe, the heavy wooden timbers of the framing were often left exposed, with plaster, or other materials, filling in the spaces between the timbers. This highly decorative style is referred to as half-timbered construction. It is common for these buildings to have the upper floor overhang the lower by a foot or so. The overhang protects the lower area from weathering, and the cantilevered overhang counterbalances the load on the interior parts of the frame.

A modern development is the light wood frame construction referred to as "balloon type." This method, uses regularly spaced, light weight studs, rather than massive posts, nailed to light weight sills and joists. Sheathing of the interior and exterior walls adds rigidity to the structure. Thus a "load-bearing wall" is constructed out of a wooden frame, that is the frame is not structurally independent. Many small residential buildings in the United States utilize this type of construction, because the light weight members are much less expensive than heavy posts and beams. The exterior walls may be clad with wood, metal, vinyl or other siding materials, or may be faced with a thin layer of brick or stone.

Framed, Heavy Clad

When the use of structural frames was introduced in the 1890's, the frame structures were covered (clad) with a layer of brick or stone to give the building a more massive and substantial appearance. The ground floor was often faced with stone, while the upper floors were clad with bricks. This makes these early frame structures difficult to distinguish from load bearing structures.

The following characteristics can aid in the identification of framed, heavy-clad buildings:

- Most buildings taller than six stories are framed.
- Framed buildings have a higher proportion of windows, especially in office buildings. However hotels will have fewer windows, commonly one per room.
- The exterior walls have the same thickness on all floors, so the windows will not be recessed.
- The columns will often be visible at the ground floor. They can be seen to extend upward by noting the position of the windows, which are always between the columns.
- Older frame buildings were constructed along classical lines to give them a more massive appearance. The ground floor forms a heavy-looking base called the pediment. It has large windows, heavy columns and is usually faced with decorative stone. The main part of the building is the shaft, and has a uniform appearance. The top floor (the capitol) is a lesser version of the first. It may also have large windows and decorative columns.

In the 1920's and 1930's, framed buildings took on a more modern appearance, as architects tried to get away from the more traditional styles. There are specific characteristics that help to identify these buildings.

- Windows are more abundant, frequently filling all the wall space between columns.
- Curved windows are sometimes present, often using opaque glass bricks.
- Curved windows are placed at the corner of the structure, demonstrating that the structure is framed.
- The building is more uniform in design, the pediment, shaft and capitol divisions are eliminated.

Framed, heavy-clad structures proved to be ideal for manufacturing and storage. The lack of interior load-bearing walls, and the ability to maximize natural lighting through large windows are of particular importance. These structures are commonly used where large open rooms and lighting are important, such as manufacturing, warehousing and for parking garages.

The principal recognition factors for a framed, heavy-clad industrial-type structure are:

- A maximum proportion of the exterior walls are devoted to windows. Cladding covers only the columns and beams.
- The interior columns are massive, either reinforced concrete or heavy steel I-beams. These would be visible in a building under construction.
- There are large open bays in the interior of the building, allowing for the storage or manufacturing functions.
- Loading docks and large doors are present on the ground floor.
- These structures are low and broad in shape.
- There are usually ventilation devices, such as monitors, present on the roof.

Framed, Light Clad

In the early 1950's, the modern high rise skyscrapers began to appear. Since then, they have become abundant in the downtown areas of cities around the world. They maximize the utilization of space in the crowded downtown areas, as they can be built to great heights at a relatively low cost. They provide large interior areas for office space or apartments.

The structural framework is composed of steel, or a combination of steel and reinforced concrete. The exterior varies from large windows to a thin covering (curtain wall) usually metal, with few or no windows.

The principal recognition factors for a framed, light clad, high rise structure are:

- The style is almost always quite simple and without ornament.
- Pediment, shaft and capitol are not present.

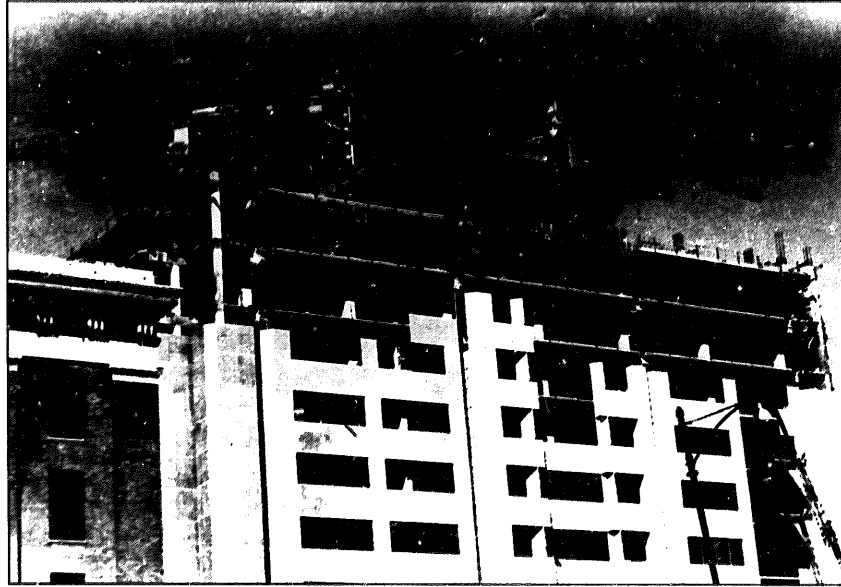


Figure 5: Photograph of a framed, light-clad building under construction. Note the column supports and the rotating, tower-mounted construction cranes.

- The exterior walls are thin, especially in contrast to heavy clad and load bearing construction.
- Columns and beams are normally visible, especially on the ground floor and often through the windows.
- These buildings normally have a very high proportion of windows.
- This type of construction is used for tall buildings, four stories and taller.

Composite

A composite structure utilizes load bearing outer walls (masonry or concrete) with framed interior walls (wood, steel, concrete, or combination). These buildings are difficult to distinguish from load bearing wall structures. This type of construction is used for single-story and shorter multi-story buildings. When the building's function requires large, open interior areas (industrial or storage), it is probably a composite structure. Poured-in-place and tilt-up concrete buildings frequently utilize framed interior walls.

Stressed Skin

This type of construction is used only to provide support for relatively light roofs. All of the loading is carried by cohesion in a thin shell which comprises the roof. Stressed skin structures may be simple (curved or domed roofs) or composite (sawtooth roofs) but always have a curved surface which carries the loading. The curved surface does not show a distinct ridgeline, and shadows on the roof are gradational.

Stressed skin roofs are usually placed on frame structures. Occasionally, as with some domed structures, the stressed skin dome may rest directly on the foundation. The structural members may be steel or reinforced concrete, with a sheet metal skin.

Pneumatic

Pneumatic structures are inflatable buildings with distinctive rounded shape and "balloon-like" appearance. They are frequently used as temporary structures until permanent facilities are constructed, or where structures are needed for a short term only. They are made of cloth or plastic, and may have a light framework of aluminum.

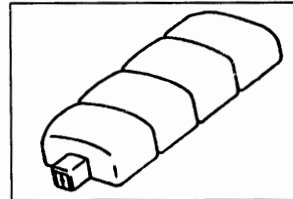


Figure 6: A pneumatic building. Note the rounded corners and the special entrance structure.

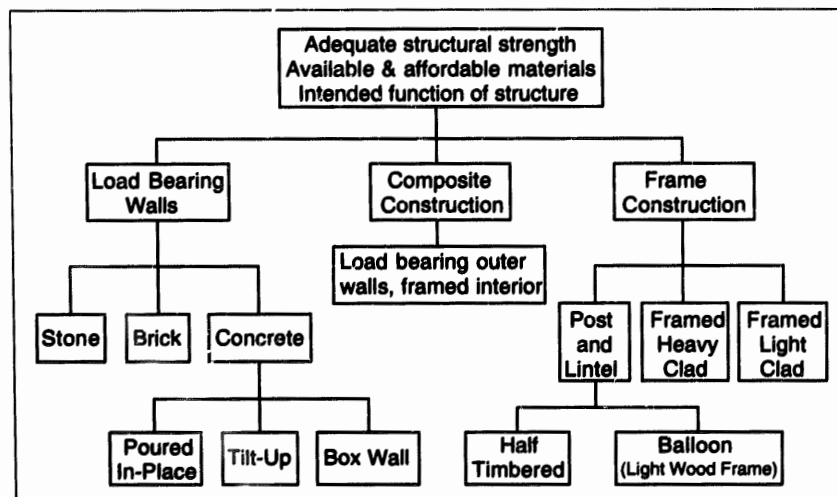


Figure 7: Summary of building structural types

Roof Types

Flat Roofs

A flat roof is one that is pitched only enough to allow for drainage of rainwater. Buildings with flat roofs are often administrative or storage buildings within industrial areas, but the presence of monitors, vents, or chimneys indicates that some type of manufacturing or processing activity is taking place inside. Numerous air conditioning compressors indicate a high cooling demand, such as an electronics facility.

Flat roofs are often covered with asphalt or asphalt and gravel, but in larger structures may be of reinforced concrete. The flat roof will have an even tone across the entire surface, except for the shadows of roof-top structures.

Shed Roof

Shed roofs have only one sloping plane. They are used on structures of light construction, often attached to a larger structure. Buildings with shed roofs are used primarily for storage or vehicle maintenance. They are relatively small in size.

The shadow is a good indicator of a shed roof. Also, it will have an even tone over the whole surface. The roof can be covered with shingles, or by corrugated or sheet metal.

Gable Roof

A gable roof is composed of two planes sloping in opposite directions, and meeting at a pronounced ridgeline. The ridgeline is almost always parallel to the long axis of the building. They are common on residential and industrial structures. Buildings with gable roofs may be of frame, load bearing or combination construction.

On residential buildings the roof is covered with shingles or tiles, or more exotic materials in non-industrial countries. Shingle or metal roofs are found on industrial buildings, where this type of roof is an indication of load bearing walls.

The shadow is a good indicator of a gable roof. In addition, the pronounced, longitudinal ridgeline separates the two halves of the roof, with the sunward side being lighter in tone.

Sometimes on wider buildings, two parallel gables are placed on a building, giving the roof a characteristic "M" shape. The two ridge lines and alternating light and dark tones of the four roof surfaces make recognition easy.

Hipped Roof

A hipped roof slopes down on the sides and the ends, with the surfaces meeting at a ridgeline parallel to the long axis of the building. If the structure is square, the surfaces meet at a peak. Shingles or tiles are common roofing materials.

Hipped roofs are common on residential and institutional buildings, and are sometimes found on administrative or engineering buildings in industrial areas. Hipped roofs are primarily associated with buildings having load bearing walls.

The pronounced ridgeline and triangular ends identify a hipped roof. The four sloping surfaces will have slightly different tones depending on their orientation with respect to the sun.

Gambrel & Mansard Roofs

The terms gambrel and mansard are often used interchangeably, however there is a distinct difference. Both have their sloping sides divided into two sections, a shallow upper portion and a steeper lower section. Gambrel roofs are commonly used on barns, with the roof sloping in two directions. A mansard roof slopes in four directions, similar to a hipped roof. Metal, shingles and tiles are common roofing materials.

Gambrel roofs are used in buildings requiring high, clear spans, such as warehouses, and heavy industrial buildings with load bearing walls.

These types of roofs are distinguished by their shadow, and by the slightly different tone of the roof components.

Deck Roof

A deck roof consists of a flat upper surface, with sloping surfaces on two or four sides. Sometimes the sloping surfaces may be narrow and hard to detect.

Deck roofs can be distinguished by their shadow and the darker tone of the sloping surfaces facing away from the sun. They will never have parapets, unlike flat roofs.

Sawtooth Roof

A sawtooth roof is very distinctive, being composed of parallel rows of oppositely sloping surfaces. One set of surfaces has a more shallow slope and is covered with roofing material. This surface may be flat or curved (stressed skin construction). The opposite set of surfaces are steeper (sometimes vertical) and contain windows for light and ventilation. The orientation is such that maximum lighting is obtained through the windows. The buildings usually are of frame

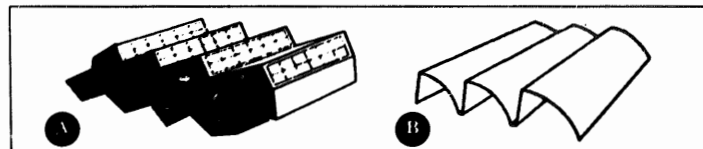


Figure 8: Sawtooth roofs. A) Sawtooth roof with skylight and ventilation windows, common on industrial buildings. B) Stressed-skin roof on sawtooth pattern.

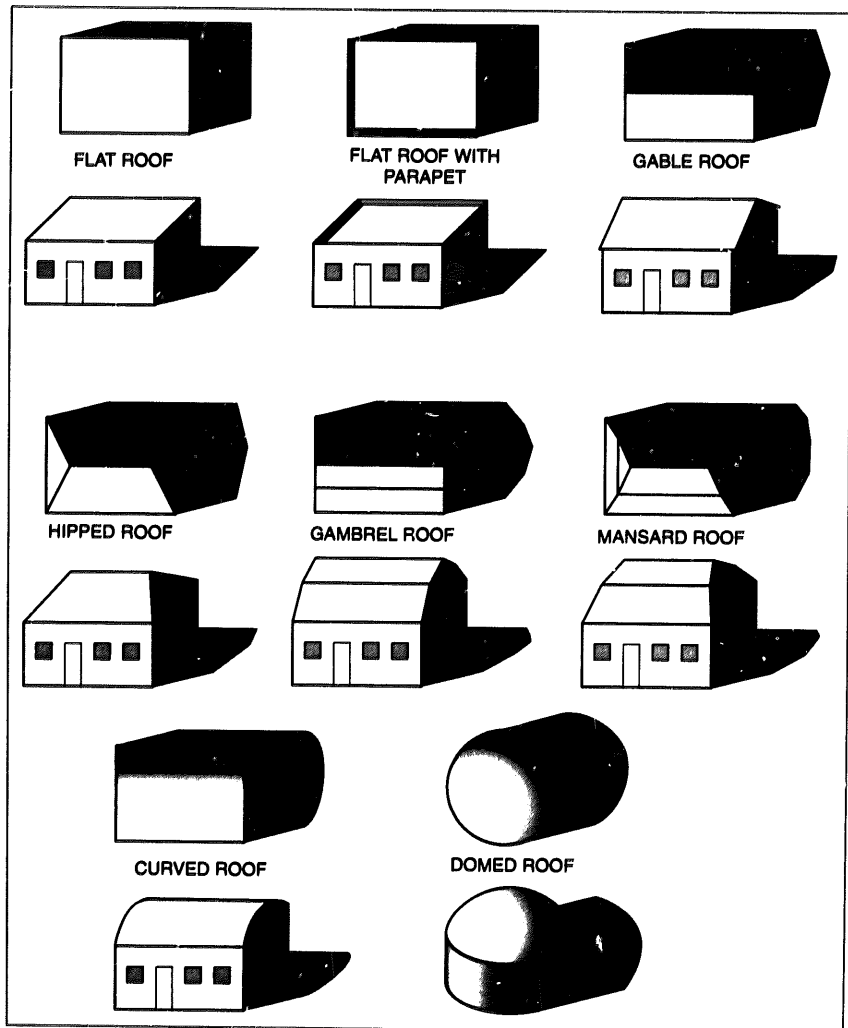


Figure 9: Diagrams of different roof types, showing vertical and oblique views, and typical shadows

construction, with steel trusses supporting the roof sections. The roof, and often the rest of the building, is constructed of metal.

Sawtooth roof buildings are most common at light manufacturing industries, such as textiles and aircraft. When located at a heavy manufacturing facility, they are on buildings housing machine shops, engineering or light assembly areas.

The "sawtooth" profile of the roof yields a distinctive shadow. In addition, the alternating, parallel lighted and shadowed surfaces create an easily recognized pattern.

Curved Roof

Curved roofs include arched or barrel-shaped structures as well as domes. These are usually of stressed skin construction, and almost invariably composed of metal, plastic or waterproofed cloth, though occasionally concrete is used.

Lightly curved roofs are commonly used on storage structures, as they allow for large, open interior spaces. Arched roofs are more utilitarian and are used for many purposes. Domes are used on stadiums and similar facilities, as well as superstructures on some government and religious buildings.

The curved surface of the roof is readily seen on the buildings shadow. There is no ridgeline, with the tone of the roof grading from light to dark across the curve.

Butterfly Roof

A butterfly roof is a cantilevered structure designed to provide overhead shelter. It consists of a single wall with two wing-like roofs projecting on opposite sides. These are commonly used as shelters in vehicle maintenance areas or storage and transshipment facilities.

Roof-top Structures

Monitors

A monitor is a raised portion of a roof with louvres or vents along the side to admit light and air. The term clerestory is also used to describe such structures, but implies a larger structure. Monitors can be either longitudinal (running parallel to the long axis of the building) or transverse (perpendicular to the long

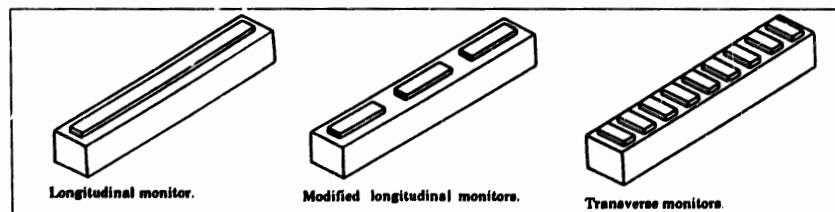


Figure 10: Flat-roofed buildings with monitors

axis). They may be found on any type of roof where there is a need for light or ventilation.

Monitors are found mainly on industrial buildings, and can have various configurations, depending on the type of roof and the particular requirements of the building. Large monitors or clerestories indicate the presence of activities that produce a great deal of heat, such as smelting or metal forming.

The shadow that the monitor casts upon the roof of the building makes the location and identification of monitors relatively easy.

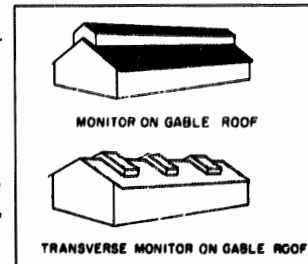


Figure 11: Gable-roofed buildings with monitors

Valley Roof

A valley roof is a V-shaped angle formed at the intersection of two inclined roof surfaces. This occurs on buildings that are composed of two or more sections, rather than a simple rectangle. It is found mainly on residential, institutional and administration buildings.

Dormers

A dormer is a small structure projecting from a slanting roof, usually housing a window or louvre. It usually indicates the presence of an extra floor under the roof. Some older industrial facilities have dormers on buildings where this space is used for administrative or living space. Dormers are normally restricted to residential and some older administrative buildings.

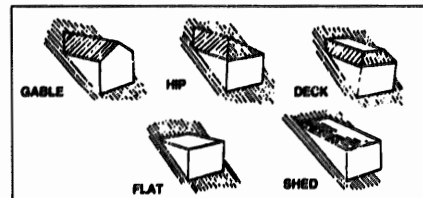


Figure 12: Dormers with various roof types

The shape and composition of the dormer will usually match that of the rest of the roof, and many styles are possible.

The shadow of the dormer is a distinctive identifier.

Parapets

A parapet is an outside wall that extends above the roofline, forming a low wall around the outside of a building. They are found almost exclusively on flat-roofed buildings.

The shadow of a parapet is its most distinguishing characteristic.

Firewalls

Firewalls are used to contain the damage from structural fires to a portion of a building. They are interior walls built of brick, concrete or other fire-resistant material. To keep the fire from spreading across the roof, firewalls are built up several feet above the surface of the roof. They may or may not be part of the structural support system of the building.

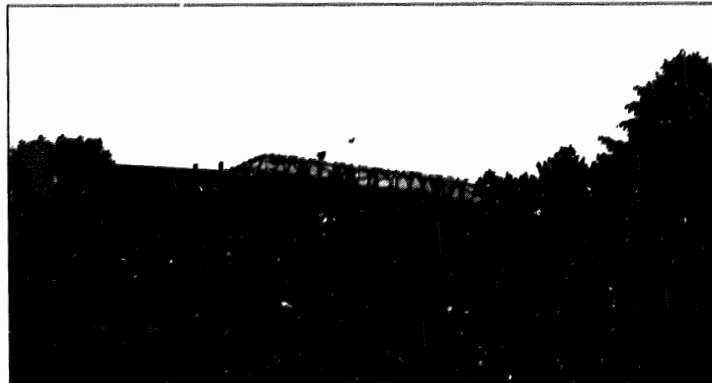


Figure 13: Building with a masonry firewall. These are common on buildings such as motels, multi-family dwellings and multi-unit commercial buildings, such as those at strip shopping areas.

Firewalls can be associated with any type of roof. They are commonly found on storage buildings and warehouses, some light manufacturing facilities, and in residential, commercial and office buildings.

Where they are present, firewalls are usually equally spaced along the building. The shadow cast by the extension of the firewall above the roof is distinctive.

Other Structures

In taller buildings, a small, rectangular structure housing the elevator machinery can be seen on the roof, especially on flat roofed buildings.

Various types of air conditioning units can be found on rooftops. These can range from small to medium sized compressors or radiator coolers to large evaporative

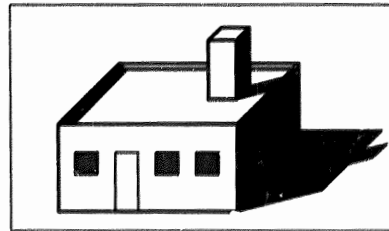


Figure 14: Flat-roofed building with parapet and tower superstructure

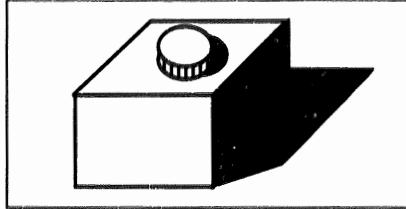


Figure 15: A flat-roofed building with a cupola superstructure. Cupolas may contain a helioly or serve as a covering for a high, circular room.

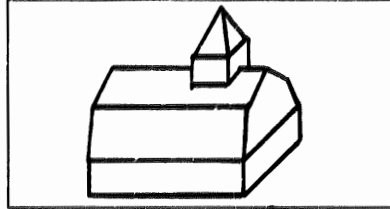


Figure 16: A gambrel-roofed building with a steeple superstructure

systems. Cooling units are partially or wholly composed of metal, and give a building a distinct radar signature. The size and number of coolers can be used to judge the cooling requirements of the facility located within the building, and can help identify its function. Electronic equipment generate a great deal of heat and need a cool clean environment to function, thus a large number of coolers is an indicator of an electronics facility.

Ventilators are abundant on buildings housing chemical processing. Smokestacks provide a vent for products of combustion, from the buildings heating system, or from boilers associated with processing activities.

Geographic Variations

Building styles and construction materials vary depending on the availability of materials, the local climate and cultural differences. These differences are most evident in rural areas, small towns and suburban parts of larger cities. The central parts of major cities tend to be similar worldwide, especially where there has been substantial new construction of high rise buildings.

Areas with high precipitation, especially snow, will have very few buildings with flat roofs. High pitched roofs are common in areas with greater snowfall. Flat roofs, conversely, are preferred in dry climates. The availability of materials is also dependant on climate.

Local variations are discussed in more detail in Section 6, Cultural Areas, but a brief summary of climatic areas and the locally available construction materials is given below:

Temperate areas:

- Moderate to heavy precipitation.
- Considerable temperature variation between seasons.
- Local building materials: wood, brick, stone and concrete.

Tropical areas:

- Heavy precipitation.
- Warm, slight variation between seasons.
- Local building materials: wood.

Highland areas:

- Very heavy precipitation, except in rain shadows.
- Moderate to slight temperature variations.
- Local building materials: stone brick and some wood.

Desert or steppe areas:

- Light precipitation, arid to semi-arid.
- Wide temperature variations.
- Local building materials: stone, brick and some concrete.

Mediterranean areas:

- Moderate precipitation (seasonal).
- Moderate temperature variation.
- Local building materials: stone, brick, concrete and some wood.

Polar areas:

- Light precipitation.
- Cold, great temperature variation.
- Local building materials: stone and some wood locally.

CHAPTER 3 – TRANSPORTATION

General

Contents

This section covers all aspects of transportation (ground, air and maritime), including routes, terminals, transshipment facilities and their associated structures. The section on Airfields includes the information needed for portrayal on cartographic products. An in depth explanation of airfields, facilities and navigational aids is given in Module 6, Aeronautical Data Maintenance, which is designed for the Aeronautical Information Specialist. Pipelines are included in this section as they are a means of transporting materials over long distances.

Although power distribution networks and communications networks are also lines of communication and share basic characteristics with these transportation systems, they have enough unique characteristics to warrant inclusion elsewhere. Power lines are discussed along with power generation facilities in Chapter 4 of this module. Communications facilities, both wire and wireless, are described in Chapter 5.

Lines of Communication

As mentioned above, transportation facilities fall into the broader category of Lines of Communication (LOC's). They are concerned with the movement of some commodity (people, materials, electrical power or information) from one point to another. As such they have several features in common.

Each LOC is composed of a network with definite starting and ending points, or terminals. The nature of the terminals is characteristic to that particular form of transportation or communication. For instance, railroad terminals are distinctly different from ports, and the nature of a radio communications installation can often be deduced from the configuration of the antennas. The terminals may be localized, such as railroad stations, ports and radio transmitters, or they may be dispersed as in warehouses receiving goods by truck, electrical customers, or the garage you park your car in.

The network connecting the terminals is also different for each system. Different "vehicles" are used in each system (ships, railroad cars, trucks, pipelines or radio waves) and each has different requirements for the route it must follow. Ships require navigable waterways, trains require tracks, trucks require roads, and radio requires a suitable geometry between transmitter and receiver. Some, like ships and trains, have a limited number of legs in their network, others, like roads and telephone lines, have a greater degree of interconnection, while others, like radio have few restrictions.

Often, the commodity may have to utilize more than one system to reach its final destination. For instance, hardwoods harvested in Southeast Asia are shipped by railroad to the coast, where they are loaded on ships for transport to the U.S. Upon arrival at the destination port, they are loaded on trucks for delivery to the distributors. At each place where the materials change from one transportation system to another, a transshipment facility is present, with specialized equipment for on-loading, off-loading, metering and storage of materials.

Transportation Systems

Transportation systems differ from the other LOC's (communication and power transmission), in that they deal with physical commodities, and that they normally require some type of storage facility for the commodity, as well as facilities for the transporting vehicles, and that they frequently connect with each other through transshipment facilities.

The various systems are fairly easy to distinguish on large scale imagery, but distinctions become more difficult at smaller scales. There are, however, certain characteristics that will help to identify them. The nature of the routes, terminals or associated features are often distinctive.

Roads

All of us use roads daily, often with little thought as to how the roads we travel on would look from the air. The large number of roads, in comparison to other types of transportation routes, their high degree of interconnectedness, and the mobility of wheeled vehicles make highway transportation extremely versatile. The relatively low capacity of individual vehicles, however, make highway transportation more expensive than those systems which can carry larger quantities of materials.

Roads are wider than the vehicles which use them, and frequently are two or more lanes wide. The small turning radius of wheeled vehicles make sharp turnouts, curves and branchings possible. Road networks are more extensive, with many intersections. Steeper grades (in excess of 7%) are possible. On major highways, the straight alignment, gentle curves and grades may resemble those of a railroad, but the greater width and presence of intersections are characteristic. Bridges usually maintain the width of the roadway. Terminal facilities are small and dispersed, and may have large paved or graveled parking areas, often rectangular in shape.

Railroads

Railroads are the second type of overland transportation systems. Trains, however, are restricted to the relatively few sets of tracks present in any given area. Their ability to handle large quantities of materials and travel at high speeds make them much more economical for hauling materials for long distances.

Trains travel on sets of tracks that are spaced less than the width of the cars. The ballast supporting the tracks forms a strip of comparable width to a single lane road, but single-lane roads rarely maintain the alignment and gentle curves and grades of a railroad. Cuts and fills are abundant, maintaining grades below a maximum of 6%. Tracks intersect and diverge tangentially. Bridges are just wide enough to accommodate the tracks, and, in some cases, do not have a solid flooring, making them appear even narrower. Terminals are in the form of railroad yards, which can be quite extensive, or isolated facilities at the ends of spurs or sidings that diverge from the main track.

Bridges and associated features

As overland transportation systems, both roads and railroads must deal with the many obstacles present on the land's surface. Since both must provide a smooth and relatively level surface for vehicles to travel on, the structures used to cross obstacles are very similar. Bridges, culverts, cuts, fills, tunnels, etc., differ very little between roads and railroads.

Airfields

Air transport differs from other systems as aircraft do not require a prepared route to travel upon. The primary features associated with air transport are the airfields. The runways, taxiways and navigation aides, are the only physical facilities involved in the actual transportation function. The rest of the airfield components can be considered as transshipment facilities. Air transportation is fast, but delivers directly to a relatively few destinations. It is also the most expensive means of transportation, and is used where speed of delivery offsets the higher cost.

Major airfields are readily identified by the pattern of the runways and taxiways, and the presence of parking aprons, hangars and aircraft. They are also somewhat isolated from the road network. Minor airfields, particularly those with dirt or grass runways, can be more difficult to detect, but are not easily confused with other systems. In some areas, specially widened and reinforced segments of roads are used as runways.

Waterways

Inland waterways and transoceanic routes have several differences. Inland waterways, like railroads, have a few set routes (rivers and canals) and are limited in the size of the vehicles they can accommodate. Terminals on inland waterways, therefore, tend to be small. Maritime transportation is relatively slow, but because of its ability to handle large volumes of cargo, it is perhaps the most economical.

Waterways may be natural or artificial. Natural waterways will curve in an irregular fashion and will vary in width. Canals will be straight or gently curving and maintain a constant width, with occasional turning basins present. Both types are

substantially wider than roads or railroads, and will have varying tones on the surface due to different sun angles and water depth. In addition, the water surface will always be below the surrounding ground. Small dams, with associated locks, are often used to maintain the water depth required for navigation. Terminals on inland waterways are often small and may be dispersed along their length. Transoceanic shipping can utilize very large vessels carrying large amounts of cargo, so coastal port facilities are often large and complex.

Pipelines

Pipelines are unique in that the material is carried directly through the pipeline, rather than in a vehicle. This means that very little human supervision is needed. Transportation is not affected by the weather, as are other systems. Liquids and gases are the only materials that can be moved via pipelines, but some solids (such as coal) are pulverized and mixed with water to form a slurry. The volume of material that can be moved depends only on the diameter of the pipe and the strength of the pumps. Although limited in extent, pipelines are very economical for long distance transportation, and are used extensively in urban areas for distribution of natural gas, and water, and for disposal of wastes.

Pipelines on the ground surface are readily recognizable. They are straight and narrow, and make angular bends. Frequent 90° bends at expansion joints are visible. Junctions and branchings are rare, except in oil fields. Underground pipelines can be very difficult to locate. A scar may be visible on the surface of the ground, and when passing through forested areas, a cleared way often reveals the route of the pipeline. In other areas, particularly urban areas, there may be no surface expression of a pipeline. Terminal facilities are composed of pump stations, storage tanks and processing facilities which are readily identified.

Roads

Introduction

A road is a long, narrow stretch of ground, usually graded, often paved, used primarily for the movement of wheeled vehicles. Roads are classified on the basis of their surface type, their ability to handle large volumes of traffic and heavier vehicles (trafficability), their ability to handle traffic in adverse weather (weatherability), and the amount of traffic they can handle (width or number of lanes). Footpaths and trails are included here, even though they are not intended for wheeled vehicles.

Road improvements (grading and paving) are done for three purposes, to smooth the surface allowing vehicles to travel faster, to improve trafficability and to improve weatherability.

Grading evens out the surface, and gives it a slightly convex shape (crown) which allows rain water to drain off the road surface. In addition, small ditches

are usually scraped out parallel to the road to carry the water away. Keeping the water away from the road surface helps to preserve the surface and prevent damage during periods of wet weather.

Paving provides water-proofing and improves the load bearing capacity of the road. Pavement consists of rigid surfaces such as concrete, stone paving blocks (Sett) or brick, or flexible surfaces such as asphalt (bituminous surface). Rigid surfaces spread the load more effectively than flexible surfaces, and are used where a large volume of traffic, or heavy vehicles are expected. Expedient surfaces, such as logs or pierced metal planks, are sometimes used to make rapid improvements to roads, often in support of military operations.

Road Construction

The weight of a vehicle is transferred to the ground in the relatively small area where the tires (wheels or tracks) touch the ground. This means that the road surface must be able to withstand heavy loads placed on a small area. In order to do so, the road must be constructed so as to distribute this load over a larger area.

The central part of the roadway, the traveled way, is the portion designed to carry the traffic, and is of more substantial construction than the adjacent shoulders, which are meant only for emergency parking. Between the shoulders and the lateral drainage ditch, there may be an area of unsurfaced fill material.

The graded surface can be compacted to improve its load bearing capacity. Compaction helps keep the soil from being pushed out from under the wheels. If further improvements are to be made, this compacted soil forms the subgrade or foundation for the road. When the natural surface is of poor quality material, or when the road must be built up to provide for drainage, additional material, usually some mixture of earth and stone is brought in for use as the subgrade.

To help spread the load from the vehicles' tires, a layer of well-graded aggregate (gravel or other granular material) is placed on the subgrade and compacted. This layer is known as the base course if it serves as a foundation for a solid pavement. When this aggregate forms the surface of the road, it is sometimes called a "metaled" road. The aggregate may also be mixed with a binder, such as bitumen, clay, etc., to help shed water and keep down dust.

A pavement is applied to the road surface to maximize weatherability and trafficability. It keeps the water away from the base course and subbase, so the road's ability to handle traffic is not reduced during wet weather. It also helps to distribute the load more effectively, giving the roadway greater strength.

Rigid pavements are used on roads designed to carry heavy vehicles or large volumes of traffic. The rigid surface is very effective in spreading the load from heavy vehicles over a broad area. Major highways are almost always constructed with a concrete surface. Stone paving block or brick surfaces are still found on some old roads, but rising labor costs make these materials uneconomical in most areas. In some places, they have been covered over with a layer of asphalt.

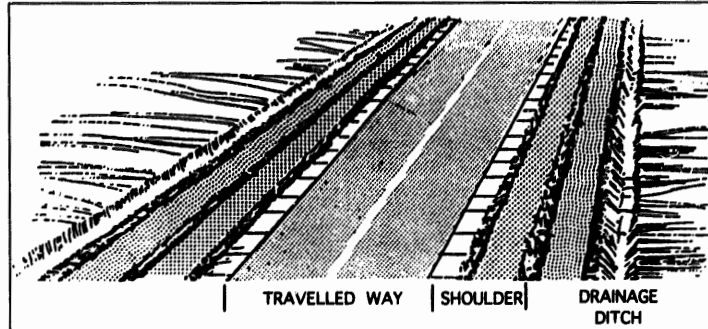


Figure 1: Diagram showing the components of a road's surface. Depending on the surface type and construction methods, the boundary between the travelled way and the shoulder may be difficult to detect.

Asphalt is less expensive and is preferred for lesser highways and feeder roads. Since it is flexible, especially when warmed by sunshine in the summer months, a substantial base course is needed if heavy traffic is expected. For bituminous-surfaced roads, the base course provides most of the load bearing strength, while the pavement serves mainly as water-proofing. A bituminous surface placed over a graded subbase has low load-bearing capacity, and is referred to as a "light-surfaced" road.

Drainage

In order to support traffic in all kinds of weather, the roadway must be kept clear of water. The first improvement made on a roadway, grading, promotes the drainage of water from the road surface by making the center of the roadway higher (crowning), and helps keep it away from the road via lateral drainage ditches. Further improvements to drainage consist of enhancing the lateral drainage ditches, building-up the road in low-lying areas, providing a path for water to flow under the road via culverts or bridges, and water-proofing the road surface.

Alignment

Alignment is the process of making a roadway straighter, with smooth, wide curves and gentle grades. This enables traffic to move at a higher rate of speed and eliminates traffic bottlenecks. Within a given area, higher classes of roads will have better alignment than roads of lower classification. Major highways will exhibit the same characteristics as railroads, but can be distinguished by their greater width, the presence of interchanges, and the lane markings will be visible at larger scales.

Road Classification

Roads are classified on the basis of their ability to handle increasing volumes of traffic, increasing sizes of vehicles, and their ability to remain serviceable in adverse weather conditions. These capabilities are widely variable, and depend on the type of road surface and method of construction, road width, alignment, drainage, terrain and climate.

Under set conditions of terrain and climate, the classification of a road is proportional to the improvements that have been made to the roadway. For instance, in an area of hilly terrain that receives substantial amounts of rainfall, only those roads with good drainage and pavement over a compacted base course can be considered as all-weather roads. In areas of level terrain and low precipitation, particularly where gravel soils predominate, a road can be classified as all-weather without improvements beyond basic grading and drainage accommodations. This has the unfortunate corollary that the photo identification factors for road classification are not constant throughout the world, particularly for loose-surface roads.

Due to variations in road construction, road condition, terrain and climate, gradations exist between road classes. This can make the determination of the proper classification difficult at times. It is important for the cartographer to be aware of all the factors affecting road classification in a particular geographic location. Ancillary sources should be consulted for information about road construction techniques and materials and climatic conditions.

Trails and Footpaths

Any route which is not wide enough to accommodate a four-wheeled vehicle (less than 1.5 meters wide) is classified as a trail. The common usage of this term describes a narrow traveled way with a natural, unimproved surface. There may be a few local improvements to carry the trail through difficult areas, such as side cuts on steep hillsides, and wooden plank paths over marshy areas.

The trail will appear as a single, narrow line, usually lighter in tone than the surrounding ground surface. Heavily traveled paths will be continuous with fairly sharp margins, but less traveled paths may appear discontinuous and have indistinct margins. Trails follow the line of least resistance, and will have an irregular trace even on level terrain. Short detours around obstacles such as rocks, wet areas and clumps of brush are common. On steep slopes, the trail will often zig-zag up the hill side with angular bends.

Trails are found in undeveloped areas, where materials are moved by

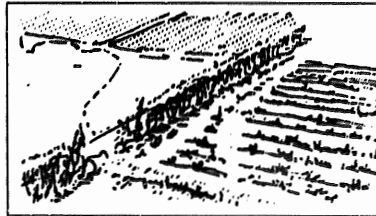


Figure 2: Trail

people or pack animals. Generally, there will be little agriculture and no industry present, however, in some undeveloped countries, large agricultural areas exist with few roads larger than trails.

In more developed regions, particularly in urban parks and suburban areas, foot paths and bicycle paths have been constructed. These may range from gravel-surfaced paths to paved surfaces with culverts and bridges and may even have stairways constructed up steeper hills. In larger parks and natural areas, hiking trails with varying degrees of improvements are also common. Less improved paths will resemble rural trails, while others may be quite distinct with sharp edges and constant width. If paved with asphalt, they may appear darker than the adjacent ground. Their common denominator is their narrow width, and for cartographic purposes they are classified as trails.

Tracks

Tracks are similar in most aspects to trails. The main difference is that tracks are wide enough to accommodate at least small four-wheeled vehicles (> 1.5 meters). A track is simply an unimproved traveled way on the natural ground surface. There are few improvements, except locally where needed to cross obstacles that cannot be bypassed.

Tracks appear as a pair of parallel lines where the vehicles' wheels have disturbed the ground and vegetation. They are usually lighter than the surrounding area, except in wet areas. In the winter, on snow-covered terrain, tracks will appear as parallel dark lines. On hard ground, bare of vegetation, tracks may not be visible. Tracks follow the line of least resistance, detouring around most obstacles, and will be straight only in areas of flat, firm ground.

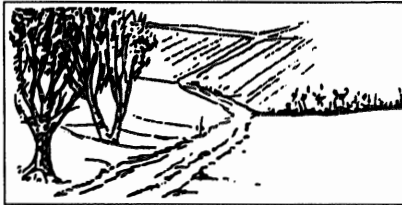


Figure 3: Track

For cartographic purposes, description of a feature as a track implies repeated usage. Tracks serve as part of the road network, connecting with villages, farms, waterholes or other tracks and roads. While driving a vehicle across soft, undisturbed ground will leave marks, this does not make it a track. The intricate network of vehicle tracks around construction sites and military maneuver areas do not constitute part of a road network, and should not be designated as tracks.

Tracks are found in undeveloped areas where infrequent use does not justify the expense of road improvements. Tracks are also common between fields in agricultural areas, where they are used for movement of farm equipment.

The width of the track is an indication of the size of the vehicles traveling there. Cars and small trucks will leave tracks 1.5 to 2 meters wide, while tanks leave tracks from 3 to 4 meters wide.

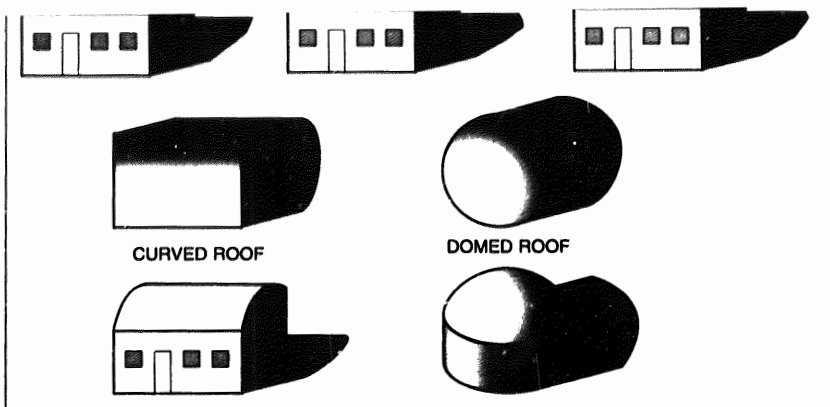


Figure 9: Diagrams of different roof types, showing vertical and oblique views, and typical shadows

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Loose Surface, Fair Weather Roads

Loose surface, fair weather roads are characterized by a limited amount of improvement to the roadway. Normally this is limited to grading the surface. Locally in areas of soft ground, some gravel or binder may be added to the roadway. On steep slopes, small side hill cuts may be present, and cuts and fills are limited to sharp breaks in slope. Where tracks follow the line of least resistance along the surface of the ground, these roads have some improvement in their alignment, making the route a little straighter with more regular curves. Because of the lack of provisions for drainage, and the natural earth surface, these roads quickly become impassable in wet weather.

These roads appear as a continuous strip, lighter in tone than surrounding areas, with an irregular edge. Locally, wet areas will have a darker tone. The width is relatively consistent, but the roadway may be wider where vehicles try to avoid bad spots in the road. Continued use in wet weather may form paired ruts in the roadway.

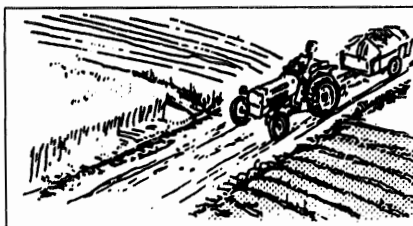


Figure 4: Single-lane, fair weather, loose surface road

Fair weather roads are distinguished from tracks by their more even appearance, the lack of a dark strip down the center, and slightly better alignment. They are distinguished from all weather roads by the lack of drainage ditches and culverts, the irregular edges with no shoulders, blotchy appearance due to wet spots, and the lack of cuts and fills. If used during wet weather, they will be rutted and irregular.

Loose Surface, All Weather Roads

Loose surface, all weather roads are characterized by extensive improvements. Alignment is good, with regular curves. Cuts and fills help to provide a more even grade. The surface is graded and crowned, and consists of some combination of rock, gravel sand and/or clay that is locally available. It may be treated with chemicals or oil to serve as a binder and to control dust. Extensive provisions for drainage help keep these roads passable to at least moderate levels of traffic in wet weather.

These roads appear as a distinct strip, much lighter than the surrounding ground, with sharp but sometimes irregular edges. Often, there will be a slightly darker band along each side of the roadway, between the traveled way and drainage ditches. Shoulders are present, but the margins of the traveled way are indistinct. The unpaved surface may display an uneven texture. The road will have prominent drainage ditches and culverts. The width of traveled way and shoulders will be uniform, but the road may appear wider where fills are present.

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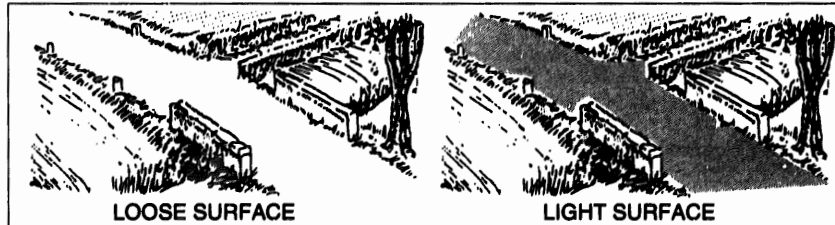


Figure 5: *Loose surface road and light surface road*

All weather roads are distinguished from fair weather roads by the presence of drainage ditches and culverts, the improved alignment, and the use of cuts and fills to keep an even grade. They are distinguished from paved (hard surface) roads by their very light tone, uneven texture, lack of distinct edges on the traveled way, and lack of center lines. Oil, bitumen or chemicals may be mixed with or sprayed on the surface material. This can give the roadway a distinctly darker tone, but the irregular edges and lack of centerlines reveal that it is a loose surface road.

Hard Surface Roads

In addition to the improvements listed for all weather roads, hard surface roads have a waterproof pavement which improves the weatherability and load bearing capacity of the road. Hard surface roads include a broad spectrum of roads, from narrow, light surface roads through divided superhighways.

Light Surface Roads

Light surface roads are built in areas where only light traffic is expected. They may form the primary road network in poorly developed areas, or they may serve as feeder roads in rural areas. They are narrow, rarely exceeding two lanes, and often only one lane wide. Because of the anticipated light traffic, improvements are kept to a minimum. These roads will quickly break down under heavy traffic.

The alignment tends to follow the terrain, with few cuts and fills, and steeper grades present in hilly areas. The pavement is also of an inexpensive type, hot oil or bitumen mixed with gravel, or a layer of asphalt over a light base course, often stabilized soil. Bituminous mix-in-place and "tar-mac" surfaces fall in this category.

Light surface roads are distinguished from loose surface roads by the darker tone of the bituminous or asphalt surface material, which contrasts sharply with the lighter shoulders. Lane markings are generally not present, in contrast to heavier surfaced paved roads of narrow width, and the edge of the paving may be irregular rather than straight.

Hard Surface Roads

Built to support heavy traffic during all types of weather, these roads have a prepared subbase and compacted base course supporting an asphalt, concrete or occasionally cut stone or brick pavement. The base course extends beyond the traveled way to form the shoulders. In the absence of divided highways, hard surface roads form the main road network, elsewhere they form a secondary network supporting a system of divided highways. They are most abundant in developed and industrial areas, and form at least the main streets in urban areas.

The importance of a hard surface road can be judged by its degree of alignment. Minor roads will follow the ground surface and have few cuts and fills. Major highways will be straight with wide, regular curves, and cuts and fills as needed to maintain an even grade. The width is proportional to the expected volume of traffic, usually two to four lanes, but occasionally wider, especially around urban areas. Drainage is well developed, and in hilly areas supplementary diversion ditches may be present.

Hard surface roads are distinguished by their even tone, constant width, sharp margins, well-developed shoulders and drainage, and by the lane markings that will almost always be present. The shoulders may be paved, in which case a solid painted line may mark the edge of the traveled way. Asphalt surfaces are most common, but concrete may be used in areas where heavier traffic is expected, especially around industrial facilities, ports, airfields and rail yards. Locally, particularly around older cities, cut stone (sett) or brick pavements may be used. These areas are rapidly being replaced or paved over with asphalt.

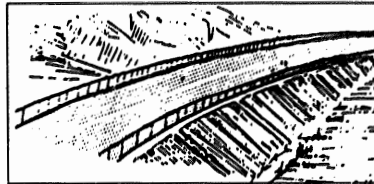


Figure 6: All weather, hard surface road on a fill. Cuts and fills allow the road to maintain a straighter alignment and more even grade.

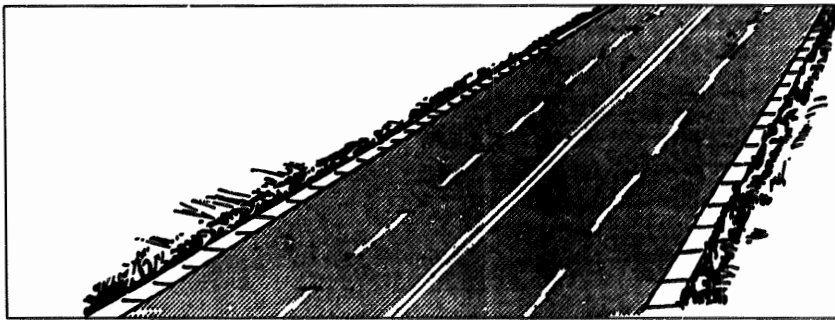


Figure 7: A multiple-lane road (four lanes). Such roads are almost without exception hard-surfaced.

Urban Streets

Urban areas contain the greatest concentration of paved roads. In highly developed areas, all urban streets will be paved, while cities in less developed or agricultural areas may have only the main routes paved. The width and development of key roads indicates the location of major through routes, and can point to significant governmental, industrial, military or institutional facilities.

Urban streets differ from roads in rural areas. In built-up areas, shoulders are not common, instead the traveled way is bounded by curbing. In many cases, the road is widened to provide space for vehicle parking. Drainage is provided by underground piping with storm drains placed along the curbs. Sidewalks are commonly present on one or both sides of the road. This configuration is easily distinguished from less developed urban areas, where the unpaved streets lack the sharp, straight edges of paved streets.

In the older, central portions of some cities, the close spacing of the buildings restricts the width of the roads, sometimes as narrow as one lane. Many urban areas, particularly in Europe and the Far East, provide separate bicycle lanes, usually adjacent to the curb, but sometimes as separate paths away from the road.

Divided Highways

A divided highway is a hard surface road where the lanes of opposing traffic are separated by a physical divider or median, and where access to the road is limited to specially built interchanges. The divider is normally a strip of grass-covered ground of varying width, but in areas where road width is restricted, there may only be a concrete or steel barrier separating the lanes. There will be at least two, often more, lanes on each side of the median. Bridges, overpasses and underpasses are common where the highway crosses other roads or railroads.

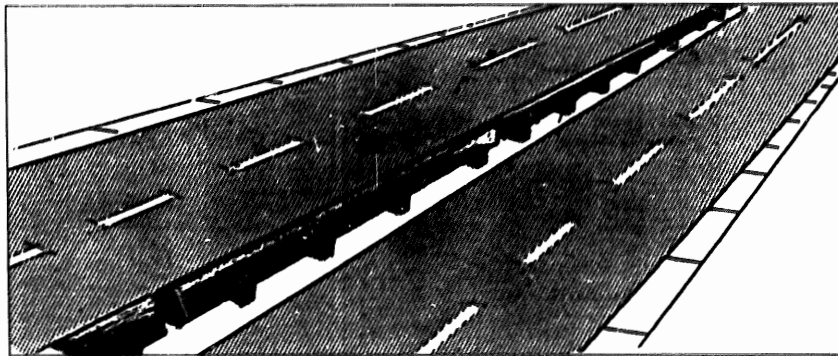


Figure 8: A four lane divided highway, without a median

Alignment is very well developed, and all curves are broad and even. Steep grades are avoided through the extensive use of cuts and fills. Drainage is provided by a well-developed system of ditches and culverts. Within a country, the lane width will be constant, somewhere between 3 and 3.5 meters. The shoulders are usually the width of a traffic lane, and are strengthened to support the weight of parked or disabled vehicles. The shoulders may be of a different tone than the traveled way, and/or marked off with a solid line. A heavy base course, up to two or three feet thick, underlies the pavement and shoulders. The surface is normally concrete, but in some areas asphaltic surfaces are used.

Interchanges are designed to provide access to and egress from the highway with minimal impact on traffic flow. Configurations vary greatly, depending on the situation at the particular intersection.

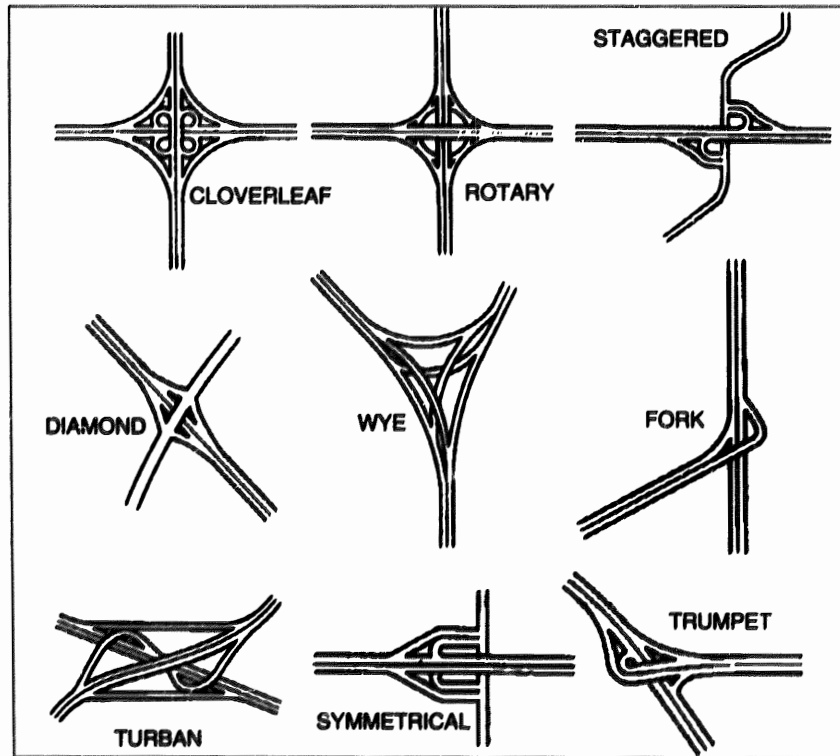


Figure 9: Nine of the most common varieties of highway interchanges

Divided highways are readily identified, even on smaller scale imagery, because of their broad width, smooth alignment, characteristic interchanges and the presence of a median strip. The cleared ground on either side of the highway and on the median, along with the road itself cut a distinctive swath across the landscape.

Elevated Roads

In some areas, the road must be elevated above the surface of the ground. This is normally accomplished by placing the road on an earthen fill. In other cases, the road is supported on a long, bridge-like structure with a series of evenly-spaced supports. These elevated roads are always hard-surfaced, usually concrete. The shadow of the roadway and supports is usually visible and identifies the elevated road. The height of the road above the ground, the lack of a fill, and the fact that other roads pass freely underneath, are also keys to identification. This type of structure is sometimes referred to as a viaduct.

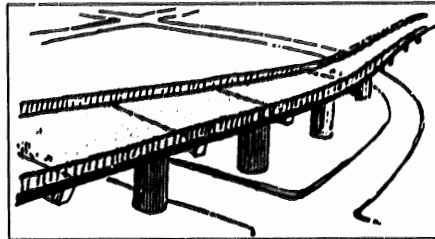


Figure 10: An elevated road

Identification of Pavement Types

Asphalt surfaces have a very dark tone when new, but appear lighter as the surface becomes older. Concrete is very light when new, but gradually becomes darker. Concrete surfaces are composed of rectangular slabs separated by expansion joints. The pattern of expansion joints is often visible on large scale imagery, and can be used to discern darkened concrete from light asphalt. Patched areas on concrete will show up as light, rectangular areas with straight edges. On asphalt, smaller patches are rounded, while larger areas are repaired by laying a new strip of asphalt. The new asphalt will be distinctly darker.

Concrete pavements can be distinguished from gravel surfaces by their even tone, straight, sharp edges that contrast with the shoulders, lane markings, and

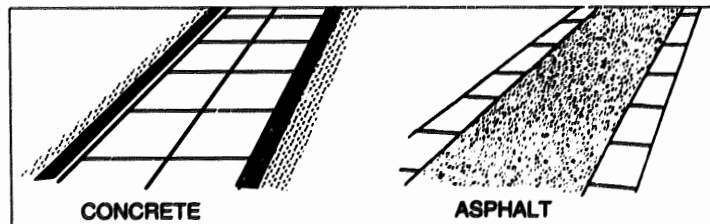


Figure 11: A comparison of concrete and asphalt surfaced roads

the pattern of expansion joints. Heavy asphalt pavements have straight, distinct edges, as opposed to the irregular margins of light bituminous, bituminous mix and oil sprayed surfaces.

Cut stone pavements will vary in tone depending on the color of the rock used, but it will be somewhat darker than concrete. At very large scales, the texture of the blocks may be visible. Lane markings are indistinct or absent. The lack of expansion joints distinguish stone from concrete, but it may be difficult to discern between stone and asphalt. Brick roads, similarly, are of a dark tone, and at large scales, the pattern or texture of the bricks may be visible. Both pavement types are confined to older roads that have not been replaced or paved over. They are found in older urban areas, and rural areas in less developed countries.

Miscellaneous Roads

Several unusual solutions have been developed for roads through difficult areas such as swamps and areas of soft or intermittently wet ground. These are used when limitations of cost or time preclude the construction of a proper all weather road. These "expedient" road surfaces are often used to support military operations in undeveloped areas.

The use of logs placed across the roadway, forming a "corduroy" surface, dates back to before the advent of motorized vehicles. Log or wood plank surfaces are used to carry roads through swampy or wet areas, and are sometimes used to provide traction on steeper slopes of unimproved roads. They have been used in areas like northern Russia where the ground becomes very wet and soft during the spring and summer, but is frozen and firm in winter. A light surface "fascine" road is made by substituting bundles of sticks for logs. This provides only temporary passage for light vehicles. Corduroy and plank roads will appear distinctly lighter than the surrounding ground, and will contrast with the unimproved roads they connect to.

An expedient variation is to lay planks or logs in two parallel strips (or treads) to support the wheels of the vehicles. Another type of tread road uses stone, or sometimes concrete to provide support for the vehicles' wheels. This is less expensive and quicker than paving a continuous surface, but provides one-way travel only and requires specially constructed turnoffs for passing. The parallel strips of the treadways will be apparent at medium scales, and may resemble a railroad track, however the poorer alignment and lack of cuts and fills will distinguish them on closer examination. Wood tread roads are more common in northern areas such as Russia, while stone tread roads are more common in central Asia.

Pierced steel or aluminum planking roadways have been used in tropical areas. They can be constructed quickly and provide a firm traveled way for heavy vehicles. Their sharp, straight edges and high reflectivity are distinctive. The metal surface may reflect light toward or away from the sensor, and these roads may have a different tone on each half of a stereopair, similar to water.

Winter only roads cross areas of marsh, swamp or open water that freeze sufficiently to support vehicular traffic. Their location is marked by vehicle tracks on winter imagery. Unless you are able to identify an area as marsh or open water, the seasonal nature of these roads is not apparent. On imagery taken during warmer seasons, the location of these roads is not visible.

Associated Features

Most features associated with roads, such as bridges, culverts and cuts and fills, are common to both roads and railroads, and will be discussed in subsequent sections. The following features are unique to roads.

Fords

Most water crossings are via bridges, ferries, causeways, or fills with culverts. The superior mobility of wheeled (or tracked) vehicles, however, allows them to cross rivers or streams where an appropriate approach is available, the water is shallow, the current is slow and the bottom is firm. A ford is any location along a river or stream where the physical conditions allow vehicles or personnel to cross. It is normally associated with a road, track or trail. A ford is used where the low volume of traffic and/or high cost of construction do not justify building an improved crossing.

Fords are classified according to their crossing potential for foot traffic, wheeled or tracked vehicles. Fords along roads, tracks or trails are usually improved to allow passage of vehicles. Fords are also used as bypasses at bridges damaged or under construction. Potential fording sites are particularly important along rivers or streams characterized by high, steep banks and/or dense vegetation along one or both banks, as crossing sites for military operations.

Classification of fords for cartographic purposes may vary for different products. When describing a ford for a particular product, be sure to verify the usage of terms with the product specifications.

Fords are found within shallow reaches of rivers and streams. The bottom of the river must be firm enough to support traffic and free from protruding rocks and boulders. In streams with soft bottom materials, rock is added to make it firmer. Rock can also be placed along the ford to raise the bottom, making the water shallow enough to cross. Concrete surfacing, layers of sandbags, metal screening or matting, timber or wooden planking may also be used to improve trafficability.

The current must be slow to moderate (less than 1.5 meters per second). Faster currents can wash away vehicles, erode the bottom or carry large debris which can damage vehicles. The maximum water depth will vary with the type of vehicles using the ford. Permissible depths range from 0.5 meter for smaller wheeled vehicles, to 4.3 meters for tanks with fording kits. Climatic conditions, such as seasonal floods, droughts, freezing and other extremes of weather materially affect the fordability of a stream.

Rapids, white water and exposed rocks or boulders indicate a rocky bottom. Bars, braiding, and steep banks often indicate coarse-grained materials such as sand or gravel. Meanders and oxbows indicate relatively slow-moving water with fine-grained bottom materials. Angular drainage patterns with frequent sharp changes in direction indicate bedrock control of drainage and a rocky bottom. In swift-flowing streams in mountainous area, fine materials do not settle; therefore, the bottoms are rocky or firm.

The banks must be gently sloping and free of vegetation. Approaches to on-route ford are often graded and cleared, and rock may be added to areas with soft bank materials. Occasionally, approaches may be paved with concrete or bituminous surface material. Off-route fords must have the vegetation cleared away from the banks to allow passage of vehicles. Natural banks greater than 1 meter in height and with slopes greater than 60% are impassable for most vehicles.

A ford extends straight across the river or stream, connecting the approaches. Fords are often only one lane (2.5 to 5.0 meters) wide, but they can be much

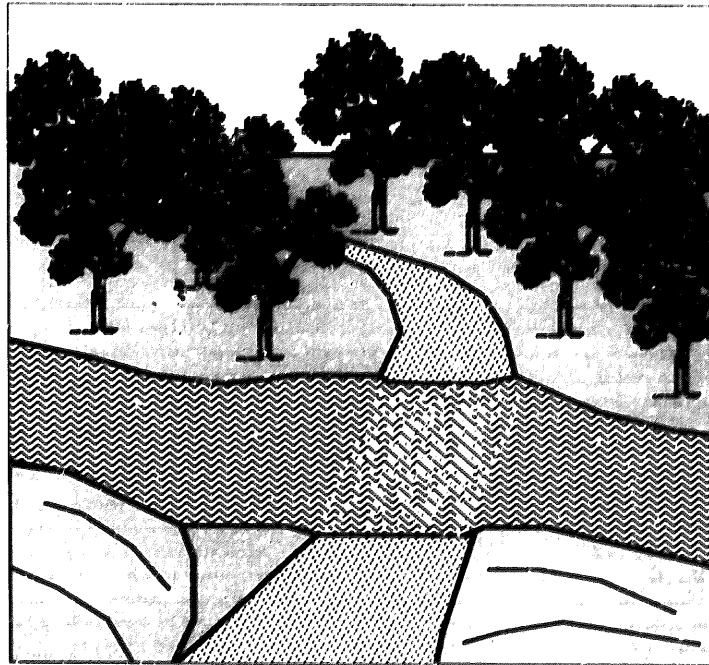


Figure 12: A ford

wider (50 to more than 100 meters) depending on the traffic and local conditions. When determining the width of a ford, look for indications that the roadway continues across the channel. Sometimes there is a change in tone where the shallow depth and coarse bottom materials create a disturbance on the water surface, or where the bottom materials have been disturbed. Sometimes, faint lines may mark the edge of the traveled way. In some cases, the edges of the ford are marked by boulders or posts that protrude above the surface of the water, and may be visible on imagery. Where material is added to the river bottom to raise the level of the ford, the sides may appear as lines of ripples or eddies of a lighter tone than the surrounding water. Even where the actual course of the ford is not visible through the surface of the water, the presence of conspicuous roads leading to opposite banks of a river and the lack of a bridge or ferry indicate that the location is probably a ford.

During periods of high water, low water bridges can be easily confused with paved fords, as both are completely submerged. These bridges consist of concrete decking set on supports at a level which keeps the deck above water during the drier parts of the year. They are contained wholly within ravines and gullies. It is important to distinguish between low water bridges and fords because of differences in their load limitations.

Prepared Float Bridge Sites

Bearing a close resemblance to fords, a prepared float bridge site has roads leading to a prepared ramp into the river. However, at these locations, the depth of the water precludes fording. These sites are built mostly for tactical military uses, as backups to provide vital river crossings in case bridges are destroyed by enemy activity. They are found in areas where military conflicts are, or were, anticipated, such as in Germany and Korea.

Drop Gates

In some countries, such as South Korea, the fear of military invasion by a neighboring country has prompted the construction of obstacles that can be quickly dropped into place, blocking roads and highways leading into the country. They are placed at critical points along the road where the adjacent terrain is too steep to allow vehicles to leave the road to bypass the obstacle. These obstacles are collectively known as drop gates. They can take many forms, but there are two basic types, the overhead drop and the side drop.

A common form of overhead drop is a large, rectangular block of concrete, set on piers over the road. It is similar in appearance to an overpass constructed across the road, except that it does not support a road or other transportation feature. Explosive charges are placed in the piers. In the event of an invasion, the explosives are detonated and the block drops onto the road.

A side drop obstacle can be a rectangular or triangular block of concrete set upright on the side of the road. Explosive charges at the base tip the block so

that it falls across the road. Another type of side drop is made by placing a large number of logs or boulders on the uphill side of the road, behind a retaining structure. The explosives would break the retaining structure, allowing the logs or boulders to roll down and block the road.

Drop gates will be found along the borders between countries where there is a threat of military invasion. They will be placed at points where vehicles cannot move off of the road to bypass the obstacles. Any massive structures similar to those described above, and with no other obvious function, located in such areas, are probably drop gates.

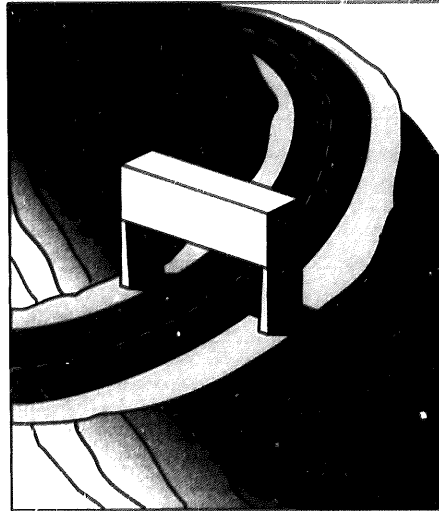


Figure 13: An overhead dropgate

Terminal Facilities

Because of the extensive network of roads in most areas, terminal facilities are more dispersed than for other transportation systems. Some can be quite large, but many are small and may be difficult to identify. Terminal facilities can be divided into four categories: freight, passenger, maintenance and vehicle storage.

Freight Terminals

Freight terminals deal with the shipping, transshipment or receiving of materials. For packaged materials, a single-story warehouse is used. Loading platforms are present along one or two sides of the building. If material is to be stored at the location, the building can be quite large. A small building indicates that it is mainly concerned with transshipment. There must be enough room around the loading platforms for the trucks to maneuver, as well as an adjacent, normally paved, parking area for waiting trucks. Trucks and trailers will almost always be present.

Bulk materials require special handling and storage. Solids are stored in silos or elevators or are piled in open storage areas. Specialized loading equipment, including conveyors and tipples will be present. Liquids and gases are stored in tanks, and special loading points, sometimes covered, are connected to the tanks

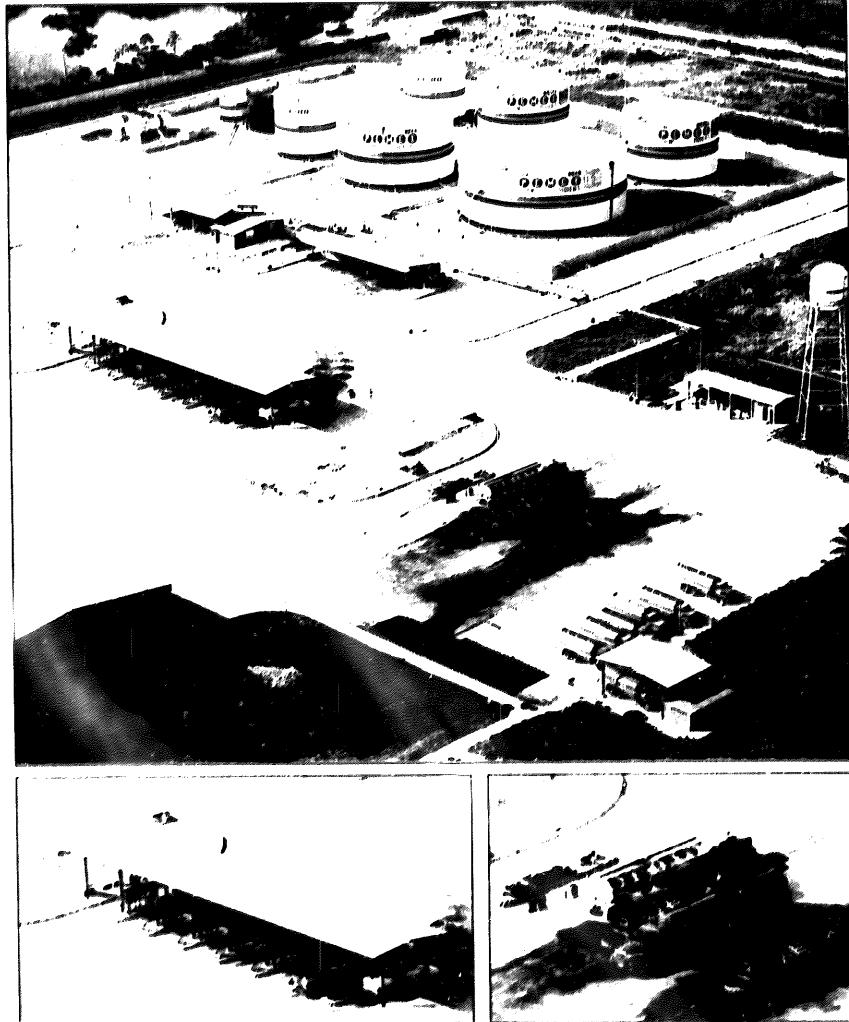


Figure 14: Overview and close ups of a POL transshipment area. Note the covered and open loading bays, and the barrels stored in the open at the bottom of the picture.

by above or below ground pipelines. The presence of a parking area and trucks, which may be specialized vehicles such as tank trucks, indicates that the facility is a road terminal.

Passenger Terminals

Passenger transportation is almost always via bus. Bus terminals are not very distinctive, especially in smaller towns, where a small, nondescript building, or a few rooms in a larger building may serve the purposes of ticketing, baggage handling and waiting area. In larger cities with more bus traffic, the terminal building will be a one or two story structure, with parking areas for the buses. The boarding area may have a roof to protect passengers from the rain, or in large terminals, the buses may drive into the building. Wide roads with rounded corners are present to allow the buses to maneuver. In some cases, the corners of the building may be rounded to provide maneuvering room for the buses. Of course, the presence of buses is helpful in identifying the terminal building.

Vehicle Storage

Most vehicle storage (parking) is in open, prepared areas. Most permanent parking areas are paved, and often are marked to designate parking spaces. Parking areas are easy to recognize. The even tone of the parking lot and regular rows of vehicles are distinctive. There will be easy access to adjacent roads, and the lot will be near a commercial, industrial, military or institutional facility. Military parking areas can be distinguished by the precise arrangement of vehicles and adjacent buildings and the uniform appearance and tone of the vehicles.

Within urban areas, vehicle parking is available in specially designed parking garages. These concrete structures provide several levels of parking spaces connected by ramps. These buildings are often open on the sides, so the different levels are visible from an oblique view. There will be a substantial parapet around the top of the building. Other characteristics are the presence of parking spaces and vehicles on the top of the structure, access roads into the building at ground level and the ramps connecting the different levels. Newer structures use spiral ramps, usually near the corners of the building.

Service and Maintenance Facilities

Servicing of bus or truck fleets is usually accomplished at a central location. The maintenance shop will be a large, single-story building with many large doors. An open parking area is normally adjacent to the maintenance facility. Military motor pool areas provide maintenance services for a unit's vehicles, and are directly adjacent to the vehicle parking area. Open-sided maintenance sheds, butterfly-roofed shelters and grease racks are spaced around an open central area.

Service stations provide fuel and maintenance services for other vehicles. These are normally small and widely distributed along the road network. They may vary

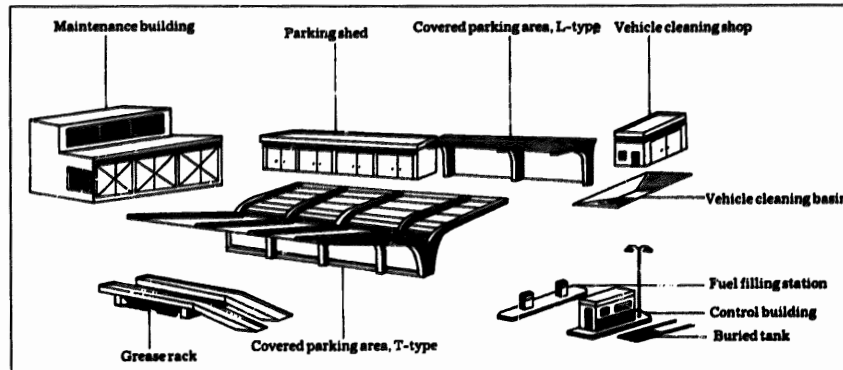


Figure 15: Vehicle maintenance area

widely in appearance, and shelters may or may not be present over the fuel pumps. There are several clues that can aid in the identification of service stations. They are frequently found at road intersections, on street corners, or at highway interchanges. Easy access to adjacent roads is provided. There is usually a paved area for maneuvering, parking and light service. Immediately adjacent to the paved area, and set back from the road is a small, usually one story building with large doors.

Railroads

Introduction

This section discusses all forms of transportation where the vehicles move along a track that both supports and guides the vehicle. In addition to the familiar railroads, this includes tramways, funiculars, cog railways and monorails. Although there are several variations on this form of transportation, the vast majority of rail lines are traditional railroads. The major part of this section discusses railroads, and the more specialized forms are included at the end of the section.

Railroads are an important part of the transportation network in any country. Even in the USA where truck and air transportation are highly developed, trains still carry a majority of the freight.

Railroad Construction

Railroad trains travel on tracks consisting of parallel steel rails which both support and guide the train. A flange on the inside of each wheel keeps the wheels on the track. In order for the train to travel safely, precise alignment and spacing

Product	Percent Carried by Rail
Coal	70 %
Canned and Frozen Food	74 %
Meat and Dairy Products	46 %
Household Appliances	71 %
Automobiles and Parts	76 %
Pulp and Paper	86 %
Timber	78 %
Chemicals	63 %
Primary Metal Products	68 %

Table 1: Percent of US freight carried by railroad (1988)

of the rails is essential. This is accomplished by fastening the rails to cross-members called ties (or sleepers). The ties lay on, and are partially embedded in a layer of coarse gravel, rock or cinders called ballast. The ballast firmly anchors the ties and rails in place, and maintains the vertical and horizontal alignment of the track. The ballast also allows water to drain away, further protecting the track.

The Permanent Way

The term "permanent way," referring to the combination of the track and the ballast, originated in the early days of railway construction. It was used to distinguish between the temporary lines used by the contractors and the finished, or permanent track. The ballast and track are placed on a carefully prepared and graded subgrade (or roadbed). This is composed of rock, gravel and/or earth, and is always built up above the ground level to allow water to drain away from the track. To either side of the subgrade, lateral drainage ditches carry water to the local drainage network.

Originally, ties were made from wooden timbers, but wood can deteriorate quickly, requiring regular replacement. However, wood treated with creosote preservative is still commonly used. Rails were first fastened to the ties by spikes with hooked heads, and spikes are still in common use. Since its invention in 1957, the spring steel "Pandrol" clip has been used on much of the newer tracks. A pair of joint bars (or fishplates) is used to keep the ends of the rails in alignment. Modern, heavy, welded rails eliminate the problems associated with joining rails together. A check rail is sometimes installed just inside the regular rail to guide the flange of the wheel. They are used on curves of short radius and on viaducts and bridges to guard against derailment.

Concrete ties are now often cheaper than wood, and are used wherever possible in Britain and are found in other industrialized countries. Steel ties, which can last for 40 to 80 years, are extensively used in continental Europe. In Switzerland,

70% of the Federal system and all of the narrow gauge systems use steel. Greece, the Congo Republics, and systems in west, east and South Africa use steel ties in 90 - 100% of their track. India has 15,000 km of broad and narrow gauge track with steel ties. Steel ties will enhance the radar signature of the railroad track. It is difficult to determine the composition of the ties, even on the largest scale of panchromatic imagery.

Paved concrete track (PACT) consists of a continuous concrete slab on which the rails are fixed. This eliminates the need for ties and ballast and gives a smoother, more stable base for modern high-speed trains. It is especially well suited for use in tunnels and rapid transit lines. PACT has been used on lines in England, Scotland, France, Japan and New Zealand, especially around tunnels. PACT can be recognized by its very light tone, smooth texture, and the absence of the cross-hatched pattern of the ties.

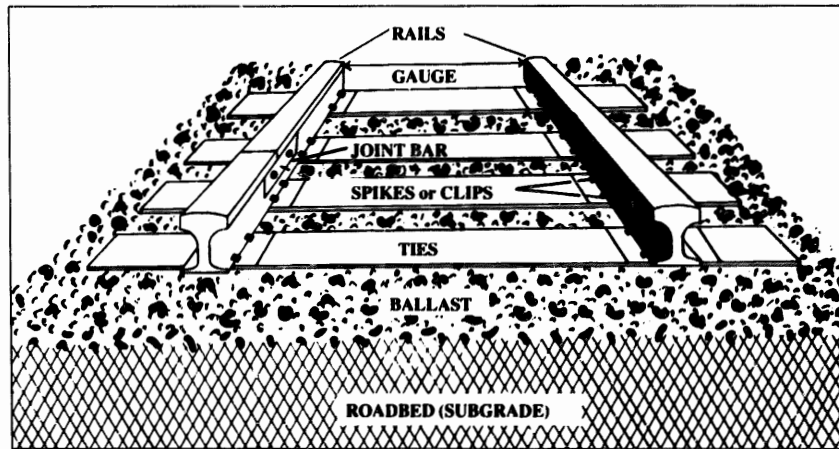


Figure 1: Railroad roadbed and components

Alignment

Trains are not able to negotiate sharp curves or steep grades. Therefore, railroad tracks will always exhibit gentle curves, and rarely will gradients exceed three per cent. The capacity required of a railroad line dictates the number of tracks or passing sidings, as well as the maximum speeds. The maximum speed, in turn, dictates the alignment, the minimum radius of curves and maximum grades. These, in combination with the terrain, control the number and size of cuts, fills, bridges and tunnels, all of which help minimize curves and grades.

Railway curves are measured in various ways. In continental Europe, they measure the radius of the curve in meters. In Great Britain, the radius is measured in

Locally, particularly around older cities, cut stone (sett) or brick pavements may be used. These areas are rapidly being replaced or paved over with asphalt.

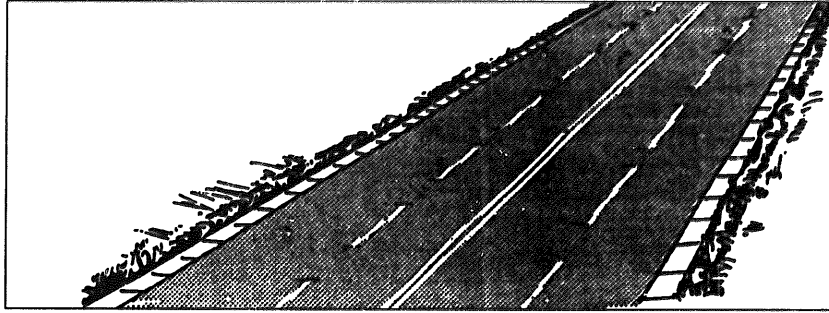


Figure 7: A multiple-lane road (four lanes). Such roads are almost without exception hard-surfaced.

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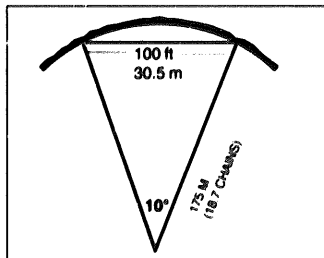


Figure 2: Methods of curve measurement

"chains" (1 chain = 66 ft = 20.12 m). Not to be outdone, U.S. railways measure curves in degrees of arc, where the arc is defined by a chord 100 meters long. The broader the curve, the smaller the angle. For example, a 10° curve has a radius of 175 meters, while a 1° curve has a radius of 1,750 meters. Figure 2 illustrates these three methods of measurement.

Curves may be super elevated (canted), where the outside rail is higher than the inside. This moves the center of gravity of the train toward the inside of the curve and allows the train to take the curve at a higher speed. In addition, transition curves, with gently increasing cant and decreasing radius, are needed to ease a train into and out of curves.

Track Gauges

The gauge of a railroad is the distance between the inside edges of the two rails. Many gauges have been used around the world, but modernization of railroads has led to increased standardization. The most commonly used gauges are listed in Table 2. The "standard gauge" of 4 ft 8 1/2 in (1.435 m) has been adopted throughout North America, most of Europe, North Africa, China, and other countries scattered around the world.

Running Direction

In order to allow trains to run in both directions on a single-track line, passing sidings (or passing tracks) are provided at intervals along the line. These are parallel lengths of track, connected at both ends to the main line. They can be recognized as passing sidings as they will be located away from other rail facilities, there will be no loading facilities, adjacent structures or connection to other transportation networks. They will be long enough to accommodate the longest train normally traveling that line.

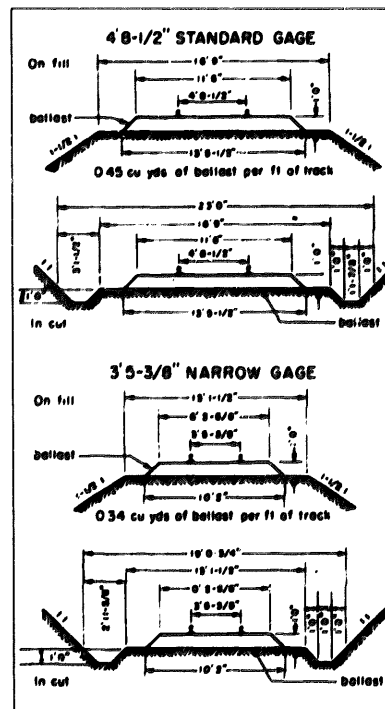


Figure 3: Measurements of standard (USA) and narrow gauge railroad beds

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other roads or railroads.

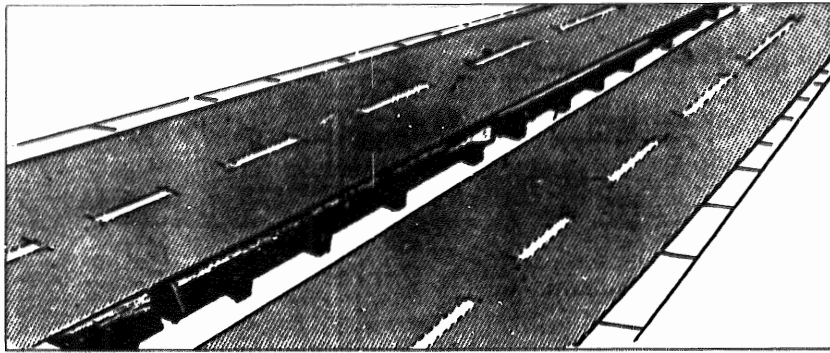


Figure 8: A four lane divided highway, without a median

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On double-track lines, the trains will run on either the left or right track, depending on the convention adopted by the country (or sometimes by individual rail lines). Right-hand running railways are found in Canada and the USA (except the Chicago & Northwestern Railroad), Russia and the former Soviet Republics, some sections of China and Austria, Bulgaria, the Czech and Slovak Republics, Denmark, Finland, Germany, Hungary, the Netherlands, Norway, Poland, Turkey and "Yugoslavia." Parts of France (Alsace and Lorraine) were under German administration when the lines were built, and are still right-running. Other countries use left-running, or have no double-line railways. Modern signaling methods have allowed several railways in Europe and the USA to run trains in either direction on both tracks.

Electrification

Using electricity to power locomotives is more efficient, and less costly than using diesel engines. However, the high cost of installing the wiring along the rail line makes electrification economical only where there are high volumes of traffic over relatively short distances. Electrified railroads are more common in Europe and Japan, where high volumes of traffic run between closely spaced cities. In other parts of the world, electrification is limited to a few high-traffic lines, and to urban rapid-transit/commuter lines.

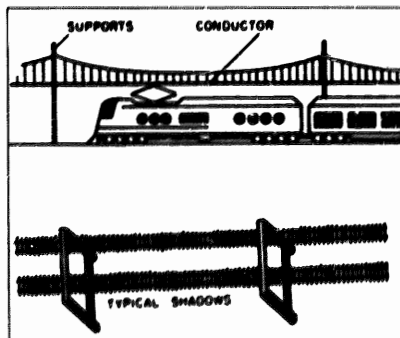


Figure 4: Overhead electrified railroad, shadows and components

Most electrification is via cables suspended over the track. On single-track lines, the cable is suspended from an arm mounted on simple poles or towers evenly spaced along one side of the track. On multiple-track lines, or where the track passes through a yard, pairs of poles or towers support either a gantry or a trans-

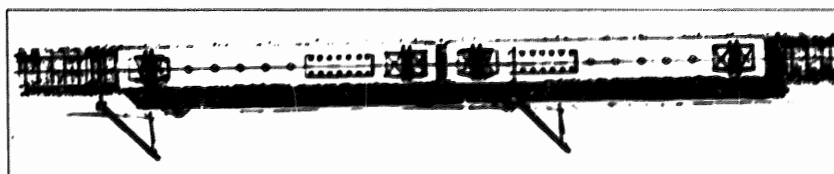


Figure 5: Overhead view of an electrified commuter train. Note the pantographs present on each car, indicating that both cars are powered

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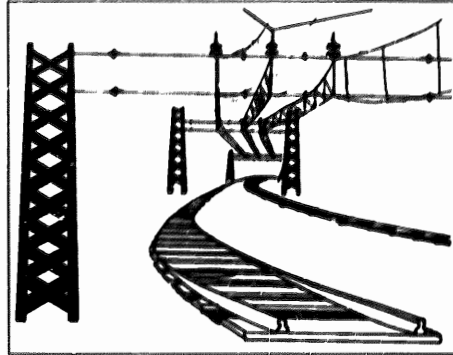


Figure 6: Catenary system

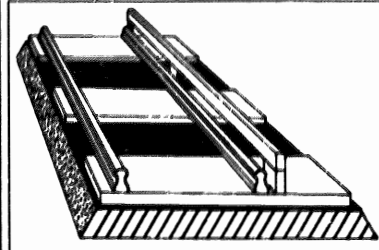


Figure 7: Railbed for a third-rail electrified line

verse cable (catenary system) from which the power cables are suspended. Since the poles are small and set close to the tracks, they may be difficult to see on imagery, especially on single-track lines. Sometimes a regularly spaced line of light-toned scars marks the base of the poles. On multiple-line tracks, the gantries are usually visible, though catenary systems may only have gantries at intervals. If poles or gantries are not visible along the track, examine the rail yards, where the gantries would be larger and more readily visible. If there is a train on the track, look for the pantograph on top of the locomotive. This is a structure of articulated rods that remains in contact with the power cable. Small electrical substations are located at intervals along the track.

Some rail lines, particularly commuter lines in urban areas, are electrified through a third rail which carries the current. The electrified rail is usually set outside the primary rails, but may occasionally be placed between them. These third-rail systems are difficult to discern on imagery, unless the resolution allows you to see the actual number of tracks.

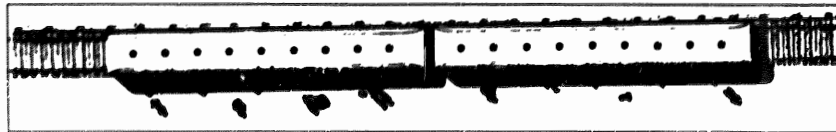


Figure 8: Aerial view of a third-rail electrified track

Signals

Railroad signals are small and difficult to locate on imagery. For cartographic purposes, they have little significance. However, on multi-track lines and in rail yards, the signals may be mounted on gantries built across the tracks. The analyst

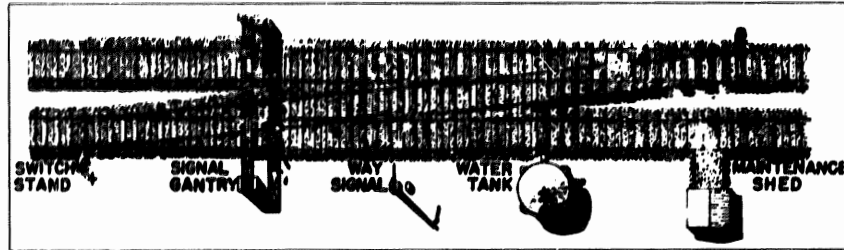


Figure 9: Aerial view of a dual track railroad with signals and other trackside features

should be careful to avoid confusing these occasional signal gantries with the regularly spaced electrification gantries.

Operational Status

There are three categories of operational status for a railway line, operational (in regular use), abandoned (intact but not in use) and dismantled (track and bridges removed). Even casual examination of a dismantled line will reveal that the tracks and bridges have been removed. Yet the graded right-of-way is still present and offers an alternative route for military vehicles.

The distinction between operational and abandoned lines is not as simple. The presence of rolling stock, of course, verifies operational status. Abandoned tracks will develop a layer of rust on the rails, eliminating the reflections seen on operational lines. In addition, vegetation will grow through the ballast, giving the rail bed a mottled texture. Where trees grow near the tracks, limbs growing across the right-of-way may be visible.

Terminals and Facilities

Railroad terminals can be divided into three main categories: loading and unloading of passengers and freight, storage or sorting of trains, and repair/maintenance facilities. Two or more of these functions may occur within the bounds of a large railroad facility, but the differing requirements, and thus the appearance, of each allows them to be identified and separated.

Terminals

Terminal facilities can be divided into four categories, passenger terminals, freight terminals, freight transfer stations, and freight storage areas. At larger facilities, these functions each have their own area, and can be easily delimited. In small stations, however, two or more functions may be combined in one area.

Terminals come in two basic configurations, through terminals and dead end terminals. In a through terminal, the tracks diverge entering the loading/unloading

area, and converge again on the other side to rejoin the main track. Through terminals can be used by trains passing in either direction. A dead end terminal is connected to the main line at one end only, and the tracks fan out into the loading/unloading area. In either case, loading platforms and connections to other transportation networks will be present.

Passenger and freight terminals are usually located close together, particularly in urban areas. They are characterized by tracks which are separated by platforms, sheds, stacks of goods, etc. Outlying areas are served by small stations and depots, or by isolated freight yards.

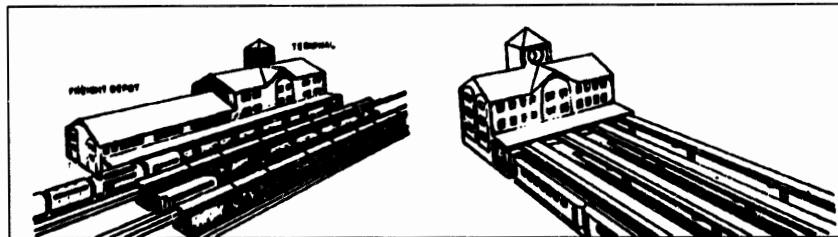


Figure 10: Through and dead end terminals. Note the freight depot adjacent to the passenger terminal on the through configuration.

Passenger Terminals

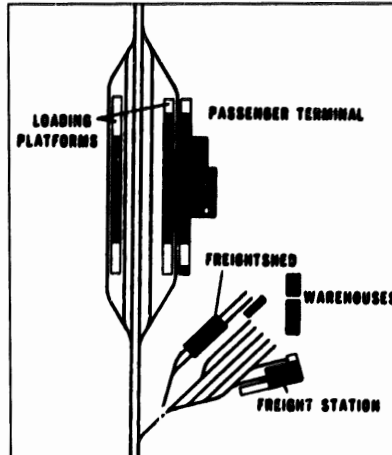
Stations and depots are smaller facilities along a railroad line where passengers can board or leave the train. These facilities normally consist of a small building adjacent to the tracks, with a small vehicle parking area. There will be at least one siding on which the trains stop for loading, with adjacent loading platforms that may or may not be covered. If there is more than one platform, access to other platforms is via pedestrian tunnels. Stations and depots are almost always of the through type, allowing trains to pull in and out and continue in the same direction.

Passenger terminals are large facilities, characterized by a large terminal building with a covered concourse immediately adjacent to the loading platforms. Abundant vehicle parking is available, as well as easy access to other transportation. The loading platform area consists of several closely spaced tracks with covered platforms between them. These distinctive covered platforms are easily visible between the tracks. Terminals may have either a through or dead end configuration. At through terminals, access to the platforms is through pedestrian overpasses. Most large passenger terminals have a large plaza across from the terminal entrance.

Freight Terminals

The presence of a siding or spur leading to a facility indicates that at least some materials enter or leave the facility by rail. These industries, warehouses, transshipment areas, etc., will have loading docks with specialized equipment to handle the freight, and either open or enclosed storage areas.

Freight terminals can also be of the through type, but most have a dead-end configuration. Freight handling requires larger spacing between the tracks, giving these areas more of a fan shape. Long, narrow freight sheds with adjacent tracks are present for storage of materials. These may have a distinctive sawtooth shape where individual cars are backed in for loading. Some areas are set aside for transshipment of freight to trucks. These "team tracks" are widely spaced, have open areas between them with easy access to roads. A set of closely spaced holding tracks is often present, where waiting cars are stored.



Transfer of freight to ships or barges occurs at ports and harbors, where the tracks will extend out onto the piers and wharves where the ships are berthed. Extensive warehouses or other storage facilities will also be present. (See also the section on Ports and Harbors.)

Figure 11: Diagram of a terminal area. Note the through type passenger terminal and dead end freight terminal.

Facilities for storage of freight will occupy a considerable portion of the freight terminal. Bulk materials may be stored in open areas. Warehouses and freight sheds are large, single-story frame structures of light construction. Metal and wood structures, as well as masonry buildings, are common. Depending on the materials being shipped, specialized structures, such as POL tanks and grain elevators, may be present. These and other storage facilities are discussed in detail in Chapter 4.

Railroad Yards

As railroad cars proceed from their origin to their destination, they must be assembled into trains for shipment, and disassembled upon arrival. They may be detached from one train and reattached to another enroute. This assembly, disassembly and reassembly of trains requires an extensive area of tracks and occurs in various through and dead-end type railroad yards. Car handling yards are characterized by their through type configuration, closely spaced tracks and absence of buildings, platforms, etc.

Arriving trains are kept in a receiving yard until they can be disassembled. These yards are always of the through type, and are smaller than the classification yard.

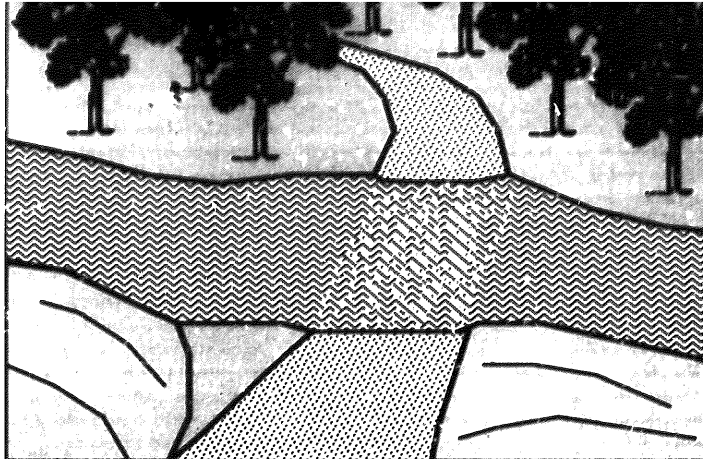


Figure 12: A ford

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Figure 12: Oblique view of a freight terminal where POL products are loaded to railroad tank cars (right side of photo) and to tank trucks (left side of photo). The rail terminal has a dead end configuration, and a holding yard for cars waiting to be filled can be seen above and to the right of the loading platforms. Note the darker tone of the ballast around the rail lines, as opposed to the surrounding concrete pavement.



Figure 13: A ground view of the terminal shown in figure 12. Note the covered loading equipment between each pair of tracks, and the darker tone and coarser texture of the gravel ballast of the rail bed.

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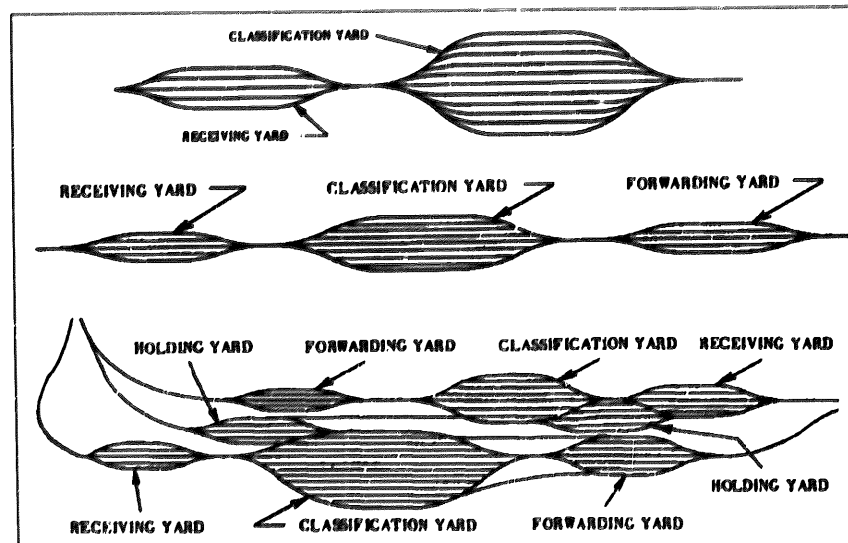


Figure 14: Simple and complex railroad yards. In the top and center examples, the traffic flow would proceed from left to right. The complex yard on the bottom could handle traffic in two directions. This yard is located on a dual-track, right running line, where traffic entering the complex always enters on the right side.

Cars are uncoupled from the inbound trains and moved into the classification yard (sometimes called a marshalling yard) by a small switch engine. Classification yards are also of the through type. Upon assembly, the trains may be moved into a small, through type forwarding yard, until the train is scheduled to depart. A small set of tracks may be provided for storage of empty or damaged cars. This holding yard will be a small area of through or dead end tracks.

The cars are sorted and regrouped by switching them onto the appropriate track in the classification yard. The switches are operated from a control tower overlooking the yard. At small or out-of-date yards, the movement of cars is done solely with a switch engine. The switches may also be operated manually at these facilities. At others, the yard may be constructed on an incline, so that as cars are uncoupled they would roll out of the receiving yard and be switched onto the proper track. A switch engine would perform only minimal work in this type of operation.

Most classification yards now use a variation of the gravity method. A hump is constructed

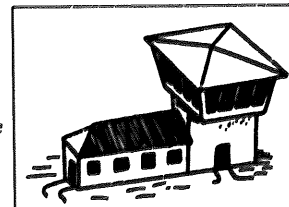


Figure 15: Railroad control tower

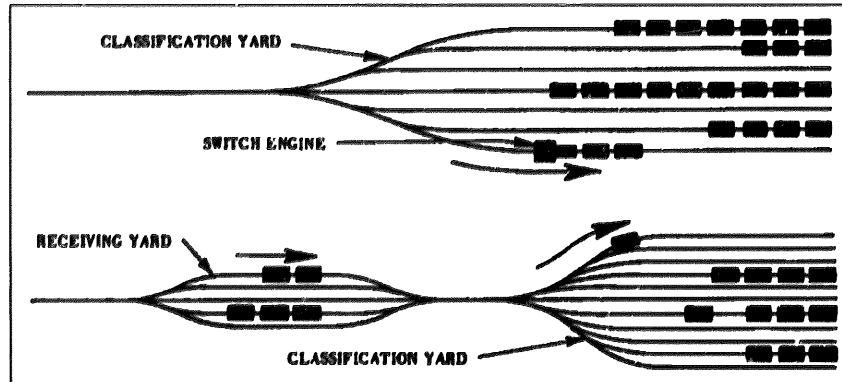


Figure 16: Flat (upper) and gravity (lower) classification yards. The gravity yard can be recognized by the presence of retarders on the tracks, by the slope of the ground (on stereo imagery) and sometimes by the absence of a switch engine. A receiving yard may be present at both types of facilities.

between the receiving and classification yards. A switch engine pushes the cars up the ramp, where they are decoupled and allowed to roll down the opposite side, where they are routed to the proper track. The speed of cars rolling into the yard is controlled by retarders, long bars which squeeze against the flanges of the wheels. The retarders may be operated through the switch control tower, or there may be a separate retarder control tower. The retarders are readily visible even at medium scales as dark rectangular areas where the tracks diverge into the classification yard.

The receiving, classification and forwarding yards are arranged end to end. In smaller yards, the forwarding yard, and even the receiving yard may be absent.

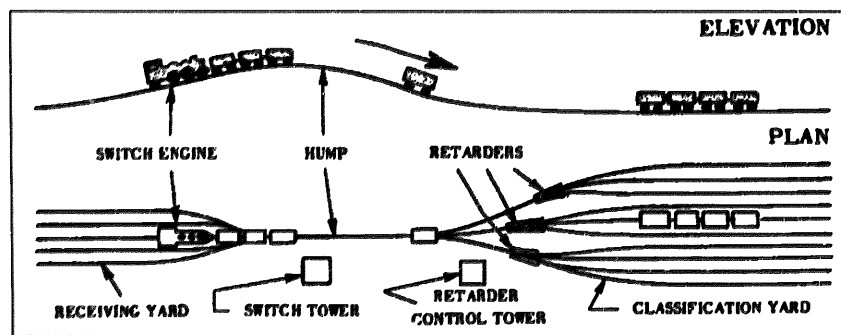


Figure 17: Side view and aerial view of a hump classification yard



Figure 14: Overview and close-ups of a P.O.L. transshipment area. Note the covered and open loading bays, and the barrels stored in the open at the bottom of the picture.

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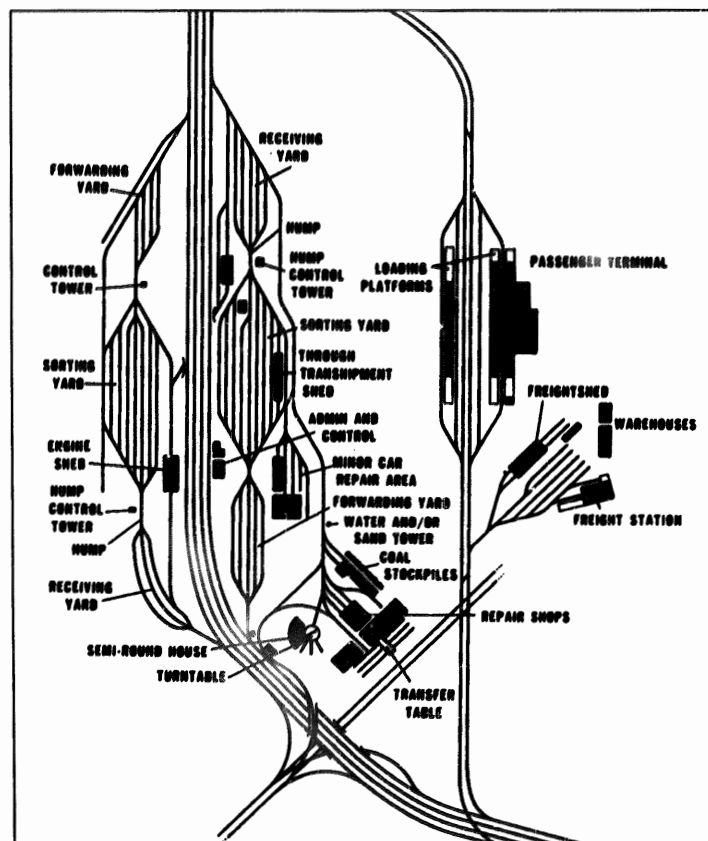


Figure 18: Diagram of a railroad yard and terminal complex. The classification yards are on the left, the terminals are on the right, and repair and maintenance facilities are centrally located.

In large facilities on double line tracks, two sets of yards may be present for traffic moving in both directions. The holding yard, if present, may have any configuration, and would be located wherever sufficient space is available (see figures 14 and 18).

Photo Interpretation Training Course

Repair and Maintenance Facilities

For reasons of convenience and centralization, facilities for maintenance and repair of rolling stock will be present adjacent to rail yards and terminals. Tracks for the storage of cars awaiting repairs or being repaired form yards mostly of the dead-end type. Individual configurations depend on the space available at the facility. Repair and maintenance facilities contain a number of large buildings with tracks adjacent to or entering the buildings. The buildings are of substantial construction and have the sawtooth or monitored roofs typical of industrial facilities.

The presence of tracks leading into large, single-story buildings and rolling stock on the tracks, and the absence of platforms, loading facilities or good road access are the keys to identification of car repair facilities.

Fueling facilities are also present in this area. In smaller facilities, both cars and locomotives may be serviced in the same building. Most facilities have separate locomotive repair areas. Locomotive repair areas are identified by the presence of a turntable and roundhouse.

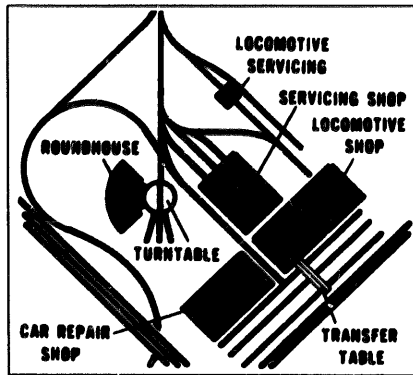


Figure 19: Typical arrangement of facilities at a railroad repair and servicing terminal

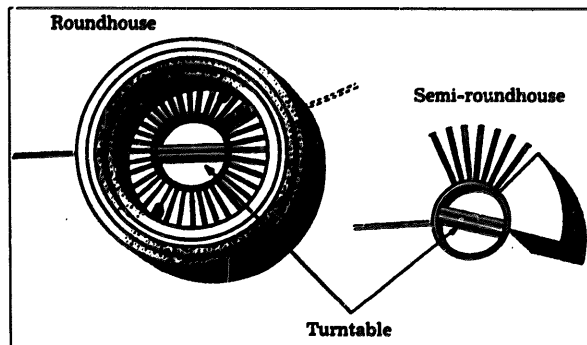


Figure 20: Roundhouse and semi-roundhouse. A semi-roundhouse can occupy any fraction of the perimeter of the turntable, and all or part of the remainder may contain open tracks for storage of locomotives.

A turntable is a section of track set on a rotating platform in a circular hole. In its simplest configuration, it is used to turn a locomotive around on the track. In repair facilities, there are several tracks radiating from the turntable, leading to a circular or semi-circular building that entirely or partially surrounds the turntable. This building is called the roundhouse, and contains equipment for

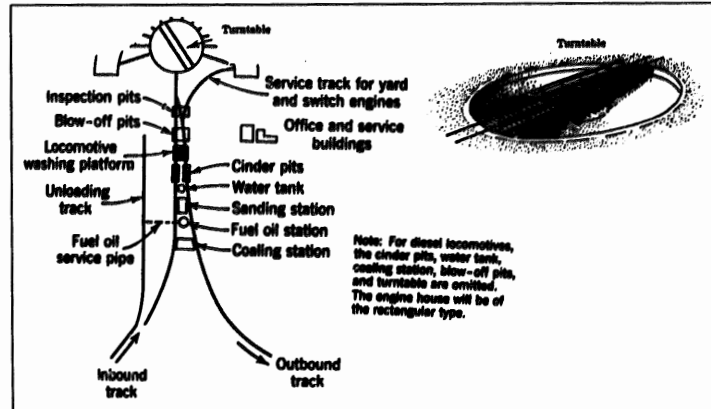


Figure 21: A turntable and associated service facilities

repair of locomotives. The circular shape of the facilities make the roundhouse and turntable easy to locate and identify.

Some repair facilities make use of a transfer table. This is located between two buildings, and consists of a section of track that can be moved laterally, to move a locomotive from one building to a particular stall in the other building.

Commuter Lines/Trolleys

Within major urban areas, commuter traffic is often carried by specialized rail lines. Although some are of standard gauge, most are of narrow gauge. Electrification of commuter lines is almost universal. Third rail electrification is used where the right of way can be isolated. In addition, the cars may be smaller in size than standard rail cars.

The tracks may be placed on their own right of way, and can be underground, on the surface, or elevated, for all or parts of the route. In some cities, the rail lines are set in the middle of existing roads (trolleys). These can be difficult to

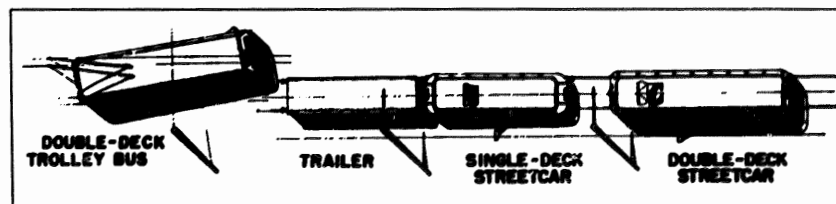


Figure 22: Overhead electrified commuter lines

detect; look for the overhead electric lines, and wider than normal streets. At the end of the commuter lines, a turning loop may be visible.

Stations for commuter lines are usually small, and may be only a shelter. Larger stations will be located at intersections with other transportation facilities, such as airports, bus depots and railroad terminals. Stations in the suburbs may have larger commuter parking lots.

Logging Railroads

Logging railroads are temporary tracks of light construction built to carry logs to the sawmill. They are normally of narrow gauge, and will have sharper curves and steeper grades than regular rail lines. They are found in forested areas where logging operations are active. The lines often branch several times as they enter the logging area. Cleared ways without tracks mark where the tracks were previously located and then abandoned as logging operations moved into a new area. Their location in a forested area, sharp curves, and branching into an area with no obvious destination are keys to the identification of logging railroads.

Cog Railways

Cog railways are used where a rail line must be built along a steep grade. Locomotives have geared wheels which engage a toothed center rail. These railways are almost always of narrow gauge with correspondingly smaller cars. The presence of the center rail and the steep grade of the track are indicative of cog railways.

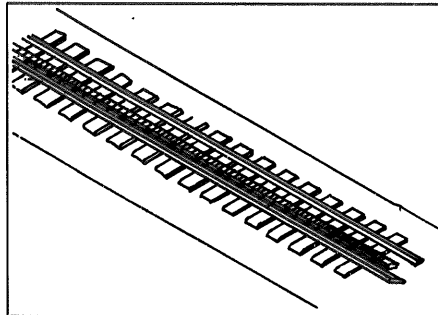


Figure 22: Diagram of a cog railway track. Note the distinctive toothed center rail.

Monorails

The term monorail refers to a class of vehicles that travel on a single large rail. The cars may either ride on, or be suspended from the rail. Most monorails are commuter lines, or are used for moving people around large facilities such as airports or amusement parks. A few high-speed, inter-city lines have been constructed using a monorail.

When the cars ride on the monorail, the line will appear similar to a normal commuter rail line, except that close examination reveals the presence of only a single, large rail. Suspended car monorails are more distinctive, as the imagery will show the rail and the structures supporting the rail. The track can vary from

Table 2: Common Railroad Gauges

BROAD GAUGES	
Gauge	Country
1676 mm 5 ft 6 in	India, Spain, Portugal, Pakistan, Bangladesh, Sri Lanka, Argentina, Chile.
1600 mm 5 ft 3 in	Ireland, South Australia, Victoria, Brazil
1520 mm 4 ft 11 7/8 in	former USSR, Finland, Mongolia. (narrowed from 5 ft in 1972, much 5 ft gauge track still remains).
STANDARD GAUGES	
Gauge	Country
1435 mm 4 ft 8 1/2 in	Great Britain, Canada, USA, Mexico, Europe (except Spain, Ireland, Finland, & former USSR) North Africa, New South Wales, China, South Korea, Western Australia, Victoria, Cuba, Jamaica, Paraguay, Uruguay, Argentina, Peru, Venezuela, Lebanon, Iran, Iraq, Mauritius, Morocco, Saudi Arabia, Syria, U.A.R.
NARROW GAUGES	
Gauge	Country
1067 mm 3 ft 6 in	Queensland, South & West Australia, Tasmania, New Zealand, Angola, South Africa, Rhodesia, Zambia, Zimbabwe, Malawi, Mozambique, Ghana, Nicaragua, Nigeria, Sudan, Japan, Indonesia, Philippines, Norway, Newfoundland, Sweden, Ecuador, Chile, Haiti, Honduras.
1065 mm	South African Railways
1050 mm 3 ft 5 1/4 in	Algeria, Syria, Lebanon & Jordan
1 meter 3 ft 3 3/8 in	Burma, Thailand, Vietnam, Malaysia, East Africa, Cambodia, Brazil, Argentina, Chile, Bolivia, Switzerland, Portugal, Greece, India, Pakistan, Iraq
914 mm 3 ft	Central America, Colombia, Peru, Mexico, Newfoundland
800 mm	Mountain and rack railways.
762 mm 2 ft 6 in	Austria, Yugoslavia, Czechoslovakia, India, Sri Lanka, Wales
750 mm 2 ft 5 1/2 in	Argentina, Brazil
610 mm (2 ft) & 600 mm 1 ft 11 5/8 in	Sierra Leone, Wales, South Africa, India, Pakistan, Chile, Argentina

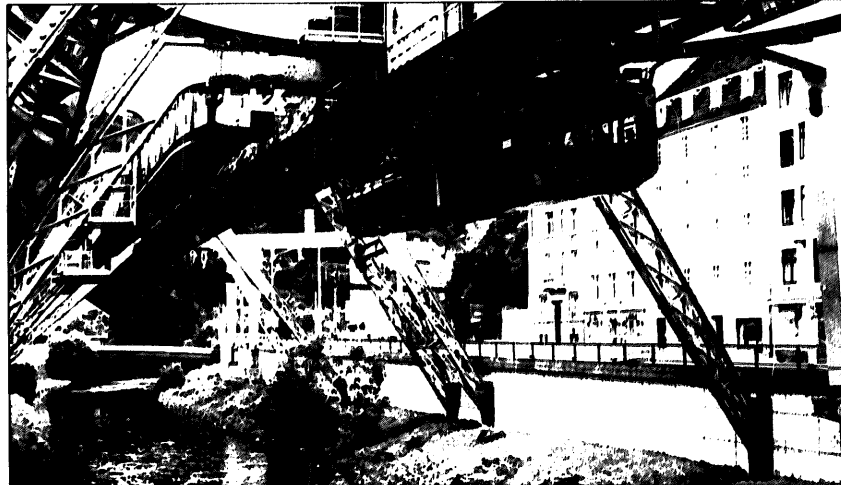


Figure 24: A monorail line built over a canal to maximize the use of available space

a single steel rail suspended from large poles, to a complex structure with massive supports shaped like an inverted "V" or "U". On an aerial photograph, the cars may be partially or entirely concealed by the rail.

Bridges

Introduction

Bridges are the most vulnerable part of any transportation system. The loss of a key bridge (or bridges) can significantly reduce or paralyze the movement of troops, armaments or supplies. Therefore, knowledge about an area's bridges is vital to military planners. The location, construction and capacity of all bridges, as well as the identification of alternate routes and bypasses are key factors in the planning and conduct of military operations.

A bridge is any structure (other than an earthen fill) providing passage for a transportation route over an obstacle. The type of bridge built at a particular location depends on several factors. Most important are the purpose of the bridge, the topography of the site, and the labor, materials and technology available. However, aesthetic considerations, and the previous experience of the designer also effect the design of the bridge. There is often no single best bridge design for a particular situation.

Changes in technology have resulted in an evolution of bridge construction methods. New materials and designs, especially within the last 200 years, have dramatically changed the appearance of bridges. Because the bridges found in a geographic area are usually of different ages, a variety of bridge types and materials can be expected.



Figure 1: Basic timber beam bridge

The earliest type of bridge consisted of a log dropped across a gap. This simple beam bridge was improved by cutting and shaping the wood into timbers, and assembling them into a continuous deck. These bridges were limited in size by the relatively low strength of wood, which required massive timbers to bridge even short gaps. Wider gaps required numerous intermediate supports. These early wooden structures were limited to light loads and short spans, until the invention of the truss. The construction of timber truss bridges reached its peak in the 18th and early 19th centuries. But wood deteriorates quickly, and is susceptible to damage by fire. Timber bridges require constant repair, and few are left today.



Figure 2: Basic masonry arch bridge

The invention of the masonry arch bridge, more than 3,000 years ago, allowed the construction of longer spans able to carry heavy loads. The Romans made extensive use of this design to carry aqueducts as well as roads. The construction of extensive canals during the Industrial Revolution utilized masonry arch structures to carry the canals over obstacles. These massive masonry bridges proved stronger and more durable than wooden bridges, and many are still in use today. But the construction of large masonry arches was a

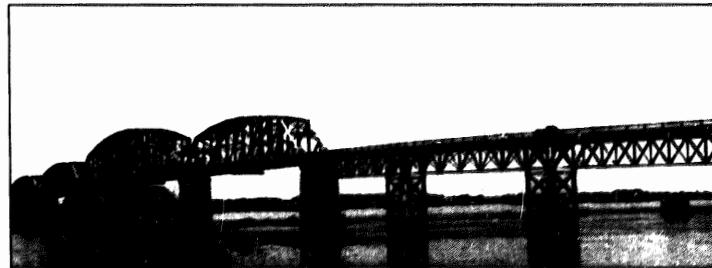


Figure 3: A steel truss bridge with several through-type, polygonal chord spans on solid concrete piers (background) and several deck-type, double-Warren spans on steel trestle piers (foreground). The through spans maximize the under-bridge clearance for ships travelling up the main channel.



Figure 4: Primitive timber and rope suspension bridges. Mainly for pedestrian use, bridges like these are still in use in undeveloped areas.

major engineering task, and required a lot of labor. This made them expensive and limited their use.

The development of iron and steel structural members gave rise to a new generation of truss bridges in the late 19th century. The parts for metal truss bridges were easily transported and assembled, reducing construction time and thus cost. The durability and greater strength of metal made truss and girder bridges popular on the expanding road and railroad networks.

A primitive form of suspension bridge, still in use in some areas, consists of three ropes suspended across a gap. The lower rope serves as the floor while the other ropes are used for balancing as one walks across, or two lower ropes may support a flimsy wood deck. Further development of suspension bridges had to wait for the development of a material with high tensile strength. With the introduction of iron chains in the early 19th century, and later, steel cables,

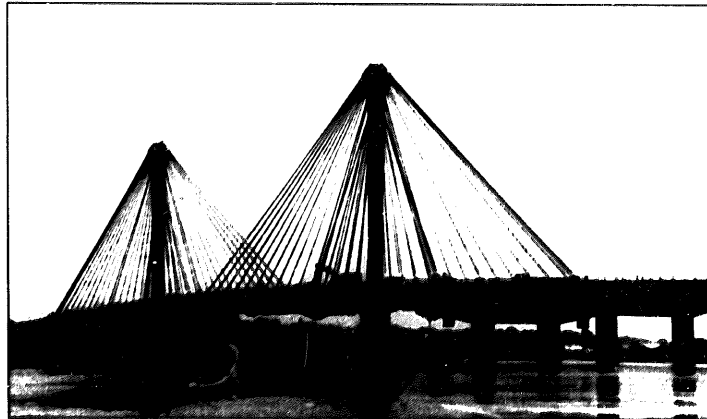


Figure 5: Modern cable-stayed suspension bridge (under construction). Note the massive towers and the concrete bents supporting the approach spans.

the construction of large suspension bridges became possible. They are still the most economical type of bridge for crossings requiring wide clearances.

Concrete was not widely used for bridges prior to the 19th century, because of its poor tensile strength. The introduction of reinforced concrete, and more recently, pre-stressed concrete, made the design of concrete bridges possible. The steel reinforcing bars add tensile strength and allow concrete to be used for structural members in tension. Pre-stressing the reinforcing bars increases the strength and stability of the structure. The use of concrete in bridge construction has been increasing steadily since the end of the 19th century.



Figure 6: A concrete arch suspension bridge. This design is also referred to as a bowstring arch.

Bridge Structural Elements

All bridges are composed of the same basic structural elements. The part of the bridge that spans the gap is called the **superstructure**. This includes the floor of the bridge and the structural elements that provide strength and rigidity. The **substructure** includes all of the elements upon which the superstructure rests. **Abutments** are the foundation-like structures that support the ends of the bridge. Intermediate supports on longer bridges are provided by **piers**, **piles**, **bents** or **trestles**. The section of a bridge's superstructure between abutments, between intermediate supports, or between an abutment and an intermediate support is called a **span**.

Some DMA product specifications use the terms superstructure and substructure differently. For example: In DFAD, "superstructure" refers only to structural elements that extend above the road or railway crossing the bridge. When describing a bridge for a particular product, be sure to verify the usage of terms with the product specifications.

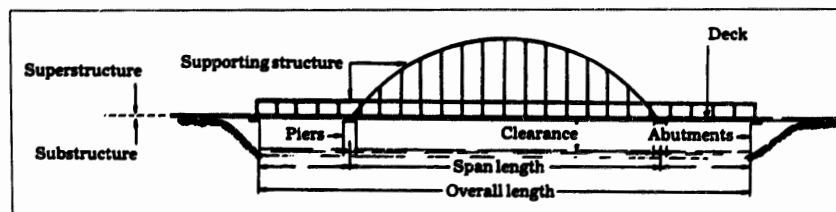


Figure 7: Diagram showing the basic components of a bridge

Bridge Substructure

Just as the foundation serves as a stable base for a house, the abutments form the stable base upon which the ends of the bridge rest. These concrete or masonry (occasionally wooden) structures protect against undermining of the bridge by erosion of the banks and approaches. The abutments also provide support to the earthen fills of the approaches, where the route is graded to the level of the bridge. The abutments are not normally visible on vertical imagery.

The distance that can be spanned without intermediate supports depends on the bridge structure type and materials. Bridging across wider gaps requires the use of intermediate supports. A pier is a solid (masonry or concrete) structure that provides a continuous support across the width of the bridge. A bent is a simple structure consisting of a single row of piles (pile bent) or posts (trestle bent), cross-braced and surmounted by a cap. A structure consisting of two or more adjacent bents braced together is also called a pier (pile pier or trestle pier). These supports may be composed of wood, steel or concrete members.

Occasionally, a continuous framework is used to support the length of a bridge between the abutments. This kind of structure (wood or steel) is called a trestle.

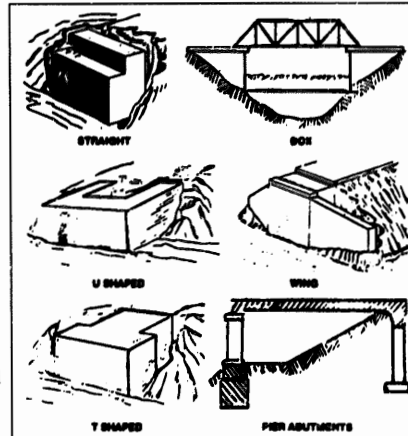


Figure 8: Bridge abutments

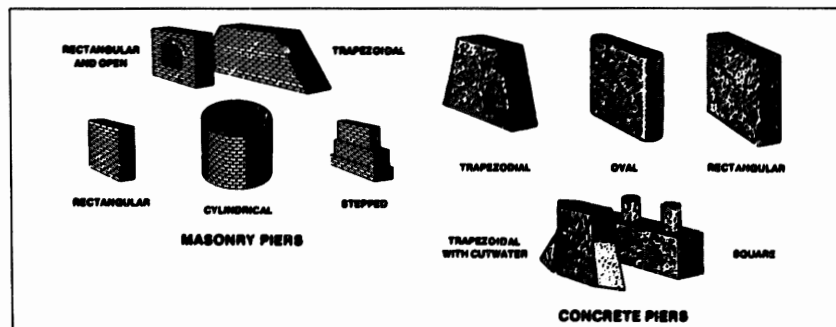


Figure 9: Several common varieties of bridge piers. Piers will only be visible on imagery taken at an angle to the vertical. Shadows of piers may also be visible.

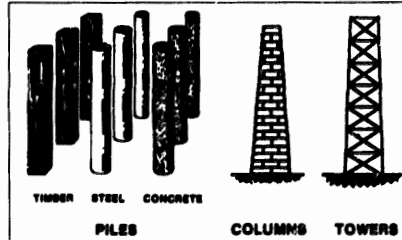


Figure 10: Piles

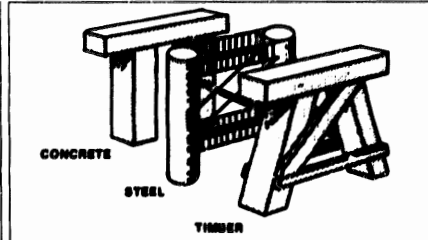


Figure 11: Bridge bents

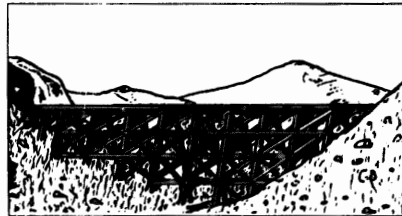


Figure 13: A bridge supported by a wood trestle

A bridge supported by a trestle does not have individual spans, as the trestle provides continuous support along the length of the bridge.

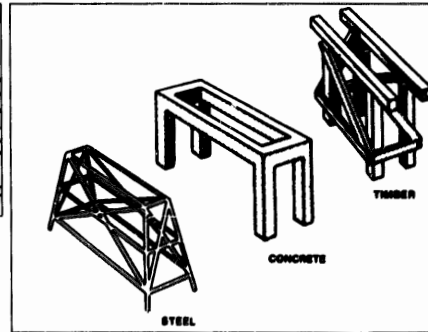


Figure 12: Trestle piers

Although piers, bents and trestles are hidden by the bridge on vertical imagery, when the sun angle is right, the shadows can reveal the types of supports present.

Bridge Superstructure

The bridge superstructure is composed of a **floor system**, which carries the transportation route, and the **supporting structure**, which supports the floor system and gives the bridge its strength. The surface of the floor system, where the traffic is carried, is called the **deck**.

The superstructure is composed of **simple** spans if each span is a distinct structural element. When the structural element runs uninterrupted across more than two supports, it is called a **continuous** span structure. A **cantilevered** span is one where the structural element is balanced on one of the supports.

The relationship between the floor system and the supporting structure is an important factor in describing bridges. When the supporting structure is entirely underneath the floor system, it is called a **deck bridge**. When the supporting

structure is entirely above the floor system, it is a **through bridge**. When the floor system is located at an intermediate position, it is called a **semi-through** or **half-through bridge**.

Various design principles are used to impart strength to the supporting structure. These design types are described under **Bridge Classification**. The materials used in the construction of the bridge may change its appearance, but the bridge type will still be recognizable.

Skew Bridges

Bridges are normally built perpendicular to the obstacle they cross, and the route is then adjusted to the position of the bridge. This minimizes the length of the bridge, and thus minimizes construction costs. In some cases, especially on major highways and railroads, changing their alignment for small bridges is more expensive than the cost of bridging the gap at an angle. In these cases a **skew bridge** is constructed. The superstructure is built parallel to the route's centerline, while the substructure is aligned with the obstacle being crossed.

Bridge Classification

There are several factors that can be used to classify bridges. Characteristics such as function, composition, design criteria, etc., can be used to divide bridges into categories. These factors are summarized in **Table 1**. The most visible distinctions are those related to bridge design. Therefore, bridge design types will be addressed individually, and the other factors will be discussed within these sections.

DMA specifications differ widely in the way they classify and describe bridges. These product and construction specs are often internally inconsistent as well. For example, the terms cantilever and deck are often used to describe bridge design types. For some types of bridges (eg. the truss arch suspension bridge in figure 35), placement into a specific category is difficult under any specification. When classifying bridges, the analyst should study the specifications and assign the bridge to the most appropriate category.

FUNCTION	MATERIAL	TYPE	INTERSPAN RELATION- SHIPS	BRIDGE FLOOR POSITION	NAVIGATION CLEARANCE
Railway	Timber	Beam (Stringer)	Simple	Deck	Fixed
Highway	Masonry	Girder	Continuous	Through	Swing
Viaduct	Iron	Truss	Cantilever	Semi-through	Lift
Footbridge	Steel	Arch			Tilt (Bascule)
Aqueduct/ Canal	Concrete: reinforced or prestressed	Suspension			Other
Combination					

Table 1: Bridge Classification Criteria

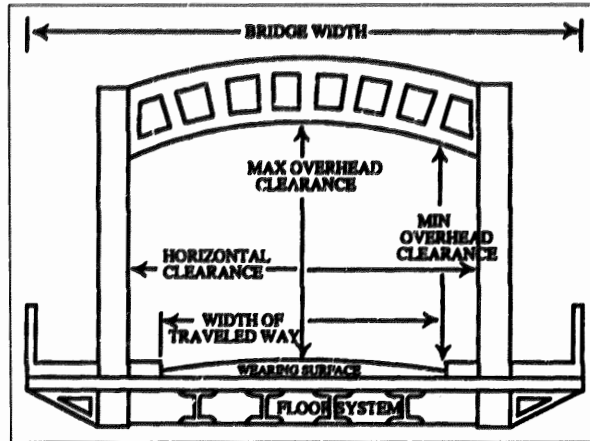


Figure 14: Cross-section of a bridge superstructure showing components and measurements

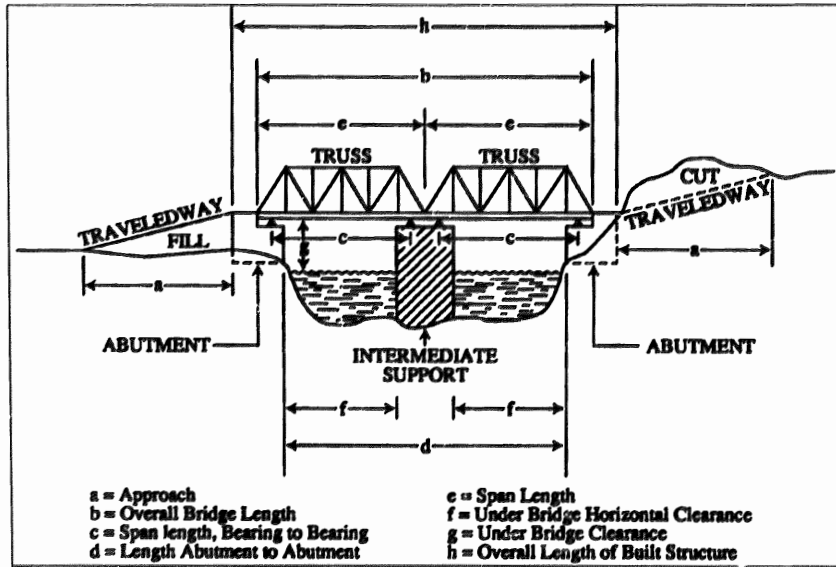


Figure 15: Diagrams of through type, simple truss bridge showing critical dimensions

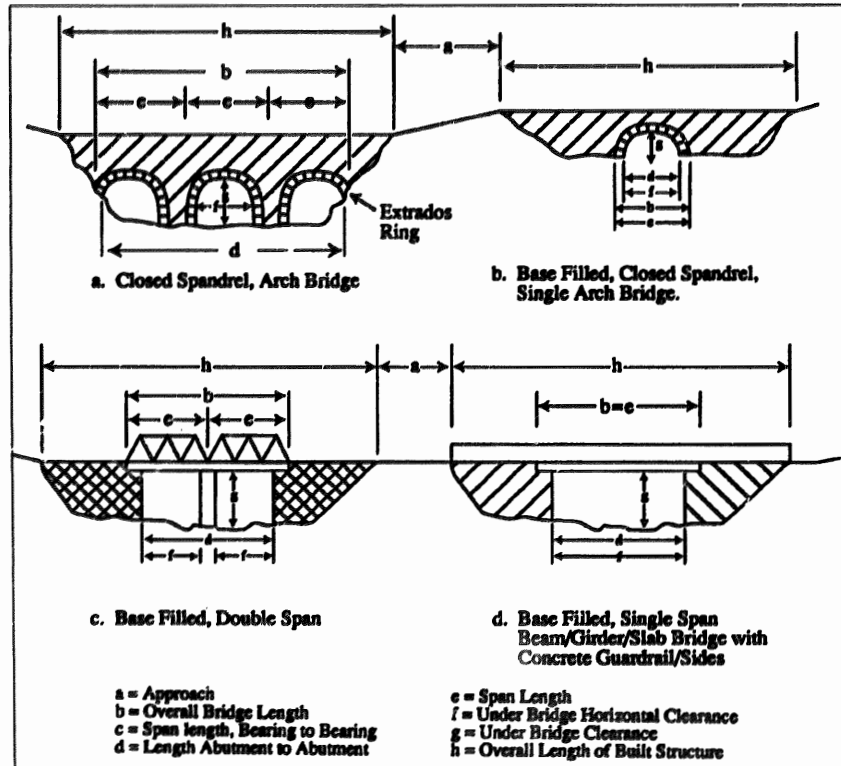


Figure 16: Diagrams of several bridge types, showing critical dimensions

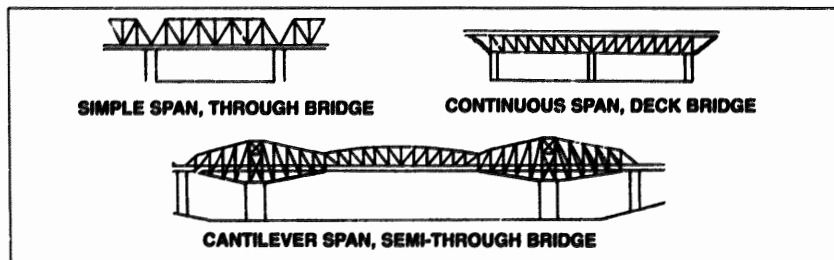


Figure 17: Diagram of bridge span relationships

Beam (Stringer) Bridges

A **beam bridge** is a simple structure, consisting of two or more parallel beams (sometimes called stringers) laid across the gap. The bridge flooring is supported directly by the beams. This type of structure is suitable only for short spans. Wooden bridges will have spans of less than 20 feet (6 meters), steel and concrete structures will have spans of less than 40 feet (12 meters). This type of bridge is commonly used for highway overpasses. Since the supporting structure is below the floor of the bridge, these are always deck bridges.

Beam bridges cannot be conclusively identified on vertical imagery. Deck-type highway bridges with short spans are usually beam bridges. The shadow will show the underside of the bridge to be parallel to the deck.

A **slab bridge** is a variation where the floor system and supporting structure are combined into one piece, a rectangular slab of reinforced or prestressed concrete. This slab sits directly on the abutments. Slab bridges are used to bridge short gaps (< 20 feet or 6 meters) on minor roads.

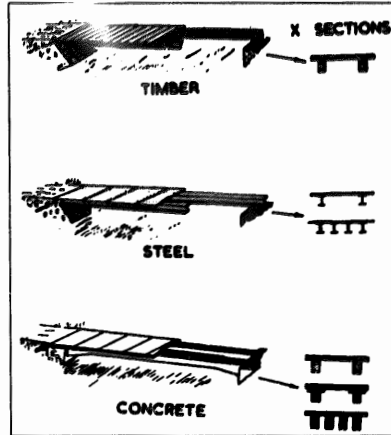


Figure 18: Basic beam bridges. Many highway bridges are merely larger versions of this simple design.

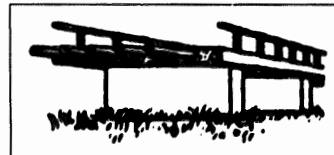


Figure 19: Slab bridge

Girder Bridges

A **plate girder** is a large beam fabricated from steel plates. Because of its large size and deep cross-section, it provides more support than smaller beams. Thus, girder bridges can carry heavier loads and span longer gaps than beam bridges. Their greater strength makes them particularly useful for railroad bridges.

The most common form of girder has an I-shaped cross section. Two parallel girders form the supporting structure, and the floor system is set between the girders. The girders can be placed below the floor system (deck bridge), but the large size of the girders then restricts the clearance under the bridge. For this reason, it is more common for the floor system to be placed at the base of, or at the midpoint of the girders (through or semi-through bridges).

When the bridge is of the through or semi-through type, the plate girders are easily visible. For deck type bridges, the only clues to identification are the greater thickness of the supporting structure, and the relatively short span length (<100 feet, 30.5 meters). Continuous span girders, extending across the intermediate supports, can bridge longer gaps. As noted above, they are more common on railroad bridges than on highway bridges.

The **box girder** is another form which has increased in popularity because of its strength, versatility and economy of materials. A box girder has a square or rectangular cross section and is hollow. They are almost always placed as supports under the floor system on deck bridges. They can be simple spans, but continuous spans are also used. Their superior strength allows for spans of great length.

Note: For some DMA specifications, box girder construction is classified as a Beam/Stringer bridge. The term "Girder" usually implies a large plate girder with an I-shaped cross section.

Box girder bridges are difficult to identify on vertical imagery. They are characterized by their simplicity of design, greater span length and the lack of other supporting structures, such as trusses, arches, etc.

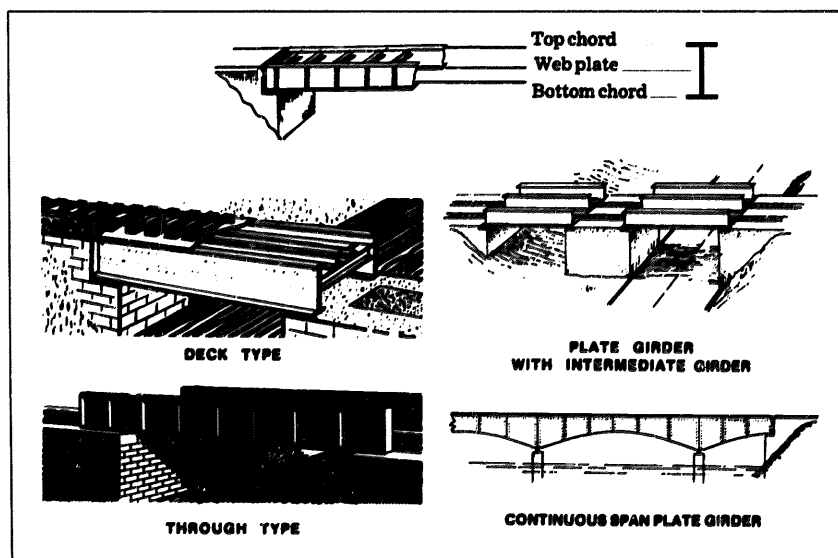


Figure 20: Various configurations of plate girder bridges. Because of their great strength, plate girders are most commonly used on railroad bridges. Note the cantilever design of the last example. When identified by its shadow on vertical imagery, this may be mistaken for an arch bridge.

Plate girder bridges are almost always made of steel. Some newer construction utilizes girders made of prestressed concrete, which can be identified by their very light tone. Box girders are normally concrete.

Truss Bridges

A truss is composed of a series of relatively small girders (members) joined together in a triangular pattern. This triangular bracing gives it the strength and rigidity of a solid beam, yet the structure is much less massive than a plate girder of equivalent strength. Truss members are subject to either compression or tension. Compression members are often thicker than the tensile members, but can also withstand a tension load. The small size of the individual members makes them easy to transport and assemble. Because of their strength, versatility and ease of construction, truss bridges are widely used around the world.

Each truss has a top and bottom girder (the **upper** and **lower chords**). The upper chord carries the main compression load, and may be parallel to the lower chord, or it may be composed of sloped or curved sections. At each end, a vertical or inclined post forms the end member of the truss. Two parallel trusses form the supporting structure of a bridge. The trusses are normally, but not always, cross-braced with each other. If the trusses are not cross-braced, it is known as a **Pony Truss**.

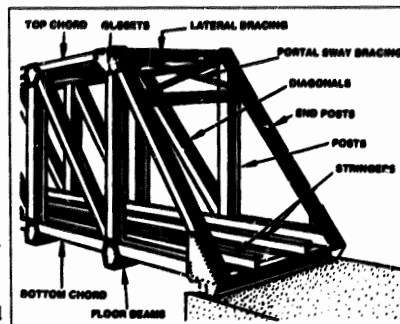


Figure 21: Elements of a truss. The combination of these cross-braced elements results in the structural equivalent of a beam or girder.

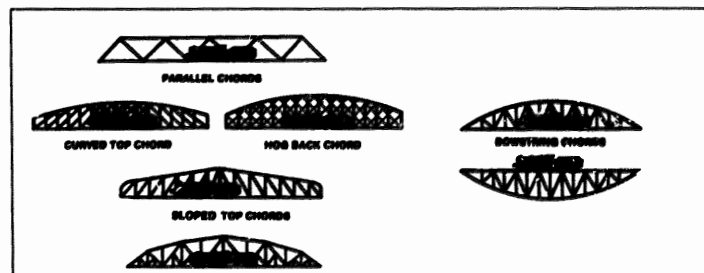


Figure 22: Basic truss shapes. The arrangement of tension and compression members within the truss determines the actual truss type.

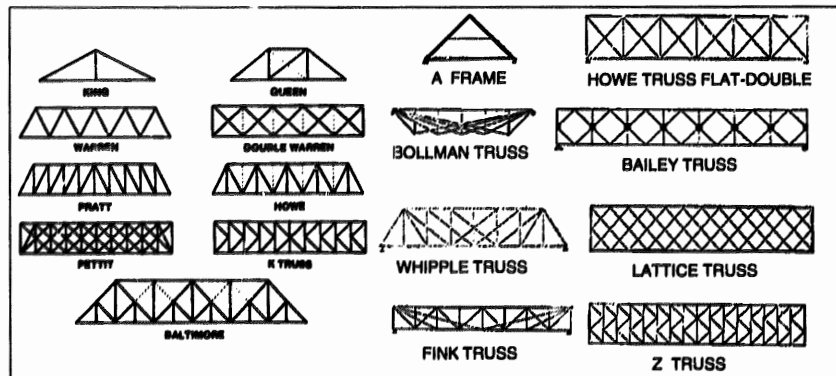


Figure 23: Basic truss types. Although these examples have parallel top chords, for most truss types they could be curved or slanted.

Truss bridges may be through, semi-through or deck type. They may have simple spans, with a separate truss on each, or the truss may be continuous over several spans. The cantilevered span achieved its greatest expression through the steel truss.

Early truss bridges were constructed entirely of wood. Later structures used iron for the tensile members and wood for compression members. Iron eventually replaced all of the wood, and by the year 1900, trusses were made entirely of steel. Recently, pre-stressed concrete trusses have been used to replace the steel. There are few surviving wooden truss bridges.

There are many forms of trusses, as illustrated in this section. The earliest form used on wooden bridges is the triangular **King-post truss**, with one vertical tension member. A series of king-posts were sometimes strung together on longer bridges. The **Queen-post truss** is similar, but has a second tension member. The problem with wooden bridges was that they tended to sag in the middle. To counter this, Theodore Burr added an arch to a multiple King-post truss. The **Burr arch truss** was patented in 1817 and remained the most popular of the arch reinforced truss bridges. Another popular truss type was patented by Ithiel Town in 1820. The **Town lattice truss**, as the name implies, was composed of a lattice of relatively small members, which form a long, stiff structure. Since this lattice truss was not susceptible to sagging, it was also widely used. Many other truss designs were developed in the early 19th century, but most found only limited acceptance.

By the mid-19th century, iron bridges were rapidly replacing wooden structures. The **Howe truss** utilized vertical iron tension members and diagonal wooden compression members. A few were built later entirely of metal. The latter part of the 19th century saw the development of several truss types composed completely of iron or steel. Some of the more popular were the **Bollman truss**, the

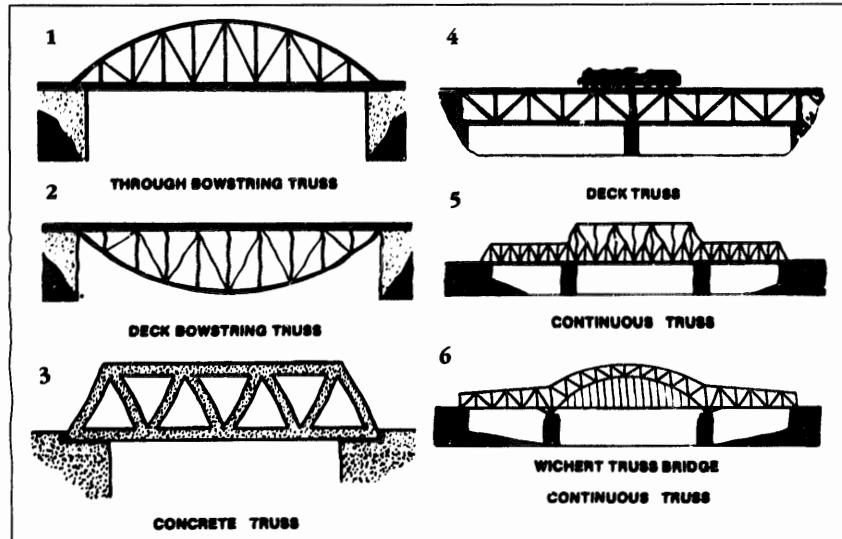


Figure 24: Basic truss bridge types. 1) A through bowstring truss, where all posts and diagonals are tension members; 2) A deck bowstring truss, this is not a true bowstring, but a variation on a Pratt truss; 3) A through Warren truss, recognizable as being made of concrete by the thickness of the members and the lighter tone; 4) A continuous span, deck-type Howe truss; 5) A continuous span through truss, centered on a Baltimore truss, which gives the longer central span added strength; 6) The Wichert truss is actually a hybrid structure. The central span is suspended beneath a cantilevered truss arch.

Fink truss, the **Post truss** and the **Thacher truss**. There were, however, three truss types that became very popular, and were adapted to many situations.

The **Pratt truss**, patented in 1844, used vertical compression members and diagonal tension members, just the opposite of the Howe truss. Its great strength, simplicity and versatility allowed it to be used in a variety of situations. Several variations were developed from the basic Pratt design. For additional stability, the diagonal tension members were extended across two or three compression members (**double-intersection Pratt** or **Whipple truss** and **triple-intersection Pratt truss**, respectively). Other variations include the **Parker truss**, **camelback truss**, **Baltimore truss**, **Pennsylvania truss** and the **lenticular truss**. The latter is unusual in that both the upper and lower chords are curved, giving the truss a lens-shape.

In 1841, the first **bowstring arch truss** was patented. A bowstring arch truss is a hybrid between a truss and an arch. It consists of a curved upper chord which

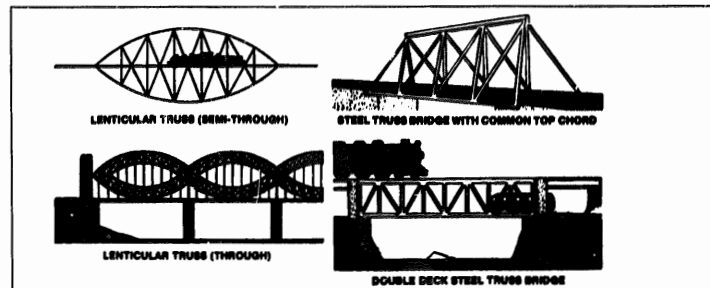


Figure 25: Some of the many possible variations for truss bridges

acts as the compression member, and a horizontal lower chord tension member. They are tied together by vertical and/or diagonal tension members. This proved to be a light weight, inexpensive, yet sturdy design, and was widely used in highway bridges, particularly in rural areas.

Patented in 1848, the **Warren truss** was slow to gain popularity, particularly in the U.S., but eventually became the favored design for truss bridges. It is different from previous designs in that the diagonal members are designed to carry both tensile and compressive loads. Thus the Warren truss is characterized by girders of a uniform size. Variations include the addition of vertical members, or extension of the diagonals to form a double-intersection Warren truss. Most

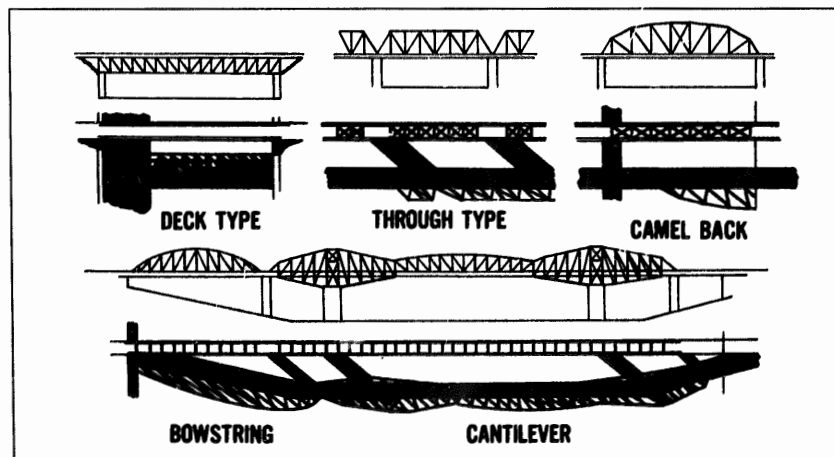


Figure 26: Various truss types and their shadows. Note how the truss under the deck bridge is revealed by its shadow.

modern steel truss bridges, as well as newer prestressed concrete truss bridges, use the Warren truss or a variation.

The lattice framework of the truss is distinctive and easy to recognize on vertical imagery. On through and semi-through bridges, the truss is readily visible. The shadow of the truss is the best recognition factor. It is often clear enough to identify the truss type, even on a deck bridge. Trusses are almost always made of steel (or iron in older bridges). New prestressed concrete trusses can be identified by their light tone and the greater thickness of the structural members.

Arch Bridges

The first major development in bridge construction was the **masonry arch**. An arch is the only structural form in which there is no tension. Therefore, larger bridges can be built without using materials of high tensile strength. Until the development of timber trusses in the early 19th century, and the mass-production

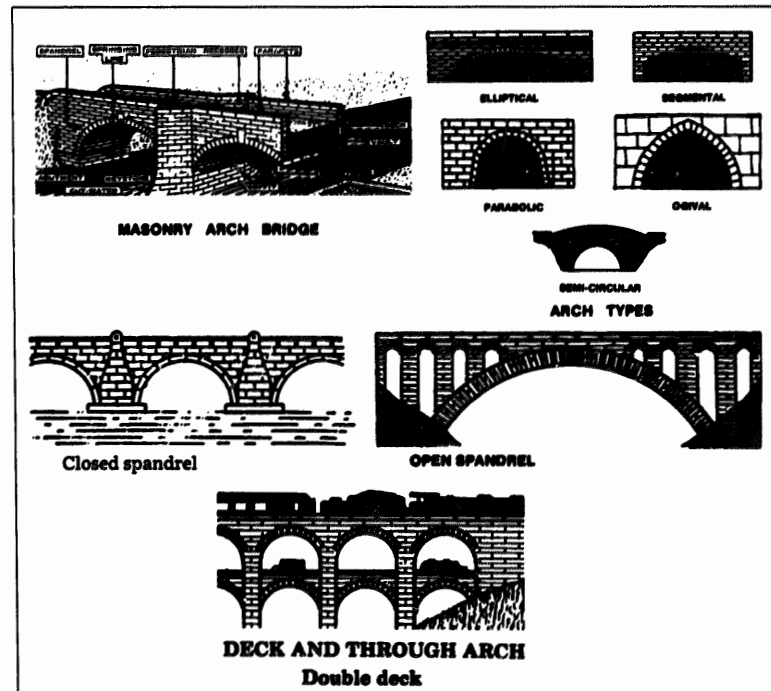


Figure 27: Masonry arch bridge variations



Figure 5: Modern cable-stayed suspension bridge (under construction). Note the massive towers and the concrete bents supporting the approach spans.

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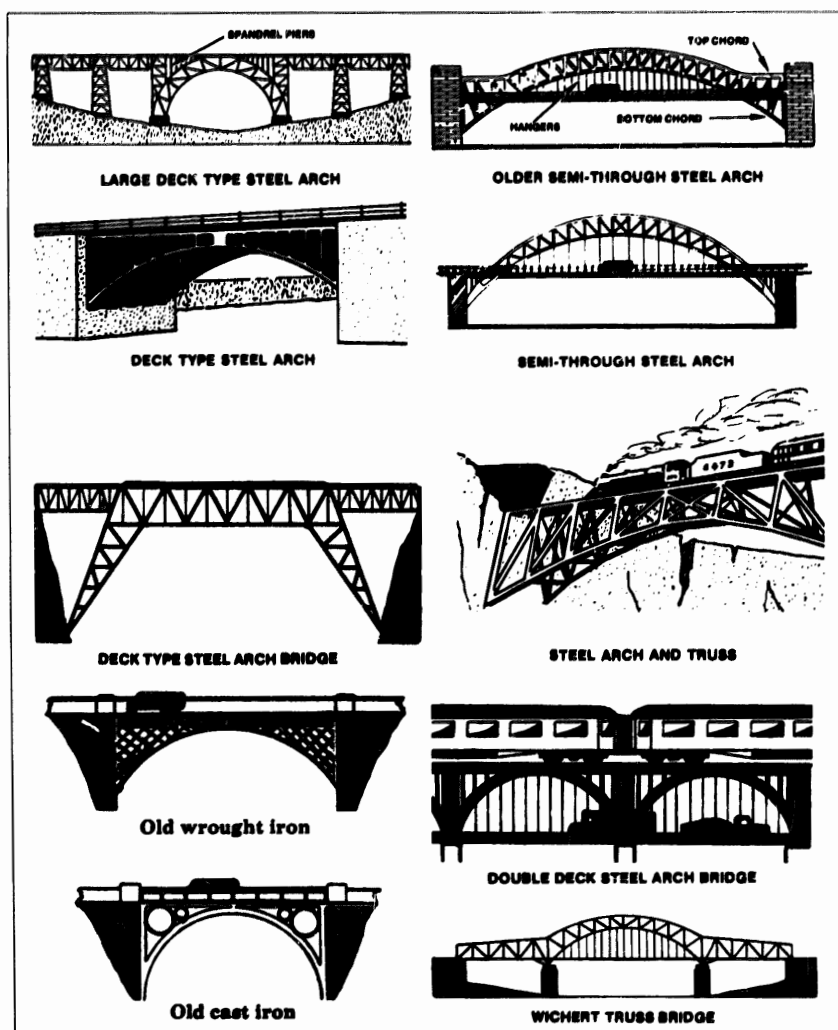


Figure 28: Steel arch bridge variations. Note that most involve the use of a truss as the main arch, and that the bridge deck is suspended from the arch on the through and semi-through structures.

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of iron shortly thereafter, the masonry arch was the only structural form available for construction of larger bridges.

The first reliable report of a masonry arch bridge refers to one built over the Nile River in 2650 BC. The oldest surviving bridge is a masonry arch built about 850 BC over the River Meles at Izmir, Turkey. The Romans refined the arch, and many examples of Roman bridges and aqueducts remain. Masonry arch bridges are found today in many parts of the world.

The basic masonry arch bridge consists of a row of shaped stones that form the arch. This is the structural backbone of the bridge. The spaces between the arch and the deck of the bridge (the **spandrels**) can be filled in with masonry, forming a solid structure. On larger bridges, however, it requires a massive amount of material to fill in the spandrels, so an **open spandrel** structure consisting of a series of smaller arches or piers is used.

Iron and steel proved to be well suited for the construction of arch bridges. In fact, the first iron bridge built was an arch span (Coalbrookdale, England, 1779). For longer spans, the metal structures proved to be more economical than the labor-intensive masonry arches. Span lengths were increased as well. A steel arch can span a gap nearly as wide as a cantilever, though both are surpassed by sus-

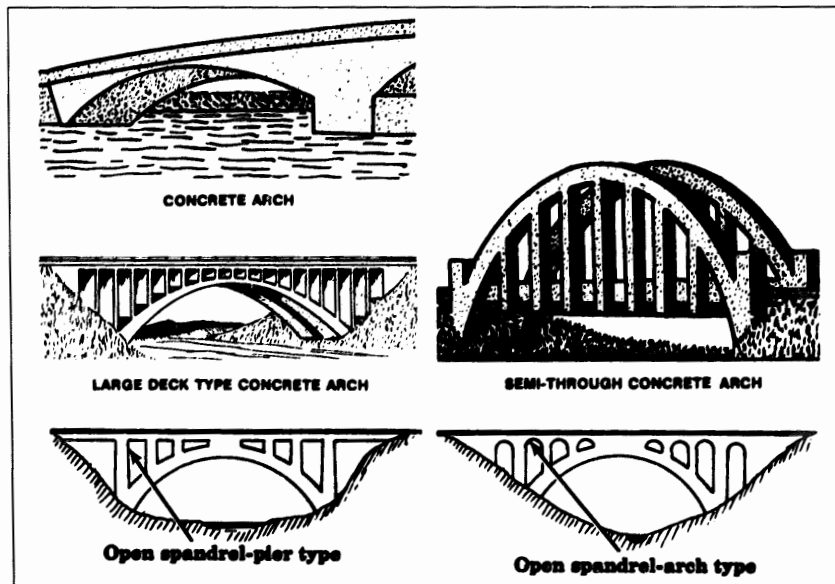


Figure 29: Concrete arch bridge variations

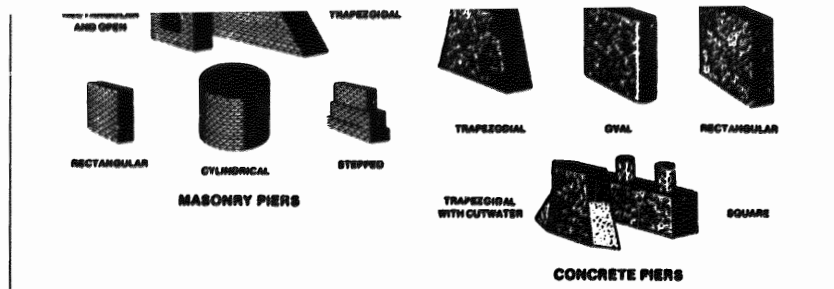


Figure 9: Several common varieties of bridge piers. Piers will only be visible on imagery taken at an angle to the vertical. Shadows of piers may also be visible.

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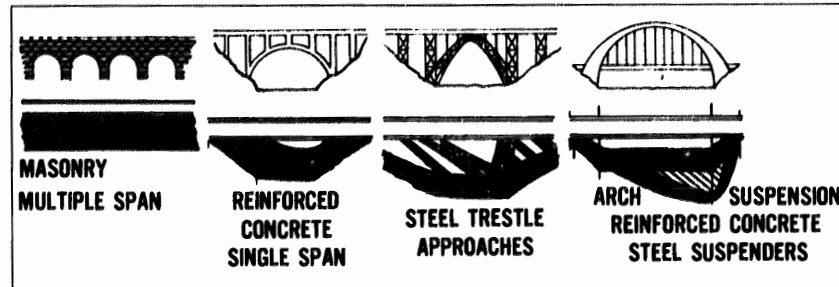


Figure 30: Several variations of arch bridges and their distinctive shadows

pension spans. Metal arches can be through or semi-through as well as deck-type structures. Few metal arches consist of a simple curved beam, most are arch-shaped trusses.

Reinforced concrete was used for construction of arch bridges starting in the late 19th century. Concrete bridges rapidly gained in popularity because they used locally available materials and could be built with relatively unskilled labor. Reductions in the amount of concrete required were accomplished by the use of open spandrel designs.

In addition to the traditional deck bridge, a through-type concrete arch structure is also used. The rainbow arch is actually a hybrid between an arch and suspension bridge. Similar to a bowstring truss, the floor system is suspended from the supporting arches.

The surest recognition factor for an arch bridge is the shadow. Some trusses with curved, top chords, such as the bowstring or camelback trusses, may be confused with an arch. Shallow-arched concrete bridges can appear identical to cantilevered spans. The difference between the two is in the way the load is carried. A definitive distinction can only be made if ancillary information is available

Suspension Bridges

Outside of primitive rope bridges, the construction of **suspension bridges** had to wait until a material of substantial tensile strength was developed. The first suspension bridges used iron chains. This method was used in China and Japan several centuries ago, but was first used in the West in Prussia in 1734. Modern suspension bridges utilize the high tensile strength of steel cables to span wider gaps than possible (or economical) with any other structural form.

The traditional suspension bridge consists of two heavy cables, anchored to the abutments and draped over two large rectangular towers. Smaller cables connect the floor system to these **catenary cables**. These are usually all steel structures, though a few bridges have masonry or reinforced concrete towers. In addition, massive abutments are needed to anchor the ends of the cables.

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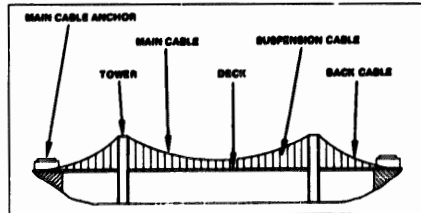


Figure 31: The structural elements of a suspension bridge

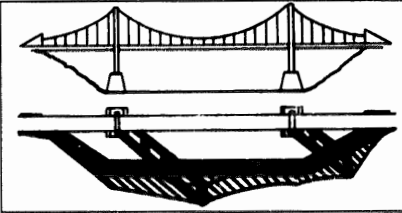


Figure 32: The distinctive shadow of a typical suspension bridge

The tall, massive towers and long spans are distinctive, and are usually easy to see, especially on stereo imagery. A good shadow allows for quick identification, as it reveals the towers, catenary cables and often the suspension cables as well.

A relatively recent improvement upon the suspension bridge design is the **cable-stayed box girder** bridge. As the name implies, it is a box girder bridge which has been augmented by suspension cables to increase the span length. Instead of using a pair of catenary cables, the suspension cables are directly tied to the tower. The tower itself is a slender structure of steel, and the cables for both sides of the structure may run through the center of the tower. Although most bridges have two towers, some short span bridges have only one. The shadow reveals the tall slender tower with the suspension cables radiating from the top.

As noted above, through arch bridges can also be classified as suspension bridges, except that the supporting structure is an arch rather than a catenary cable. The arch extends above the deck of the bridge and cables suspended from the arch support the floor system. These bridges are difficult to distinguish from trusses with curved top chords. If a shadow is visible, the shadows of the vertical suspension cables will be parallel, as opposed to the angular shadows of the truss members.

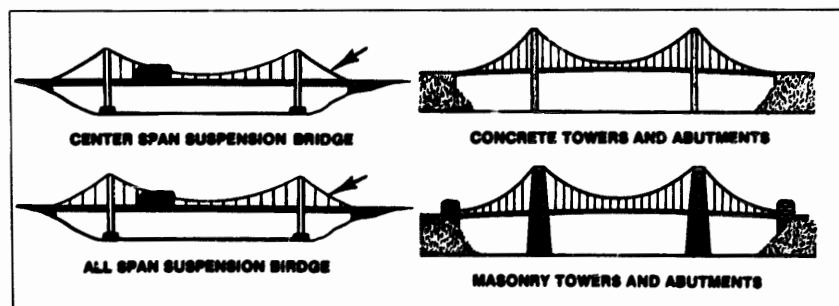


Figure 33: Four variations on the basic catenary suspension bridge design

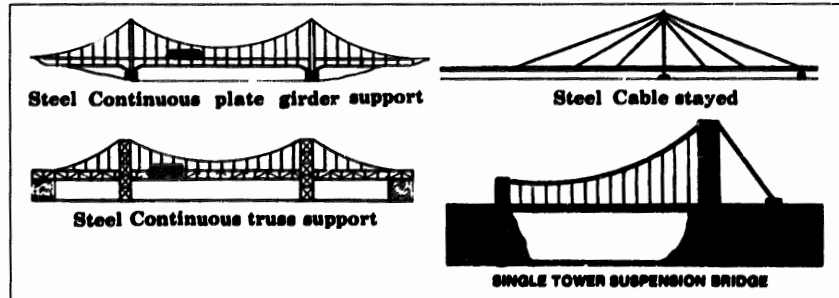


Figure 34: Variations of the suspension bridge design

Suspension bridges are almost always steel structures. A few bridges, particularly of the arch type, have used prestressed concrete for the supporting structure and sometimes even the suspension cables are replaced by prestressed concrete members.

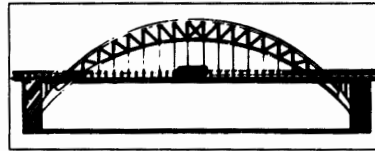


Figure 35: An arch suspension bridge

Cantilevered Bridges

Cantilevered bridges are often classified as a bridge design type. However, the term "cantilever" refers to the relationship of the bridge's supporting structure to its piers and abutments. As mentioned previously, a simple span structure is supported at each end by an abutment or pier, while a continuous span structure is supported at each end and by one or more intermediate piers. A cantilevered structure, however, is balanced on its supporting pier. To increase the distance between piers, a **suspended span** may be inserted between two cantilevers (see Figure 36).

Any of the previously mentioned bridge design types can be constructed as cantilevered spans. The easiest to identify is the cantilevered truss, on which the key recognition factors are the most visible. The supporting structure is continuous across the pier, and it is the most massive (tallest) directly over the pier, tapering off to both sides. The suspended span, when present, is a parallel or curved top chord truss, which can be distinguished from the tapered cantilevers. Plate girder and beam bridges also utilize cantilever spans, but in most cases, these are difficult to identify, especially on vertical imagery. Some cantilevered bridges closely resemble arch bridges and may be difficult to distinguish, even on ground photos. The use of cantilevers on arch or suspension bridges can lead to unusual designs, such as the Wichert truss. Placing these hybrid designs into conventional classifications can be difficult.

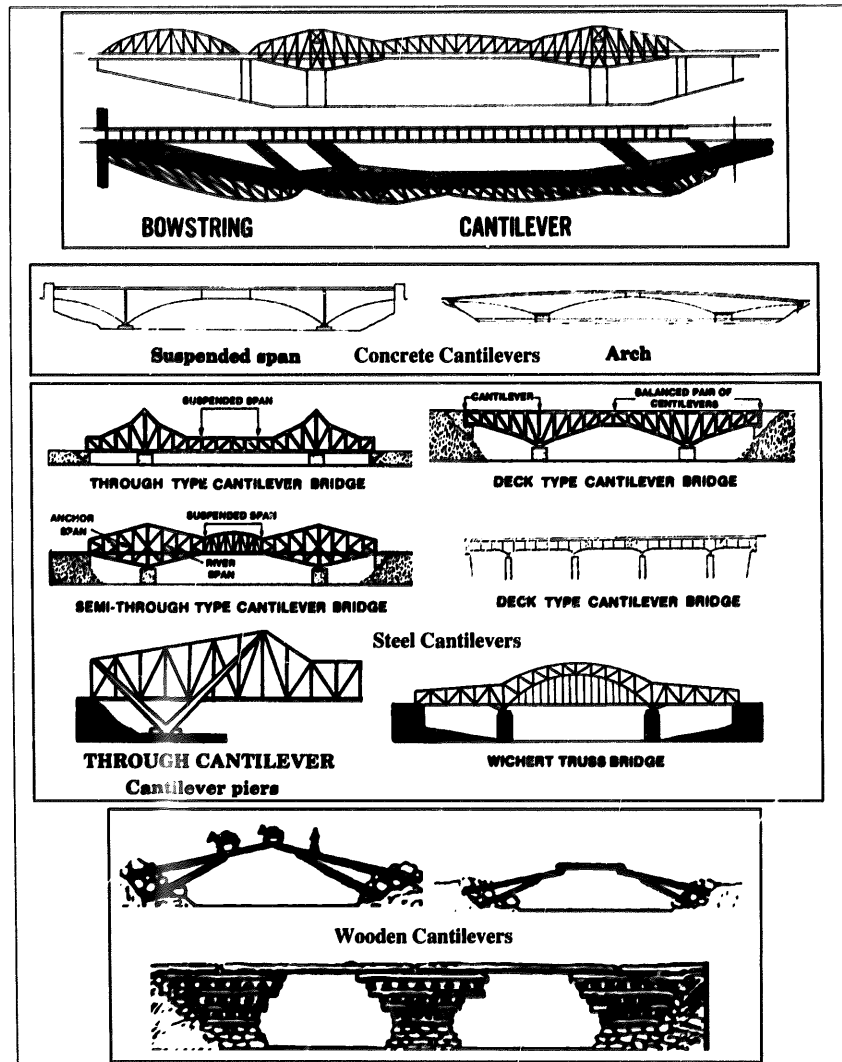


Figure 36: Diagrams illustrating the application of cantilevered spans to various bridge types.

Floating Bridges

Floating bridges are most commonly used as temporary structures to support military operations. They are the fastest and most economical form of expedient river crossing available for large rivers. Under special circumstances, they are also used as permanent structures to cross large water bodies. Most float bridges are constructed to support roads. However, float bridges supporting single and even double-track railroads have been constructed.

A floating bridge has no substructural supports between the embankments. The floor system rests directly on a series of **floats** or **pontoons**. The flotation device used can be empty steel drums tied together, inflatable rafts, portable military pontoons, small boats upon which the floor system rests, or large, permanent, multichambered pontoons of reinforced concrete.

Tactical military and temporary float bridges are single-lane structures. If another lane of traffic is needed, a second set of floats must be constructed. Permanent float bridges use larger pontoons capable of supporting two or more lanes.

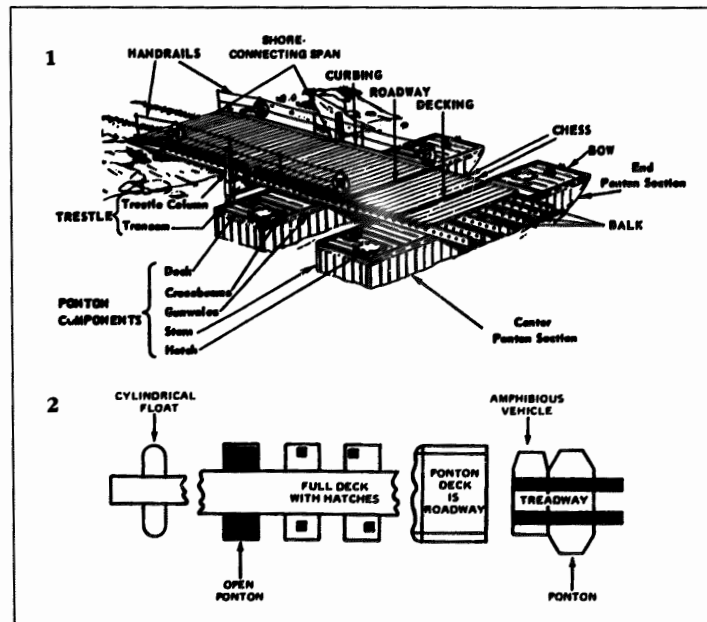


Figure 37: 1) Components of a military style float bridge. 2) Common types of floats and bridge decks.

Float bridges can only be used where strong currents are absent. Even low to moderate currents can require additional anchoring and bracing of the pontoons. On water bodies where the water level fluctuates, the spans linking the shore to the first floating section must be hinged to maintain the connection as the bridge rises or falls.

Float bridges are identified by the low elevation of the bridge deck, no more than one or two meters above the water's surface. There will be very little shadow visible, even at a low sun angle. The floats or pontoons are often visible, protruding out from beneath the floor system.

Prepared Float Bridge Sites: In areas where military conflicts are, or were, anticipated, such as in Germany and Korea, special sites may be prepared to allow the rapid construction of a tactical float bridge. Bearing a close resemblance to a ford, a prepared float bridge site has roads leading to a prepared ramp into the river. However, at these locations, the depth of the water precludes fording. These sites are built mostly for tactical military uses, as backups to provide vital river crossings in case bridges are destroyed by enemy activity.

Movable Spans

Bridges across navigable waterways must allow for passage of vessels under the bridge. Whenever possible, bridges are constructed so at least one span sits high enough to allow ships and boats to pass underneath. However, construction of a span with sufficient underbridge clearance may not be physically or economically feasible. The alternative is to construct a span which can be moved out of the way to allow the marine traffic to pass. Movable spans are more common on older bridges. Currently, the increased cost of the higher spans is justified by the need to keep traffic moving without interruptions.

The most suitable structural form for a movable span is a truss. It provides strength and rigidity, but is still light enough to allow the span to be lifted or swung out of the way. For short spans, girder construction can be used.

There are three common types of movable spans, **lift**, **swing** and **bascule**. These three types are easily distinguished from each other and from stationary spans. The recognition features of a moveable span are:

- The presence of a bridge with low underbridge clearance on a waterway that carries shipping.
- Traffic backed up on either side of the bridge.
- The moveable span in an open position.

Lift Bridges

A lift bridge has two towers, one at each end of the movable span. When the bridge opens, lifting mechanisms in each tower lift the entire span straight upwards, with the span remaining in a horizontal position. The clearance

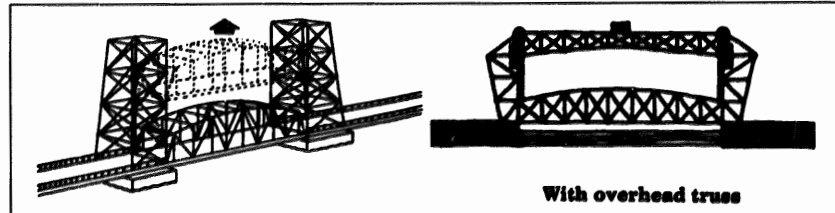


Figure 38: Two examples of lift bridges, note the massive towers on both bridges. The bridge on the right has an additional overhead truss which serves to strengthen the towers.

provided in the open position is limited by the height to which the span can be raised. The two massive towers readily identify this as a lift span, and the large pulley wheels are often visible. Through type trusses are the usual structural type. Occasionally, the two towers may be braced together at the top by an additional truss.

Swing Bridges

A swing bridge, the most common type of movable span, pivots the span in a horizontal direction. When open, the span is perpendicular to its normal position, and the ends of the span rest on special piers set in the watercourse. The span is, by necessity, cantilevered. The truss shape may be a traditional cantilever or a bowstring. The span may pivot at its center (symmetrical), at an off-center point (asymmetrical) or at one end (end pivot). In order to provide a wider opening, two adjacent swing spans may be used (double-opening type). This is especially true of end pivot bridges. The advantage of a swing span is that it provides unlimited vertical clearance when open.

Swing bridges can be identified by the presence of the supporting piers placed perpendicular to the bridge, as well as navigation channel markers and fenders around the piers. If the moveable span is adjacent to the shoreline, a portion of the shore may be cut out to allow the span to swing around. Through type trusses are the usual structural type.

Bascule Bridges

On a bascule bridge, one end of the span is lifted upwards, tilting the span towards the shore. Bascule bridges may be single opening, or double opening, with opposing tilting sections. The opposing bascules act as two cantilevers locked together when in the down position, since an intermediate support cannot be used. They may be through or deck truss structures, or lighter deck type beam spans. Bascule bridges also have unlimited vertical clearance when open.

A large counterweight is needed to allow the span to be tilted. The counterweight may be above or below the bridge deck, or may be concealed within the

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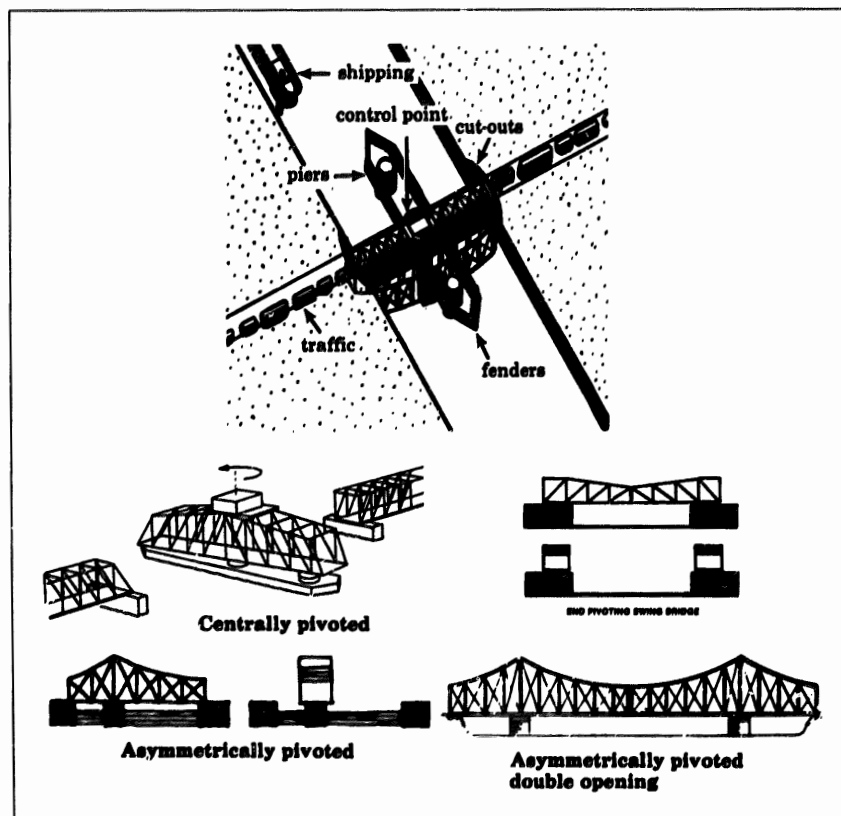


Figure 39: Top: Recognition factors for swing bridges. Bottom: Several varieties of swing bridges. Note the cantilevered structure of the spans.

pier. The span usually pivots open, but on a rolling lift bascule bridge, it actually rolls back onto its toothed end quadrant, which meshes with a rack on the bank. Bascule bridges can be identified by their presence on a navigable waterway, the counterweights on the shoreward ends, the small control building usually present, the signals or drop gates which stop traffic when the bridge is open, and the lack of lift towers or support piers.

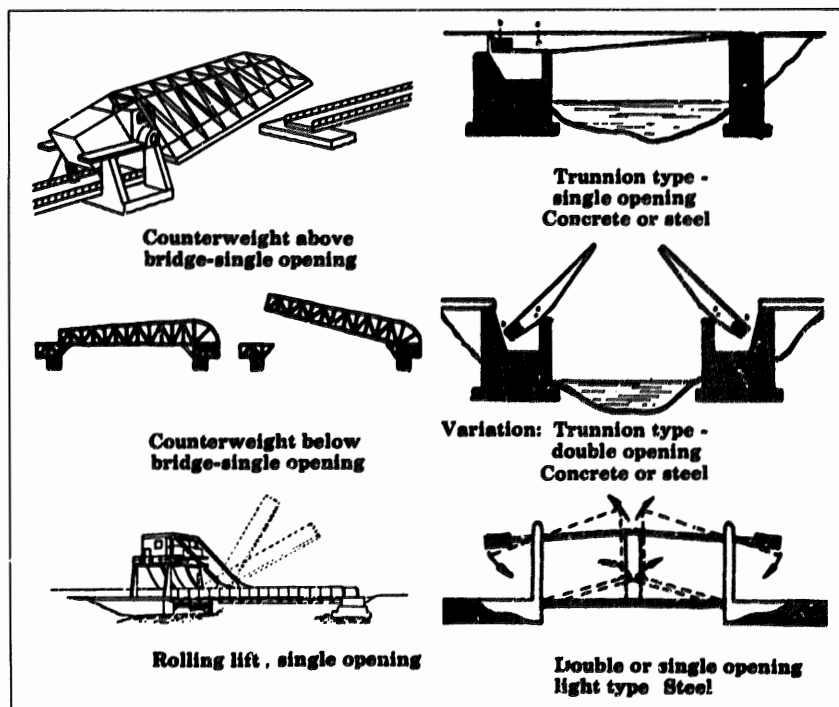


Figure 40: Six of the many possible variations on a bascule bridge

Other Moving Spans

Other configurations of movable spans are relatively rare. A sliding span is retracted horizontally under or beside the supporting structure. A sinking span (existence reported only in Iraq) drops below the water surface to allow boats to pass over it. Other configurations may be encountered. The analyst should be alert to the presence of a moveable span whenever a low bridge crosses a navigable waterway.

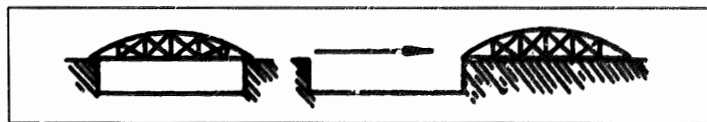


Figure 41: A sliding span bridge, in place, and retracted

Unusual Bridges

The last century was a time of extensive building of roads and railways. Bridges were needed to cross larger gaps and carry heavier loads. These new demands led to different engineering solutions. They are usually variations or combinations of the main bridge types discussed above. These bridges are often difficult to fit into classification schemes.

One unusual bridge type is the transporter bridge, which functions much like a bridge crane. A platform suspended from an overhead truss ferries vehicles across the river. (*The continued existence of transporter bridges has not been verified.*)

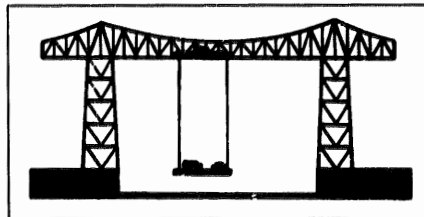


Figure 42: Transporter bridge (Ferry bridge)

A Wichert truss is a continuous span cantilever truss on which the main span forms a semi-through arch. The deck is suspended below the arch.

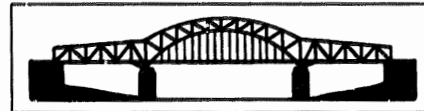


Figure 43: A Wichert truss bridge

Other configurations that may be encountered are limited only by the imagination of the engineers and designers. Other features, such as conveyors, may strongly resemble a bridge. A thorough knowledge of bridge structures is required in order to properly identify and describe these features.

Bridge Functions

Identification of a bridge's structural type and the identification of its function are two separate problems. Common engineering principles and practices are used to construct all bridges and bridge-like structures. The best way to identify the function of a bridge is to identify the transportation feature leading up to the bridge. Nevertheless, there are some characteristics that may be visible.

Highway Bridges

There is almost always a distinct contrast between the materials used on the bridge and on the bridge approaches. This will appear as a sharp line perpendicular (except on skew bridges) to the centerline of the bridge. In addition, the roadway usually maintains its width across the bridge, especially on major routes.

Railroad Bridges

Railroad bridges fall into two categories, those with solid decks and those with open decks. A solid deck bridge carries the ballasted track across the gap. These resemble highway bridges in that they maintain the width of the permanent way across the bridge. An open deck bridge has the rails fastened to the floor system of the bridge, and the space between the rails and supports is open. These bridges appear to be very narrow in comparison to the travelled way of the rail line.

Aqueducts and Canal Bridges

Aqueducts are man-made structures that carry water from a distant source to the place it is utilized. The term aqueduct is also used for a bridge that carries a waterway over an obstacle. Canals are man-made structures designed for the use of ships and barges. Irrigation ditches carry water to crop land. All three types of structures may have to cross obstacles to reach their destination.

Some DMA product specifications define the terms aqueduct, canal and ditch differently. Refer to the appropriate specifications to verify the usage of these terms.

The majority of these structures are masonry arch bridges. The majority of canals were built before steel and reinforced concrete were widely used. Recent construction of structures to carry water emphasize the use of pipelines, so the more modern types of structures are less common.

The most distinctive feature of these bridges is the water course which they carry. In hilly or mountainous terrain, aqueducts are often routed through tunnels and across bridges to maintain the downhill grade from source to destination.

There are several other types of structures designed to carry water for short distances for various purposes. These include flumes, penstocks, and elevated pipelines. These may be confused with aqueduct and canal bridges, but closer examination will reveal that the source and destination are close together.

Pipeline Bridges

When pipelines cross areas of high relief, it is frequently more economical to carry the pipeline across a gap, rather than following the ground's surface. Various types of bridging structures can be used, but most are less substantial than other bridge types. Suspension type and steel truss platforms are the most common.

Again, the key to their identification is the pipeline approaching the bridge. Underground pipelines will often be exposed only where they bridge gaps. The absence of any visible transportation features leading to a bridge structure of light construction also implies that this is a pipeline bridge.

Multi-purpose Bridges

The most common multiple use of a bridge structure is the addition of a pipeline (or aqueduct) to an existing road or railroad bridge. Pipelines may be carried alongside or underneath the bridge. Unless the pipeline is quite large, or the pipeline leading up to the bridge is visible, it may not be possible to detect the presence of the pipeline from imagery alone. Older aqueduct bridges, in particular, carried a road on a level above the aqueduct.

Another common combination is the double-deck road and railroad bridge. In some cases, it is economical to build only one bridge to carry both the highway and railroad over an obstacle, with each being carried on a different level. Inspection of the bridge itself, even with a good shadow, may not reveal the existence of the lower deck. Examination of the approaches to the bridge will reveal the convergence of the highway and railroad at the bridge entrance. The analyst must be careful to avoid confusing this with a double-deck highway bridge, where traffic going in each direction is carried on a different level.

As mentioned above, unusual situations lead to unique bridge designs, and the analyst must be alert to the possibility of non-standard features. Familiarity with the geographical area, bridge types and lines of communication, combined with ancillary sources and imagery are required to properly identify and describe the bridges in an assigned area.

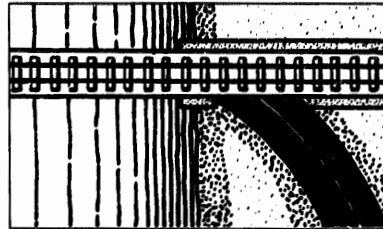


Figure 44: The approach to a double-deck bridge (railroad over highway).

Other Transportation Features

A number of other features are associated with transportation routes. These are mostly concerned with carrying the route past obstacles or through difficult terrain. Cuts and fills, causeways, culverts, galleries, tunnels, snowsheds, rocksheds, and ferries will be discussed in this section. These features are most commonly associated with roads and railroads, less commonly with canals, and rarely with pipelines.

Cuts and Fills

In order to allow traffic to move at higher speeds, the transportation route must have relatively low grades and good alignment with broad curves. This is important for major highways, critical for railroads, and essential for canals. In areas of level terrain this is not a problem, but as the relief becomes greater, it becomes more and more difficult to meet the grade and alignment criteria for these routes

The most common method for meeting these grade and alignment criteria is through the use of cuts and fills. A cut is an excavation of the ground surface, while a fill is an area along the route built up by addition of rock and soil. Both are designed to allow passage of a transportation route at an even grade. The term cut is also applied to the edges of excavations made for other purposes. Fill is sometimes used to describe an area which has been built up for construction, but these areas are not mapped as fills. Levees, embankments and berms are similar to fills, but their primary purpose is not to support a route.

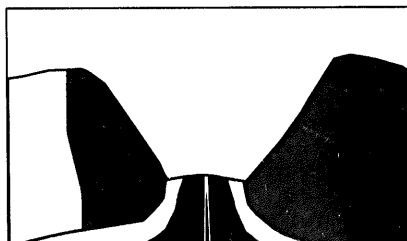


Figure 1: A road cut through a hill. Note that the left side of the cut is in shadow, as compared to the road fill in Figure 2.

Cuts and fills are commonly found together along a transportation route, and the material removed from the cuts is used to construct the fills. When the route is perpendicular to the slope, cuts and fills will alternate as the route goes over hills and across valleys. Where the road is parallel to steeper slopes, a cut may be present on the uphill side, while a fill supports the road on the downhill side.

Cuts and fills are more common along railroads and major highways, where low gradients and good alignment are necessary. They are less common along secondary highways, and are infrequently used on minor roads.

Note: The rules for delineation of cuts and fills vary with the product being compiled. Consult the appropriate product specification(s) for inclusion conditions and delineation instructions for cuts and fills.

Cuts and fills are long, narrow features that follow the transportation feature that they support. Thus they tend to be straight or gently curved in plan view. The size of the cuts and fills will vary with the relief of the terrain that the transportation feature crosses.



Figure 2: A road fill. The shadowed side is on the right compared to the cut on Figure 1, with the same sun angle.

The length can vary from a few meters to hundreds of meters. Fills are generally low structures, rarely exceeding ten to twenty meters in height. Cuts can be much deeper, but rarely exceed 75 meters. Beyond a certain height or depth, construction of bridges and tunnels is usually more economical.

The side slopes on fills will be even to gently concave, and rarely exceed 60% because of soil slope stability problems. Shallow cuts through soil or unconsolidated materials will also have gentle, even side slopes, while deeper cuts will often be terraced. Cuts made through rock can have nearly vertical slopes and are usually terraced to lessen the danger of falling rock. Cuts, and less commonly fills, may have diversionary drainage ditches to channel runoff away from the road and prevent erosion.

Cuts and fills appear as narrow bands alongside and parallel to the transportation route. If recently constructed, they will show the tone of the local rock and soil, which normally appears lighter than the surrounding terrain. Some areas, however, are underlain by soil and/or rock of very dark color.

Cuts through rock will have a rougher texture and steeper slope, and will remain devoid of vegetation for much longer than those through soil. Older cuts and fills gradually become covered with vegetation, and will take on the tonal and textural characteristics of the local vegetation. Eventually, the cuts and fills may become so overgrown that they are difficult to distinguish from the natural ground surface.

Because of the relatively shallow side slopes, shadows are not obvious, except on steep cuts through rocky areas. Slopes facing the sun will be lighter in tone than slopes facing away from the sun. Where the relief is slight, or on monoscopic images, cuts and fills can be distinguished by noting the location of the shadowed side in relation to the sun angle.

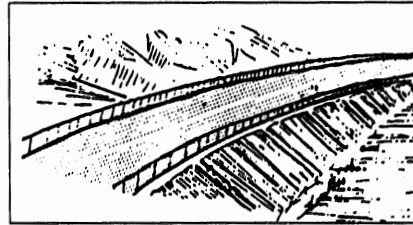


Figure 3: A road running parallel to the terrain. A fill is present on the downhill (right) side, and on the left, the roadway is locally cut into the hillside.

Causeways

A causeway is a fill built across a low-lying wet area or across a shallow body of water. In these areas, the cost of hauling in the necessary rock and earth is less than that of building long bridges or elevated roadways. Causeways are built of rock, gravel and/or soil, whichever material is locally available. Where erosion by waves or current is a problem, the sides may be faced with large rocks or with concrete.

The causeway will be built just high enough to insure that the transportation route will remain passable at all times. Tides, seasonal rainfall and flooding potential, all effect the height of the structure. In some wetland areas, where causeways several kilometers in length are needed, they may be locally widened to accommodate other facilities.

Causeways are identical in appearance to fills. They are even easier to spot because of the contrast between the dry materials comprising the causeway and the water or wetlands being crossed. Bridges may occur along the causeway, and culverts are common.



Figure 4: A causeway across a body of water

Culverts

Culverts are used to carry water past a transportation route and prevent erosion of the route's foundation. The water could be from an existing drainage feature such as a stream, or it could be from drainage ditches constructed alongside the route itself. There may be a perennial flow of water through the culvert, or it may only carry runoff after periods of rain.

A culvert can be a single pipe, a series of pipes, or a box-like structure. It extends underneath the route and is open at both ends. The diameter of the culvert can range from less than one half meter to five meters or greater, depending on the amount of water it is expected to handle. It can be round, oval or rectangular in cross section. In order to minimize erosion, the culvert will extend out beyond the route's foundation, or headwalls may be added. In some cases, the area around the culvert may be faced with stone or rubble.

A layer of fill material is placed over the culvert in order to distribute the load from the route, so that the weight does not collapse the culvert. **Box culverts** are large, rectangular structures of reinforced concrete, and may be strong enough to bear the load without overhead fill. These "load-bearing" box culverts can be easily mistaken for small slab bridges. The difference is that box culverts have a concrete "floor" while bridges are underlain with the natural stream bed materials. However, the floor of the culvert may be covered by water or gravel.

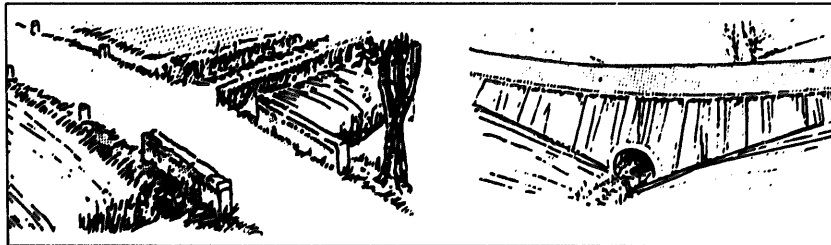


Figure 5: Two examples of culverts. The left example has stone headwalls to protect the road from erosion. In both cases, the intersection of the ditch or stream with the roadways indicates the presence of a culvert.

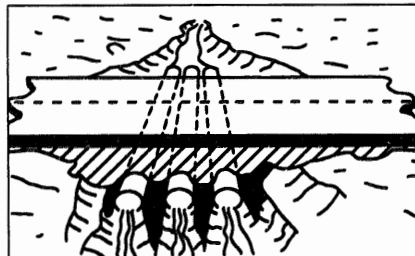
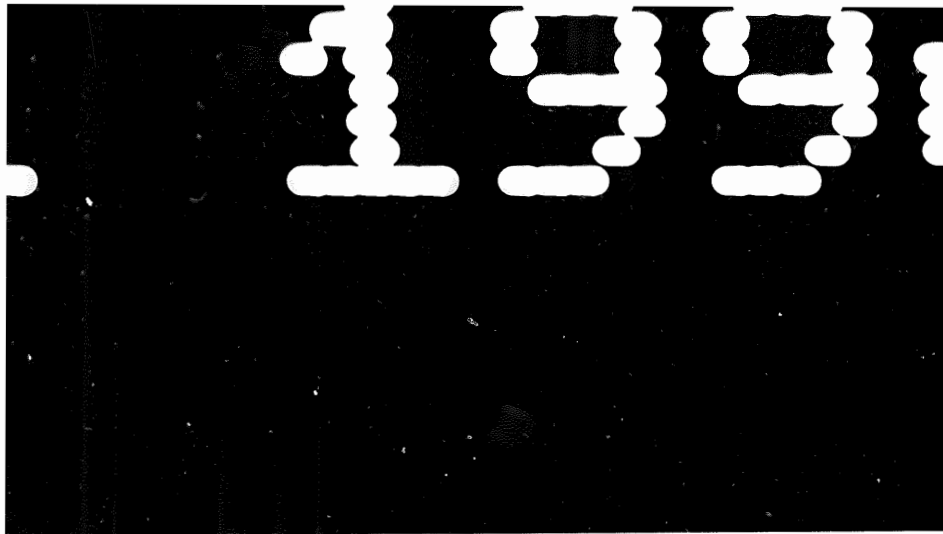


Figure 6: This culvert consists of a set of three conduits. A single conduit of equal capacity would have to be much stronger to support the weight of the road.

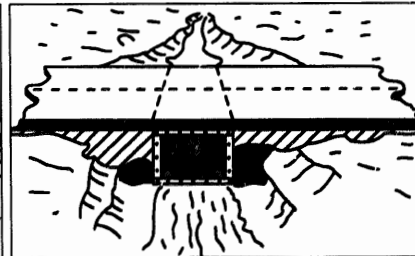


Figure 7: A load-bearing box culvert. Note: On some DMA products, large load-bearing box culverts are treated as bridges.

Most culverts are fairly small and difficult to see, except on very large scale imagery. Vegetation may be dense along the water course, further obscuring the view of the culvert. The best clue to the existence of a culvert is the presence of a stream or drainage ditch crossing under the route where there is no bridge present. For larger culverts, the round, oval or rectangular shape of the opening, and the shadow within, may be visible.

Note: The inclusion rules for culverts vary among DMA products. For most, only the larger culverts need to be delineated. Consult the appropriate product specifications for instructions on the delineation and description of culverts.

Tunnels

A tunnel is an excavation through a hill or mountain to allow passage of a transportation route. They are normally associated with roads and railroads, but are occasionally found along canals and aqueducts. Tunnels are also used to carry roads and railroads under rivers and other bodies of water. Since tunnels are expensive to build, they will rarely be found on minor roads.

Tunnels range in length from a few tens of meters to several kilometers in length. The tunnel itself is underground, and is not visible on aerial photography. The entrance/exit (portal) to the tunnel and the transportation route leading up to it are the keys to its existence and location. The portals are normally constructed of masonry or concrete, and typically have a rounded or arched shape for strength and stability. This structure stabilizes the entrance to the tunnel and prevents material from falling on the route. The interior (bore) may be lined with masonry or concrete, or left as natural rock if the rock is stable.

The disappearance and reappearance of a transportation route on either side of an obstacle, such as a mountain or river, indicates the presence of a tunnel. A closer examination of the point of disappearance reveals the light tones and geo-

metric shape of the portal. Depending on the orientation of the portal in relation to the sun angle and viewing angle, the shadow may or may not be visible. There will be a cut of varying length just before the portal. Often there will be a turnout prior to the tunnel entrance and a device spanning the road at maximum tunnel height to prevent passage of over height vehicles. On longer tunnels, ventilation fans may be present at the portals or along the length of the tunnel.

The route followed by the tunnel is, of course, hidden from view. For shorter tunnels this can be approximated by connecting the portals with a straight or gently curved line. For longer tunnels, tracing the route may not be possible without other source materials. Ventilation fans placed along the tunnel may be visible.

Note: The symbolization and description of tunnels will vary among different DMA products. Consult the appropriate specifications when delineating this feature.

Tunnels may be confused with underground storage facilities, and the difference is not always apparent. The feature must be analyzed in relation to the regional transportation network. Tunnels will always have at least two portals, an entrance and exit. On rare occasions the route may branch inside the tunnel, and a third portal would be present. Examination of the transportation network will reveal that the route passing through the tunnel is a part of this network. Underground storage facilities can have from one to several entrances. The routes entering the portals will be a branching series of "dead-ends" and the portals will be relatively close together. In addition, there will usually be some above-ground facilities in the area.

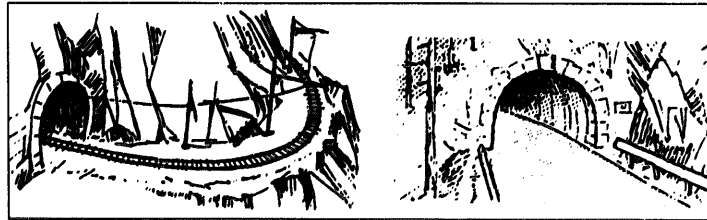


Figure 8: Railroad and highway tunnel portals

Galleries, Snowsheds and Rocksheds

In mountainous areas, special precautions must be taken to prevent damage to or blockage of roads and railroads due to avalanches and rock slides. On steeper slopes, accumulations of snow or rock debris are unstable, and can break loose, showering snow, ice or rock onto the lower slopes. For this reason, special structures are built along roads and railroads that pass through these regions. They are located along the steepest slopes, where avalanches or rock slides are most common.

A **gallery** is formed when a road or railroad is cut into a very steep hillside. If the rock is stable enough, an overhang of rock may be left over the road or railroad. This overhang protects the road from falling rock, debris or snow. The overhang may be stabilized by the placement of supports along the outside edge of the gallery. Galleries may be difficult to see on vertical imagery, especially if the look angle creates a terrain masking effect. If the look angle is properly oriented, the shadow of the overhang should be readily visible.

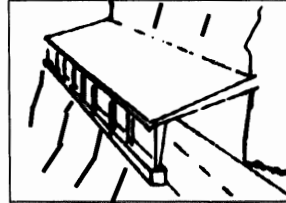


Figure 9: A gallery cut into the side of a steep slope

Snowsheds and **rocksheds** are special, reinforced structures built at points along the route where avalanches or rock slides are common. They are usually built of reinforced concrete and/or masonry, though some snowsheds are built of heavy timbers. The massive construction of these features and their location along steep slopes where landslide or avalanche scars may be visible are the keys to their identification. Heavy walls are often erected above the structure to channel the snow or rock across the section protected by the snowshed or rockshed.

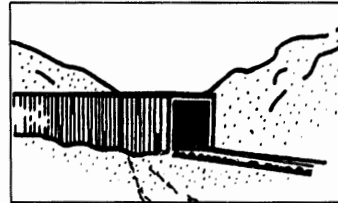


Figure 10: This snowshed was built to protect the road from drifting snow.

Snowsheds and rocksheds are very similar in appearance, as they are similar in function. If the structure is located at a higher elevation in the mountains, where large accumulations of snow are normal, it can be called a snowshed. Those at lower elevations, or in the valleys between the mountains can be called rocksheds. This classification is somewhat arbitrary, as the structures will protect the route equally from both types of hazard. Snowsheds are sometimes built along roads and railroads in areas where drifting snow would otherwise close the route.

To identify snowsheds and rocksheds, look for points along and at the base of steep slopes where the road or railroad disappears into a structure that seems to be built into the slope. The structure will have an angular configuration, will

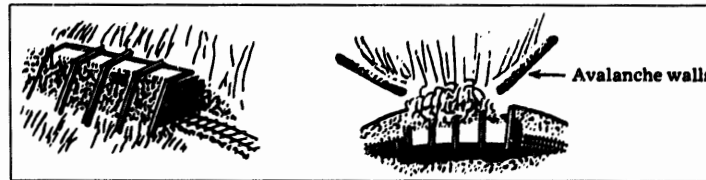


Figure 11: Rockshed (left) and snowshed (right). Note the similarity in appearance.

be partially open on the downhill side, and will have wing walls upslope to direct debris and snow over the structure. Landslide or avalanche scars will normally be visible on the slope above the structure. Concrete structures will be very light in tone, and may be difficult to spot against a snowy background. Masonry, native stone or timber structures will be darker. In all cases, look for the angular shadows cast by the structure and the wing walls, and the disappearance and reappearance of the route on either side.

Ferries

Occasionally, a road or railroad will cross a water body where it is impractical to build a bridge or other crossing device. Either the traffic is too light to justify the cost, or the water is too wide or too deep. In these cases, **ferries** can be used to carry traffic across the water body. Ferries also carry traffic out to islands not connected to the mainland by roads. Ferries vary in size from small pedestrian barges, to large ships capable of handling trains, cars, and/or hundreds of passengers. Depending on the volume of traffic, the facilities for loading and unloading can vary from a ramp leading down to the water's edge, to a well-developed **ferry slip**, complete with terminal buildings and passenger waiting areas.

Ferries across narrow water gaps, such as rivers, are easy to spot, as the road or railroad stops abruptly at the water's edge and continues on the other side. Except for the presence of the ferry, the crossing may resemble a ford or a prepared float bridge site. When the ferry crossing is on a larger body of water, and the opposite terminal is farther away, the ferry slip may be confused with facilities used for other shipping activities.

Dumb ferries

Most large ferries are self-propelled, and operate independently like other ships. A **dumb ferry** is a small (from 2 to 5 meters (8 to 15 feet) wide by 6 to 12 meters (20 to 40 feet) long), rectangular barge, without a motorized propulsion system. It has no superstructure or holds, and safety rails are normally present around the sides. It can handle only passengers or a few small vehicles, which will be visible on the open deck of the ferry.

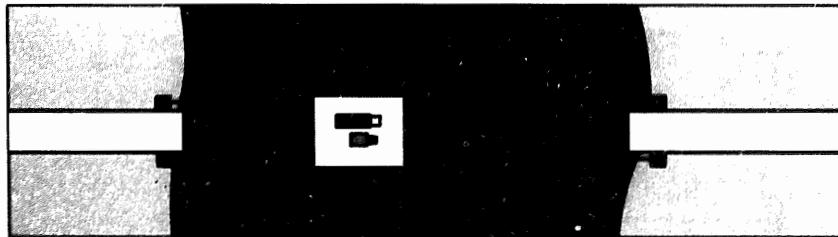


Figure 12: A cable-guided dumb ferry

Dumb ferries may rely on tug boats for motive power, while others are propelled via poles or currents. On narrow rivers that have little or no marine traffic, a dumb ferry may operate via a set of cables stretched across the river. The opposing slips are simple, rectangular in shape, and may or may not have a ramp (the ramp may be on the ferry). The slips are connected by a set of parallel cables to which the ferry is attached. The most primitive ferries are moved by poling, currents, or by people pulling the barge along the stationary cable. Some cable ferries use a winch on board the ferry to pull themselves along. Others are attached to cables which are pulled by winches on either side of the river. The winch gear and pulley system will be visible next to the slip, though it may be housed in a small building.

Powered ferries

Powered ferries fall into two categories, paddle-wheel or propeller driven craft. Both have clear decks fore and aft of a raised center section. The main difference between the two is the abrupt widening of the beam to accommodate the paddle wheels. Both will have stacks in the center of the vessel, and rectangular pilot houses facing in each direction. Powered ferries range from 4.5 to 18 meters (15 to 60 feet) in width and 12 to 60 meters (40 to 200 feet) in length.

Passenger ferries may load from the sides or from the end. Vehicular and rail ferries load from one end and unload off the opposite end. Side-loading passenger ferries, particularly larger ones, resemble other ships, and have a pointed bow and rounded stern, while end-loading ferries are more rectangular, tapering slightly toward the squared-off ends.

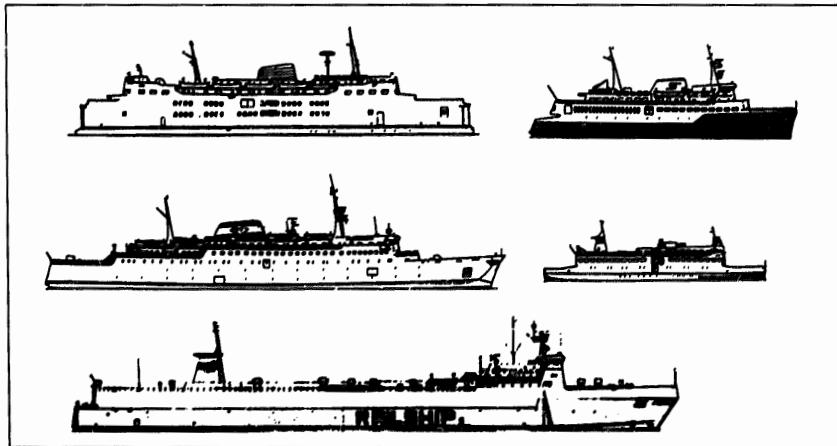


Figure 13: Examples of several types of powered ferries

Ferry slips

Small ferries can operate from a paved or unpaved ramp leading down to the water's edge, or a small, rectangular dock. Larger ferries can have a large dock, with a terminal building, and waiting areas for passengers and vehicles. For road and railroad ferries, the road or railroad track will extend right to the edge of the dock. A gate or cross bar near the edge of the dock will be visible. The dock may extend out into the water to insure a sufficient depth of water for the ferry. The slip will be wide enough to accommodate the vehicles being loaded onto the ferry.

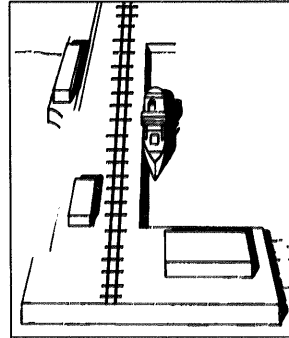


Figure 14: A railroad ferry slip

The alignment of the ferry with the road or railroad track from which the vehicles are being loaded is critical. Small, wing-like structures may extend out from the end of the slip to help guide the ferry into the proper alignment at the dock.

Ferry slips can be distinguished from other port facilities by the road or railroad extending out to the edge of the dock, the presence of a ferryboat at the slip, or the presence of passenger or vehicle waiting areas at the slip. If the water gap is narrow, the slip at the opposite side would also be visible.

Ferry Routes

The ferry's route may be anywhere from less than a hundred meters to many kilometers in length. The route is not visible but can be inferred by the placement of the slips and ferry traffic along the route. For longer routes, the route must be obtained from an ancillary source.

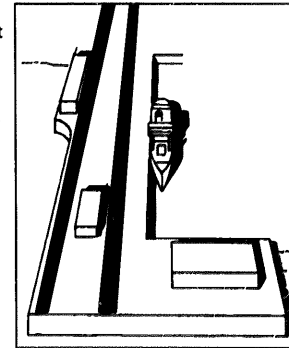


Figure 15: A vehicular ferry slip

Airfields

Air transportation differs from the other transportation systems in that there are no physical structures associated with air travel routes, although preferred routes can be plotted on maps, especially for commercial air traffic. Therefore, this chapter will cover only the terminal facilities, that is, the airfields themselves. The task of identifying and describing airfields is made somewhat simpler by the fact that *all airfields, from the simplest dirt strip to the most complex civil or military air facility generally look alike, and provide the same services, using similar equipment, worldwide.*

Before the Wright brother's motor driven plane flew a distance of 850 feet in December 1903, two basic ground support problems had to be solved. A place was needed to store the aircraft for maintenance and protection from the environment, and a cleared and level piece of ground was needed to build a take-off and landing area. The solution to these basic problems provided the United States with its first airfield and associated support facilities. Although there are more types of aircraft now, and aircraft designs have changed since 1903, the fundamental airfield ground support problems have not. This chapter will explain and illustrate these problems and their solutions affect the appearance of airfields and their facilities.

This chapter only discusses the basic aspects of airfields, those necessary for the accurate depiction of airfields and associated features on standard maps and charts. A detailed discussion of airfields and associated facilities is contained in Module 6, Airfield Imagery Interpretation.

Airfield Definition

An airfield is an area specifically designed and constructed for landing, accommodating, and launching military or civilian aircraft. Synonyms for the term airfield include: airdrome, airport, airstrip, air base, air park, heliport, helipad, seaplane station, and landing ground. For purposes of this discussion the term "airfield" is used in the broadest sense to designate all facilities, regardless of complexity or size designed for use by aircraft.

Airfield installations are those facilities that support the continued operation, maintenance, and repair of aircraft using the field. These installations consist of runways, taxiways, parking facilities, hangars, fueling and fuel storage facilities, navigational facilities, weapon storage areas, and passenger or cargo handling areas. To be categorized as an airfield facility the site must have a minimum of one visually identifiable runway.

Military and Civilian Airfields

Civilian and military airfields have several identifiable differences that reveal the intended use of the airfield. Civilian airfields are usually located near the city that they serve. Airfields found nearby or within heavily populated areas are usually classified as civilian or joint use civil/military airfields.

Military airfields normally occupy more land area than civil airfields because of the large amount of housing, storage, and related services that are associated with military operations. Military airfields are usually located away from large population centers. The presence of barracks areas for personnel, military combat aircraft, munitions storage, parade grounds, and a generalized military appearance leaves no question that the airfield is solely used for military air operations. The presence of military fighter, bomber and transport aircraft parked at the

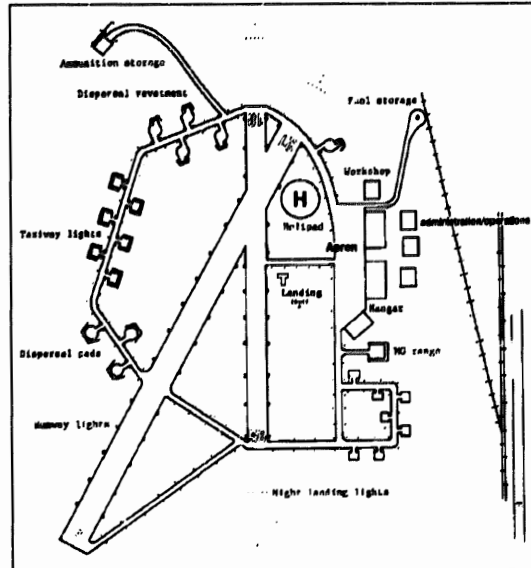


Figure 1: Military Aircraft Facility

airfield is the best means of confirming that an airfield is used for military air operations. It is not uncommon to see several rows of the same type and model of aircraft parked at a military airfield. In the past, the number and size of aircraft hangars at an airfield indicated the primary use of the airfield, however, that generality is no longer reliable.

Heliports include helipads and other cleared areas that are marked and specially designated to serve helicopter take off and landings. The main characteristics of a heliport are the presence of helicopters parked on separate pads, a short runway or no runway, and helicopter specific landing zone markings on the pads and aprons. The runway at a heliport is usually not paved, it is short and wide when compared to the proportions

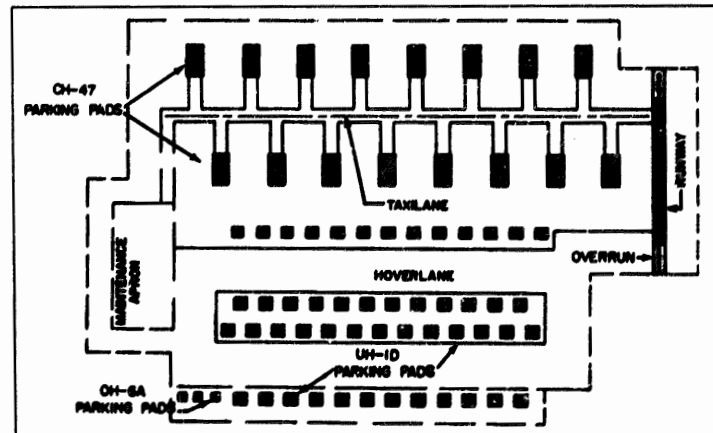


Figure 2: Military Heliport

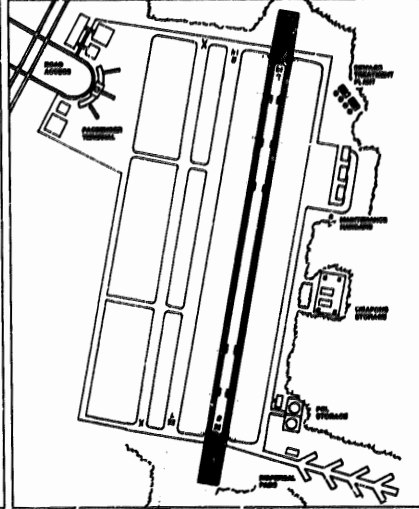


Figure 4: Joint Military/Civilian Air Facility

Joint military and civilian airfields are commonly found near large metropolitan areas. For economic reasons, joint use airfields are quite common throughout the world, they serve passenger, cargo and military aircraft operations and save money by sharing the operating expenses for the runway.

Highway airstrips are common throughout the world. Some sections of the interstate highway system have been modified to serve as runways during wartime or emergency conditions. Portions of the highway that are suitable for use as landing surfaces offer long stretches of unobstructed highway (no overpasses or overhead powerline crossings), a good tactical location, and a level surface. For the roadway to become the runway, the road is paved and reinforced to sustain repeated aircraft landings, and aircraft turn around aprons are added to each end of the selected roadway. During periods of normal use, the turn around aprons serve as automobile rest stops and have the same appearance on overhead imagery.

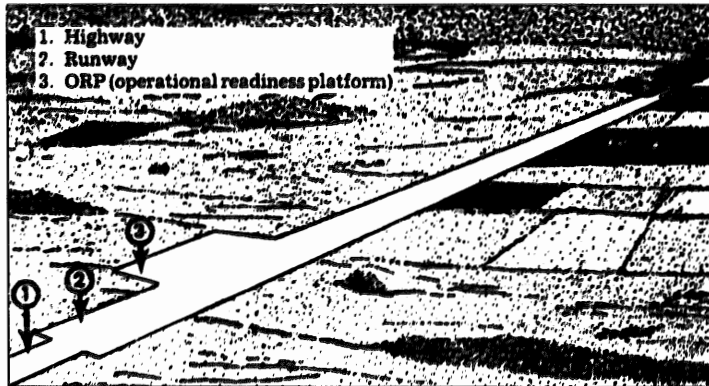


Figure 5: Highway Airstrip

Id Location

The most advantageous location for an airfield is in an area free of natural and cultural impediments to operations. An elevated site for airfield construction is preferred because of the absence of terrain obstructions and the likelihood of having more favorable local weather.

Whenever possible, airfields are constructed at locations away from river bottoms and flood plains, to avoid flooding and ground fog problems. Lower elevation areas are sometimes selected for airfield construction because the cost associated with acquiring the property is usually quite low. In heavily forested or jungle areas, low land along rivers is often the easiest to level and clear.

Prevailing winds at the proposed building site are evaluated in order to select a orientation that will receive the least exposure to hazardous crosswinds. A orientation parallel to the prevailing wind direction is selected, thus avoiding dangerous crosswinds at the airfield. Another consideration of site

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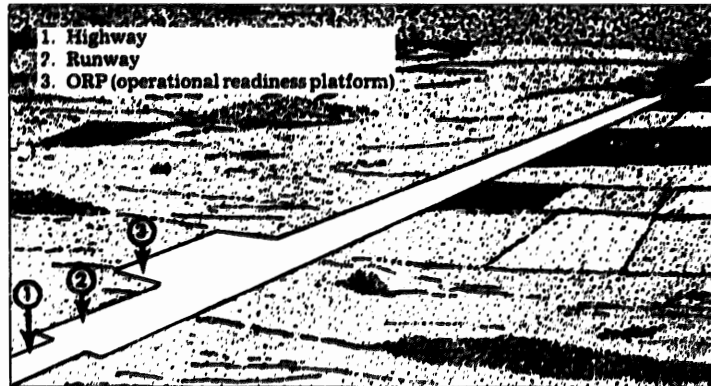


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Airfield Location

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Prevailing winds at the proposed building site are evaluated in order to select a runway orientation that will receive the least exposure to hazardous crosswinds. A runway orientation parallel to the prevailing wind direction is selected, thus minimizing dangerous crosswinds at the airfield. Another consideration of site

selection is extendibility. Natural or man made obstructions may exist that would limit the distance a runway can be extended. Water areas, built-up areas, canyons, hills or mountains, are all examples of obstructions that would impose a significant increase to the construction cost of increasing the length of a runway. Under normal conditions, the expenses involved in bridging the natural obstructions influence the decision to extend a runway more often than do civil engineering limitations.

Runways

The main distinguishing characteristic of an airfield is the presence of one or more visible runways. A single runway is the only element necessary for an area to be identified as an airfield facility, no other components need to be present. The presence of an aircraft parked on the ground (such as those found at static aircraft displays) does not constitute an airfield.

The length, width, condition, and type of landing surface material have a direct impact on the type and amount of aircraft traffic a facility can bear. These characteristics of the runway are all aerial photo discernible traits and can be correctly identified by a trained imagery analyst.

Airfields can have single or multiple runways to accommodate various traffic loads and changing wind conditions. The most common multi-runway patterns are parallel, V-shaped, T shaped and X-shaped.

Landing Surface Types

Perhaps the most difficult of all the runway characteristics to determine on imagery is the landing surface type. Runway surfaces are divided into **natural**, **prepared natural**, **semi-rigid**, **rigid**, and **prefabricated** landing surfaces. The load bearing capacity of each surface material varies, as does the wheel load weight of the aircraft and the anticipated amount of air traffic at the airfield. Thus, the length of the runway is not the single most important factor in determining an airfield's operational capacity.

Natural Surfaces

Natural surface runways are paved with the natural soil and vegetation that covers the earth at that location. These runways require minimal surface preparations (grass mowing) to ready them for aircraft landing and take off operations.

Natural surface runways made of **sod**, **grass**, and **turf** are sometimes delineated by day markers placed along the sides of the runway and at the corners of each runway end. During wet seasons, natural surface runways become soft and are easily imprinted with aircraft tire tracks. During drier than normal conditions, surface vegetation on the runway erodes and takes on a lighter tone due to repeated daily use and drought.

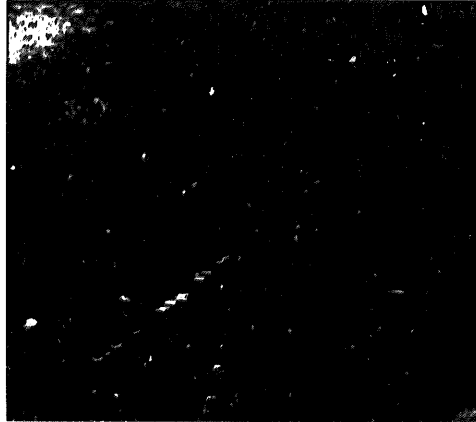


Figure 6: A grass runway used primarily for gliders and their towplanes. Note the similarity in tone between the runway and surrounding areas.

The edges of natural surface runways are irregular and their tone varies from dark to light gray depending on the season of the year and the type of soil present or vegetation growing there. When the tone of the runway and surrounding surface vegetation are similar or exactly alike, you can be certain that you are looking at a grass, sod or turf covered runway. By finding a cultivated field and comparing the tone of the exposed soil to that on the runway, you can confirm that the surface is made of soil or sand and not grass.

The texture of a grass runway is usually smoother than the surrounding vegetation when the runway surface has been mowed and maintained.

Natural surface runways are sometimes only usable during the dry season or when the ground is frozen. Multi-seasonal use of natural surface runways depends upon adequate soil drainage, the weight of the aircraft using the runway, and the presence and duration of ground frost.

Natural surface runways are found in all five length categories. Many modern cargo and passenger aircraft are designed to operate on diverse landing surfaces, including grass and sod, military transport aircraft routinely land on these surfaces.

Natural surface runways are low contrast features and are difficult to detect because they are made from the same material as the surrounding natural surface cover.

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Prepared Natural Surfaces

Natural surfaces used for runways can be improved by modifying the surface through grading, leveling, draining and conditioning the soil prior to use for air operations. Surface materials that are commonly used for airfield construction are: graded earth, sand, clay, coral, laterite, gravel, crushed stone, and soil/cement mixtures.

Graded Earth: Prepared natural surface runways have a different appearance than natural surface runways. Various surface preparation techniques initially require the upper layer of vegetation or surface material to be scraped off the runway site, thus leaving freshly exposed subsoil to become the base for the new runway surface. The exposed subsoil will exhibit the same tone as the exposed subsoil found on local

farms and unimproved roads. When natural soils at a site have properties that do not provide adequate drainage, or that compaction will not improve, they can be corrected by the addition of sand, clay, calcium chloride, sodium chloride or bituminous materials, any of which can alter the tone of the runway, making it differ from the surrounding soil. Earthen runways are generally short and narrow, and serve small aircraft only. Military forces use earthen airstrips during wartime and military exercises for the delivery of cargo to forward areas. Earthen strips deteriorate under heavy use, thus it can be assumed that a facility with an earthen strip is used infrequently. Earthen airstrips for military use are much larger than the usual graded earth airstrip.

Laterite: Laterite is a red, residual soil containing large amounts of aluminum and ferric hydroxides. It is formed by the decomposition of many kinds of rocks, and is only found in well drained tropical rain forests. Runways made of laterite soils are most commonly found in East Africa and Southeast Asia (Laos, Viet Nam, Cambodia). Laterite runways are usually short (1200ft) and narrow (30-50ft), and can only accommodate small single or dual engine aircraft. A laterite runway generally has a light or mottled tone that is somewhat lighter than the surrounding soil. Airstrips made of laterite may be smooth in texture or imprinted by grader marks. These runways have irregular shoulders and indistinct corners on the runway ends.

Gravel Surfaces: Gravel is low cost surface treatment that is sometimes used for runway construction. On runways with gravel surfaces, large particles of loose aggregate can be kicked up by aircraft tires and exhaust, thereby inflicting damage to the aircraft and engines. To reduce the possibility of damage to aircraft, gravel consisting of small aggregates is mixed with binders and compacted to create a safe runway surface. When gravel, crushed stone, or a soil cement mix is deposited over the subsoil, the tonal difference between the area covered and the exposed subsoil is usually noticeably different and easily detected. Typically, these surfaces are light-toned due to the surface application of calcium chloride for moisture retention and dust suppression.

Coral Surface: Coral surfaced runways are found mostly in the Caribbean, Indian, and Pacific oceans. Coral runways usually exhibit the same tone as the surrounding earth's surface. With the exception of looking cleaner, (because of sparse ground vegetation and removal of surface irregularities by grading), coral runways look remarkably similar to the rest of the island that they occupy. The similarity in tone is greater for runways located near the beach or coastal area.

The analyst must make certain that the island where the runway is located has a coral substructure, as not all island runways are coral surfaced. Coral is absent from the West coast of continents, and can only exist in areas with an ambient temperature above 68 degrees. It

will only be found in areas within 30 degrees north or south of the equator (except Bermuda). The crushed coral surfaces are graded smooth and level to provide good drainage, and create a consistently smooth surface for take-off and landing.

Sand surface: Sand surfaced runways are found in all size categories, however the majority of them are normally smaller in size. The overall tone of a sand runway is lighter than the surrounding sand and is normally characterized by grader marks and tire tracks. Sand runways are found in desert areas, on islands, and along coastal areas.

Ice and snow: Ice or snow surfaced runways are found in the high latitudes and are commonly temporary features that disappear with the onset of the spring thaw. When made of snow or ice, and located in no thaw zones, they are permanent features and can be found in all length categories. Because ice that is formed over water creates a naturally level and smooth surface that is free of obstructions, many permanent or temporary runways are found on frozen lakes and bays. These runways always have a white tone and smooth texture with some evidence of tracks from landing aircraft. Runway edge lights and/or day markers are often used to delineate the ice/snow runway.

Clay: Clay surfaced runways are virtually indistinguishable from earthen runways on aerial photography. Ancillary sources (soil survey maps) are the best source of information to confirm the presence of a clay runway.

Bedrock: Bedrock runways are found throughout the world and will have the same tone as rock outcroppings in the local area. Bedrock is locally exposed on the surface of the earth and is a very stable surface for landing all sizes of aircraft.

Semi-Rigid Surfaces

Semi-rigid runway surfaces consist of **asphalt, bitumen, or macadam**. All of these surface treatments are relatively permanent and differ mainly in terms of water penetrability, type of materials used in the mix, percentage of bitumen added and surface preparation prior to application. Bitumen is the main binding ingredient in macadam and bitumen type runway surfaces, it is also used with asphalt on asphalt runways.

The American Society for Testing Materials (ASTM) defines bitumen, the binding or cementing agent in bituminous paving materials, as follows:

Bitumen, a mixture of hydrocarbons of natural or pyrogenous (produced by application of heat) origin, or both, frequently accompanied by their non-metallic derivatives, which may be gaseous, liquid, semi-solid or solid and which are completely soluble in carbon disulfide.

Asphalt, a black or dark brown solid or semi-solid cementitious material which gradually liquifies when heated, in which the predominating

constituents are bitumens, all of which occur in the solid or semi-solid form in nature, or are obtained by refining petroleum, or which are combinations of the bitumens mentioned with each other or with petroleum or derivatives thereof.

The primary difference between bitumen and asphalt are:

1. bitumens remain liquid or semisolid at or slightly above normal temperatures, whereas asphalt compounds will remain solid.
2. Asphalt runway surfaces do not permit water penetration, whereas bitumen compound runways do.

Bituminous mixes for paving purposes consist of aggregate and bituminous binding material. These constituents are blended and mixed to give a product which when laid down and compacted will result in a pavement or runway having the desired durability and load bearing capacity. The most important variable in a bituminous paving mix is the quantity of bitumen. If excess bitumen is present, the mix will lack stability and will rut and creep under traffic. A slight excess will result in an oily, slick surface that is dangerous, particularly when wet. The four major bitumen surfaces are: Soil-bitumen, Sand-Bitumen, Oiled earth and Macadam.

Soil-Bitumen: These surfaces are water-resistant, cohesive soil systems that provide medium weight bearing ability for all weather runways. Their surfaces have a very dark tone and are created by mixing soil and bitumen together, then curing and compacting the material. These surfaces are found worldwide and are usually associated with temporary airfields or airfields that do not receive much traffic.

Sand-Bitumen: These surfaces are water resistant systems in which loose beach, dune, pit, or river sands are cemented with bituminous material. This construction differs from soil-bitumen mainly in type of aggregate mixed with the bitumen. This type of surface is commonly found in the desert areas of the Middle East, where large amounts of sand and bitumen are easily and economically acquired. These runways are markedly darker in tone than the surrounding area.

Oiled-Earth: These runways are made water and abrasion resistant by the application of slow or medium curing oils to the graded earth surfaces. This type of treatment will yield a runway that is dark in tone and suitable for light, all weather traffic.

Macadam: This surface pavement for light traffic was named after its inventor, John MacAdam. It consists of a layer of crushed stone that has the voids filled with smaller stones and stone screenings and is compacted and bonded in some way to prevent its displacement. A bituminous material or cement grout may be used as binder. A macadam surface without binders, or with cement grout is light in tone compared to the dark bituminous bonded material.

Asphalt: This type of pavement consists of a refined asphalt that may or may not require the addition of a non-volatile petroleum oil to render it suitable for paving purposes. One source of asphalt is native asphalt lakes, another is derivation from the residue from the fractional distillation of asphaltic base or petroleum. There are various types of asphalt mixtures and processes for creating a pavement of the desired surface roughness and durability.

When viewed on imagery asphalt runways appear to have neat straight edges, are predominantly dark in tone and may have visible (painted) runway markings. The exception to this is found on aged asphalt runways. As time passes the surface becomes lighter due to accumulated dirt and surface wear. Aged runways are frequently re-sealed and appear as dark as freshly laid asphalt.



Figure 7: A weathered asphalt runway, with grass encroachment along the runway edges

Rigid Surfaces

The design of rigid concrete pavements for airports is unique because of the varying wheel loads and operating characteristics of the aircraft using the runways. Throughout the central 70% of its length, the thickness of the runway is thinner than at the approach ends. Taxiway thickness is usually equal to or less than the runway. The reduced thickness of the center runway and taxiways is permissible because at those areas, aircraft are moving, thus the stress on those surfaces is of a short duration. When the aircraft is stationary, surface stress is increased due to heavier static wheel loads and the sustained transmission of motor vibrations to the operating surface. The runway approach ends must be substantially thicker to absorb the tremendous impact they receive from inbound landing aircraft. Tire marks on one or both ends of the runway attest to the beating these areas receive. Due to their infrequent use, paved runway overruns are the same thickness as taxiways or the middle portion of the runway.

Aircraft parking areas, (when paved), are usually made of concrete in order to support the concentrated weight of aircraft over long periods. In addition, concrete will not soften when exposed to high daily temperatures.

Concrete Runways: On optical imagery, concrete runways generally appear light in tone, with neat straight edges, non-rigid shoulders and sometimes visible runway markings and edge lights. Typical concrete runways are poured on site, however in areas of frost heaving, prefabricated cement blocks are brought in and laid down to create a stable yet flexible runway surface.

Concrete runways that have been poured on site have expansion joints built in to them to allow for expansion and contraction due to heating and cooling of the cement surface. Expansion joints extend across the runway from edge to edge and like runway drainage grates, creating dark lines across the runway that are often noticeable on airfield imagery.

Cement Block: Runway surfaces composed of cement blocks (rectangular or octagonal blocks), have dark lines where the blocks are joined and sealed with waterproof asphalt sealers to prevent water penetration and freeze damage. Taxiing and landing on prefabricated cement block surfaces gives passengers and crew the same physical sensation that an automobile receives when driving on a brick paved street.

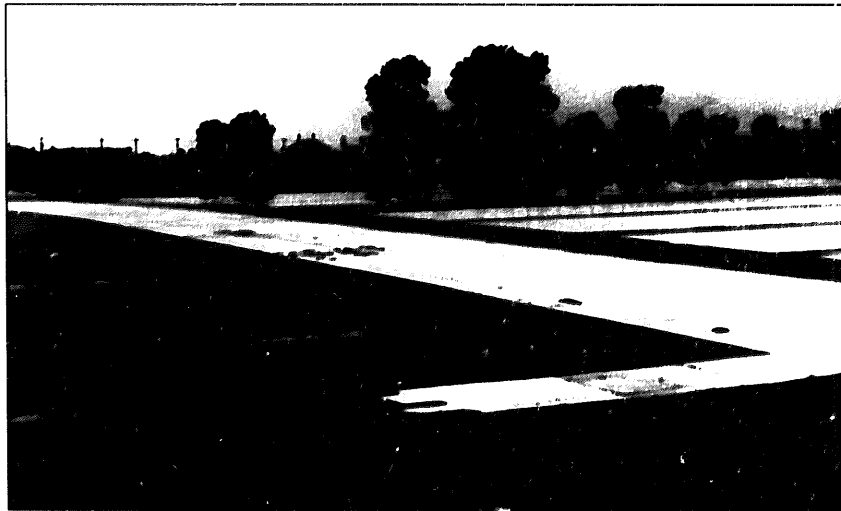


Figure 8: Concrete runway with markings painted on the surface

Prefabricated Surfaces

Prefabricated surfaces for landing and parking surfaces differ from precast cement slabs in that they are made of thin, lightweight materials and are intended to be used as a temporary surface. Prefabricated surfaces are usually found at temporary military airfields in areas where military exercise or war conditions exist. Prefabricated runways are also found in remote regions (polar or jungle), where scientific research or exploration base camps need a temporary and hasty runway surface. The main function these surfaces serve is to allow engineers to quickly construct a stable and level runway or parking surface over minimally improved airfield sites.

Prefabricated panels are designed to be assembled quickly and handled by a minimum of personnel. They are made of lightweight materials such as aluminum mat or thin steel. Each sheet measures approximately 4 ft. X 10 ft. Pierced steel planking (PSP) sheets are made lighter by perforating each panel with a matrix of uniformly placed 3in. holes across the panel. Both solid and PSP prefab panels are constructed with edges that interlock or weave together, thus enabling easy removal or replacement when needed.

Pierced Steel Planking: Because pierced steel planking is essentially a grid work of holes in a steel panel, grass can easily grow on the exposed earth inside of the holes, this results in a surface appearance that is dark in tone and somewhat textured. When PSP is placed on a newly graded surface or upon sand, the lighter subsoil showing through the panel yields an overall light tone when contrasted against the darker rusty steel panel.

Aluminum Mat: is made of solid panels with an olive drab green painted and textured surface that appears either darker or the same tone as the background that it is laid upon. Aluminum mat and PSP form similar patterns made of fine lines in a grid pattern where the panels join together. When taxiways and parking areas are added to the runway, sawtooth or stepped edges are formed around their outer edges, due to the rectangular shape of each panel that is used to create the area.

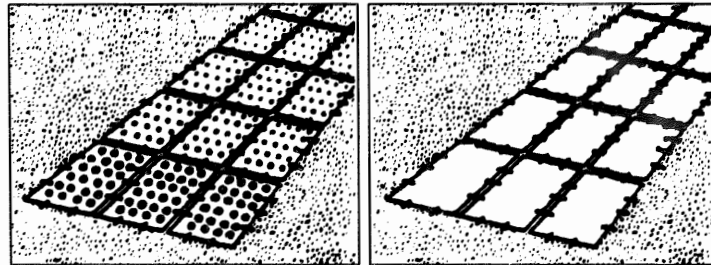


Figure 9: Expedient runways of pierced steel planking (left) and aluminum mats (right)

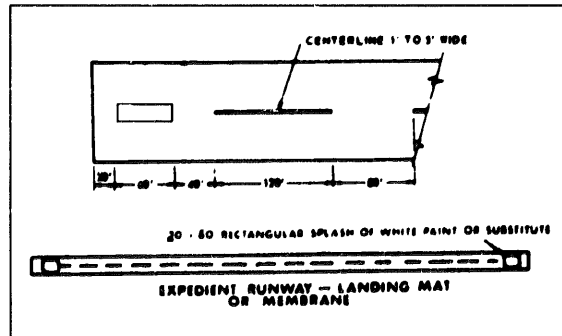


Figure 10: Diagram of an expedient prefabricated membrane runway

Prefabricated Membrane:

Prefabricated membrane is made of vinyl or rubber impregnated fabric and is packaged in rolls that allow it to be rolled into place, easily joined, and anchored around the edges. The main advantages of this type of surface lies in its apparent ease of installation and ability to prevent water from penetrating and softening the soil beneath it.

Prefabricated Membrane surfaces have very little impact or abrasion resistance, and are best used in light wheel load fixed wing aircraft or helicopter operations. Prefabricated membrane is olive drab in color. On imagery it will generally appear to be dark or medium toned, depending on the overall tone of the background it is placed against.

Type of Surface	Description	Tone	Options
Sod	irregular	same as surrounding	day markers
Grass	irregular	mottled light to dark	tire tracks
Turf	irregular	mottled light to dark	tire tracks
Graded Earth	smooth	light to dark subsoil	tire tracks
Sand	irregular	light to medium	sand fence
Gravel	smooth	light to medium	n/a
Coral	smooth	light to white	day markers
Asphalt	regular	dark to medium	markings
Bitumen	regular	dark	n/a
Macadam	regular	dark to light	n/a
Concrete	smooth	lt. gray to white	markings
Prefab panel	grided	mottled med. dark	piles of PSP and panels

Table 1: Summary of characteristics of runway surface types

Runway Length

Runway length is determined before construction by establishing how many, what size, and what type of aircraft will use the airfield. Specific characteristics about the types of aircraft that will be using the runway are vital to the process of runway length calculation.

The amount of runway required for the safe take off and landing of an aircraft is determined by the aircraft design limits and site specific meteorological conditions. Aircraft designers and manufacturers create an index for each aircraft that tells the pilot how much runway is needed to take off and land with a predetermined margin of safety. To produce the index, aircraft engineers analyze the thrust to drag figures of each aircraft, its maximum and minimum load (fuel, passengers, cargo), the annual high/low pressure density of the atmosphere at site. After the data for each aircraft and the atmospheric conditions are considered, the "minimum distance, take off and landing table" is published for that specific aircraft. By obtaining the maximum and minimum runway requirements for each aircraft using the runway, an acceptable runway length is determined.

Five classes of airfields (based on runway length and width) have been established. These five airfield categories have corresponding runway lengths that will accommodate virtually all the types of aircraft that operate in the USA.

Airfield Runway Dimensions

Airfields are classified according to length of delineated runways as shown in the following Table.

Type of Service	Runway Length	Runway Width
Class 5 (personal)	1500-2300 ft.	50 ft.-20 ft.
Class 5 (secondary)	2301-3000 ft.	75 ft.-30 ft.
Class 5 (feeder)	3001-3500 ft.	100 ft.-40 ft.
Class 4 (trunk line)	3501-4200 ft.	150 ft.-50 ft.
Class 4 (express)	4201-5000 ft.	150 ft.-60 ft.
Class 3 (Continental)	5001-5900 ft.	150 ft.-75 ft.
Class 2 (Intercontinental)	5901-7000 ft.	200 ft.-75 ft.
Class 1 (Intercontinental)	7001-8400 ft.	200 ft.-75 ft.

Table 2: Runway classification by length

Runway Safety Measures

An important aspect of runway length is the inclusion of a safety factor. In the event of an aborted take off or a "far beyond threshold" landing, some aircraft are not able to stop rolling before reaching the end of the runway. For safety, many airfields have added **runway overruns** and cleared areas at the runway ends to allow aircraft to safely continue rolling beyond the ends of the runway.

Another safety measure to prevent aircraft from rolling beyond the end of the runway is the **runway barrier net**. This device resembles a tennis net that is activated from the control tower at the pilots request. Normally the net is at or below the surface level of the runway and will look like a dark line across the runway with two black or white boxes on each side. In the stowed position, aircraft can roll over the net without being restrained. When deployed the net is raised above the runway and looks like a tennis net. Two square boxes on each side of the runway contain retractor reels with cabling that absorb the force of the aircraft enabling it to stop. The aircraft rolls into the barrier net, is caught, and stopped before running off the end of the runway. A runway barrier net is usually located on the extreme end(s) of the runway in order to keep aircraft from going beyond the runway overrun.

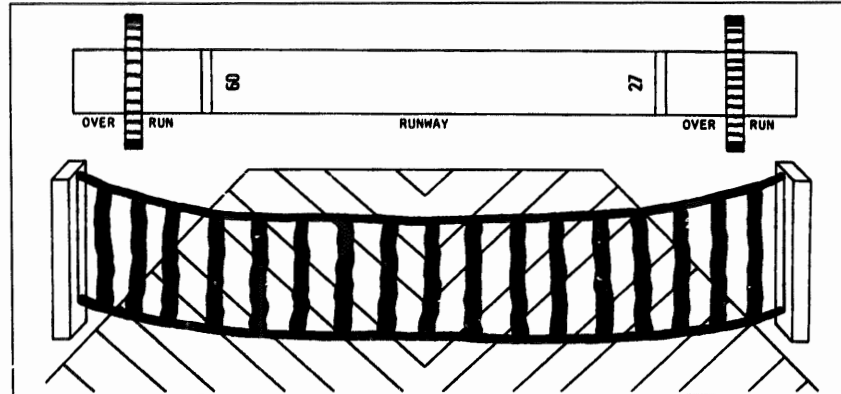
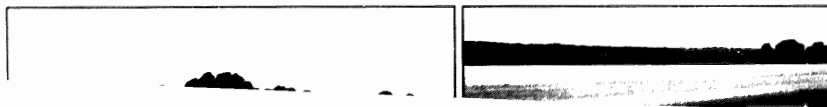


Figure 11: Runway overrun and barrier net

An **arresting gear** is a type of barrier system device consisting of an elevated cable connected to reels mounted on both sides of the runway. It is used for the purpose of stopping tail hook and non-tailhook equipped aircraft. A cable is stretched across the runway and is caught by the tail hook or landing gear of the inbound aircraft, as the cable is stretched the energy of the aircraft is reduced thus preventing the aircraft from going beyond the overrun. Arresting gear cable systems are usually located just beyond the designated wheel touchdown zone.

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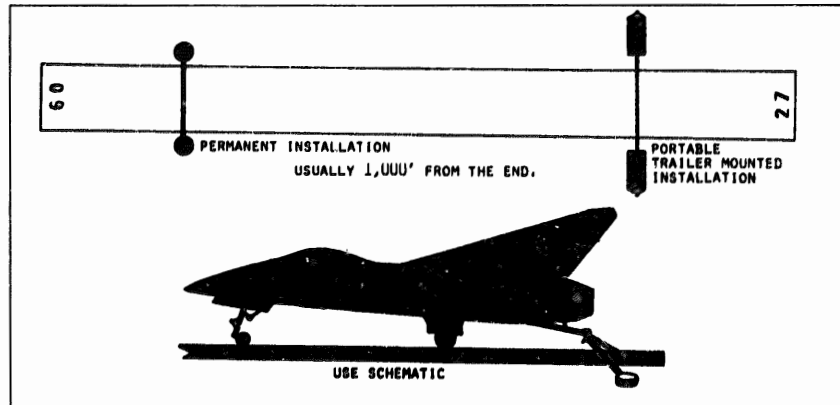


Figure 12: Runway with arresting gear. Note that the arresting cables are located inside of the runway's thresholds, as opposed to the barrier nets which are placed on the overruns.

Runway Markings

Airfield marking systems serve as visual aids to help locate and identify runways, taxiways, and parking areas. They also provide approach heading and glide slope information for inbound aircraft.

The arrangement, size and type of runway markings in the United States is standardized by the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO). ICAO standards are observed by countries worldwide but are only mandated at international airfields. Nation specific runway marking schemes may be found at non-ICAO airfields. Runway marking requirements are divided into four groups, each related to the severity of the operating conditions and the intended purpose of the airfield. These conditions are defined as follows:

1. **Privately owned non-public access airfields** and primitive bush strips may have daytime markers, (white painted objects arranged in an L shape used to define the corners of the runway), or they may have no runway markings at all.
2. **Basic Visual runway markings** are used for operation during daylight, good visibility weather and (Visual Flight Rule) VFR conditions. These consist of:
 - a) Centerline markings
 - b) Runway designators
 - c) Fixed distance markers on runways greater than 4000 feet.
 - d) Holding position markings and an illuminated visual landing system.

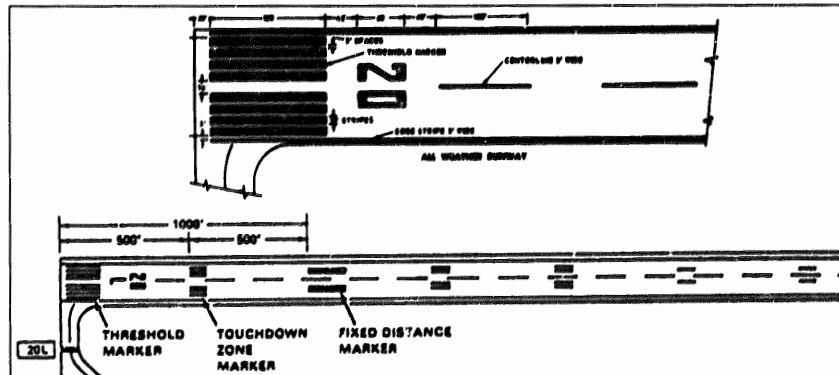


Figure 13: Precision Instrument Runway Markings

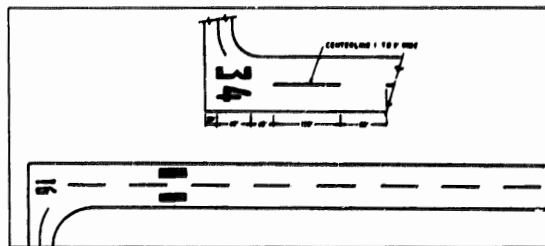


Figure 14: VFR (Visual Flight Rules) Runway (Basic Markings)

3. **Non-Precision Instrument Runway Marking** used for aircraft operating under Instrument Flight Rule (IFR) conditions have all of the above markings plus a visual landing system.
4. **Precision Instrument Runway Airfields** accommodate aircraft operating in all types of weather, they have illuminated runway markers, all of the above-mentioned markings, edge stripes, edge lights, landing zone markers, and (non-visual approach) landing systems.

Non Illuminated Runway Markings

The basic function that runway markers provide, is to delineate the usable operational limits of the runway. Just as there are many types of highway signs and roadway markings for automobile drivers, there are also numerous runway markings to identify runway orientation, centerline, threshold, touchdown zones and usability status. For ease of discussion, illuminated and non-illuminated markers will be covered separately.

Day Markers

Associated with natural surface runways, **day markers** are made from stone, semi-buried tires, cement, wood, metal panels or any material that when painted white and arranged in an (L or I) shaped pattern is large enough to be viewed from aloft. Day markers as described, are used to visibly delineate the ends and sides of the runway.

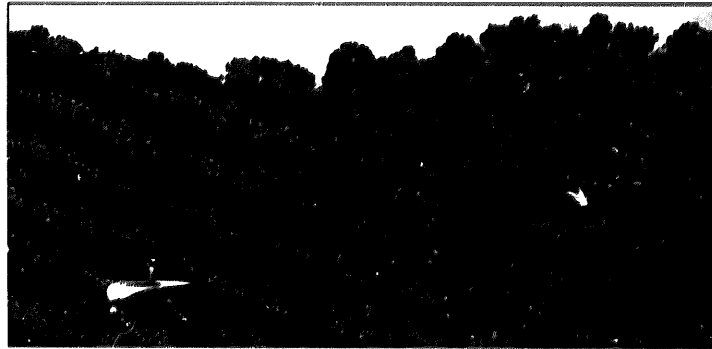


Figure 14: Day Markers with lights made from tires painted white

Runway Designators

Runway heading markers are used to name the runway, indicate the magnetic orientation and identify left/right runway designation on rigid and semi-rigid surface runways. They are white numerals and letters that are large enough to be identified from the air at a distance of one quarter mile in clear weather are applied to the runway ends. These markers also accent the landing and take off area of the airfield.

White numerals are used to depict the magnetic azimuth of the runway to the nearest ten degrees. When portrayed on a runway, azimuth is always depicted by a combination of two digits. For example, a runway orientation that is surveyed at 085° East and 265° West, is marked by rounding the magnetic orientation of the runway up to the nearest ten degrees and then abbreviating it by deleting the last zero. Runway heading marker numerals are then displayed as 09 and 27.

Heading indicator numerals do not identify the north, south, east, or west ends of the runway, they indicate the heading or azimuth that will be read on the aircraft compass if you are approaching the runway from the indicated end. Heading markers indicate the magnetic heading needed to approach and align an aircraft with the runway.



Figure 16: Runway Heading marker and centerline

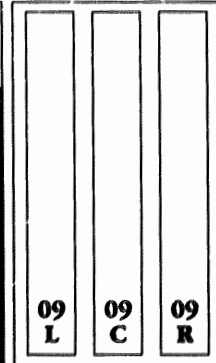


Figure 17: Runway designators on a three runway airfield

Thus, on an east to west oriented runway, the 09° numerals are applied to the west end of the runway to match the compass heading that an inbound aircraft would have when approaching the runway from this direction.

In order to eliminate confusion when naming runways, a scheme of letters and heading numerals was instituted. At airfields having multiple, parallel runways, left from right differentiation is made by including the relative position of the runway (as viewed from the approach ends), left, center, or right in the heading marker name. Left, right and center runways are separately identified by the placement of a white capital letter (L, R, or C), beneath the respective heading numerals. This is illustrated by the diagram shown as figure 17.

Centerline marking

A runway centerline is applied to rigid and semi-rigid runways to provide the aircraft pilot with a visual reference for finding the runway center during landings, taxiing and take-off. Centerline stripes are commonly depicted on the runway surface as a white 120ft. line broken by 80ft. spaces. The minimum width for the centerline at a basic airfield runway is 1 foot. At Day/Night all weather runways the centerline is 3 feet wide.

Threshold Marking

The runway threshold is the designated end of the runway. Although inbound aircraft can make initial wheel contact with the runway at the threshold, usually the touchdown zone is just beyond the runway end or threshold. Threshold ends of the runway are paved with material that is thick enough to sustain the impact of a landing aircraft.

[illegible]

Figure 19: Threshold markings, heading designator, centerline and edge stripes

A displaced threshold is a portion of the runway located at the ends of the runway that is not intended to be used as a landing zone. Some airfields have displaced thresholds due to the addition of paved overruns. Areas indicated by displaced threshold markings are not strong enough to withstand the impacting wheel load of a landing aircraft. Often, displaced thresholds are added years after a runway was constructed, thus providing an extension to the previous runway for landing roll out, taxiing, or take off. These areas are not strong enough to withstand repeated landings.

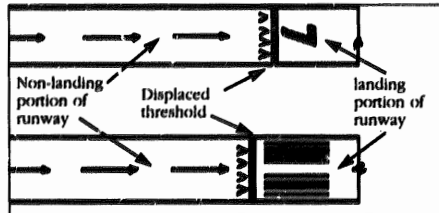


Figure 20: Displaced Thresholds

Displaced threshold markings are depicted by a series of two symbols. Beginning as a single row of separate arrow tipped white lines placed along the centerline of the threshold, these markings are terminated by a series of small inverted "V" or chevron shaped symbols extending across the displaced threshold end, and pointing toward the solid line that indicates the beginning of the runway.



Figure 21: An asphalt runway with a displaced threshold

Touchdown Zone Marking

These markings provide the inbound aircraft pilot with a visual target that indicates where to make wheel contact with the runway.

Touchdown zone markers are very similar in appearance to threshold markings. They consist of a series of two groups of white stripes extending inward from each edge of the runway. The primary difference is that the touchdown zone is located just beyond the threshold marker. The surrounding runway pavement at the touchdown zone is usually darkened by tire marks from repeated aircraft landings.

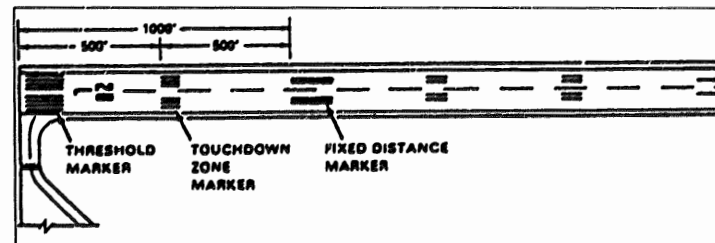


Figure 22: Touchdown zone and fixed distance markers

Edge Stripes

Edge stripes are solid white lines that are used to mark the point where the outer edge of the runway surface meets the shoulder. The visual reference that they provide for the pilot is the same cue that highway edge lines provide for the motorist.

Fixed Distance Markers

Fixed Distance Markers have a similar appearance and function as touchdown zone markers. This marker is composed of two large solid white rectangles on each side of the centerline and located 1000 feet from the threshold. The fixed distance marker is used as a visual reference for landing turbo-jet aircraft on precision and non-precision runways.

Stopway Markings

Stopways are paved areas beyond the end of the runway that are suitable for use during an aborted take off or whenever an aircraft unexpectedly requires a stopping distance beyond the normal limits of the usable runway. Stopways are marked with a repeated series of large, chevron shaped white lines, painted across the width of the stopway, and pointing toward the runway end.

Closed Runway

A runway that is unusable, hazardous or no longer used is marked by white "X" shaped markings. The markers are painted along the runway center at even intervals along the entire length of the closed runway. The same designation is used to mark taxiways that are closed.

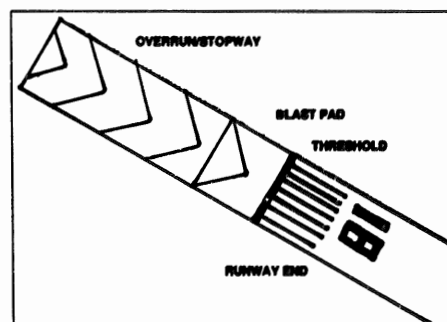


Figure 23: Stopway (Overrun) markings

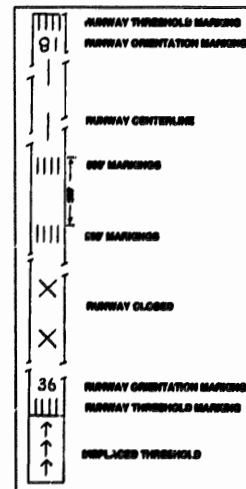


Figure 24: Summary of runway markings

Illuminated Runways

When night flying was introduced, most airports consisted of an open area covered with either turf or cinders. Pilots could land in whatever direction they chose. Rotating beacons provided the pilots with the general location of the airport but did not provide sufficient visual cues to permit them to actually locate the cinder area and land. This problem was solved through the introduction of airport boundary lighting.

Lighting systems on illuminated runways define the outlines of the runway, and are used during times of darkness or low visibility when painted runway markers are not visible. Special purpose lighting systems provide visual glide slope information to the pilot both day and night.

Approach Light Systems

One of the most difficult tasks facing pilots occurs near the end of an instrument approach, during this time they have to maneuver the aircraft into position and land, all within the space of a few seconds. Approach light systems provide the means to transition from instrument flight to visual flight for landing. Operational requirements dictate the sophistication and configuration of the approach light system for a particular runway.

The first approach light systems were quite simple and consisted of three incandescent light bulbs placed 500 feet apart along the extended centerline of the runway. Today approach lighting systems are more elaborate, the specific type of system used is dependent upon the type of aircraft using the airfield. Current systems consist of specially configured signal lights located at the landing threshold and extending into the approach area a distance of 2400-3000 feet for precision instrument runways, and 1400-1500 feet for non-precision instrument runways.

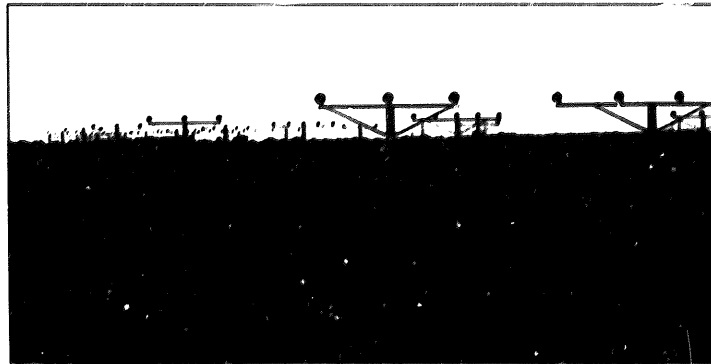


Figure 25: Approach Lighting System as viewed when facing oncoming aircraft.

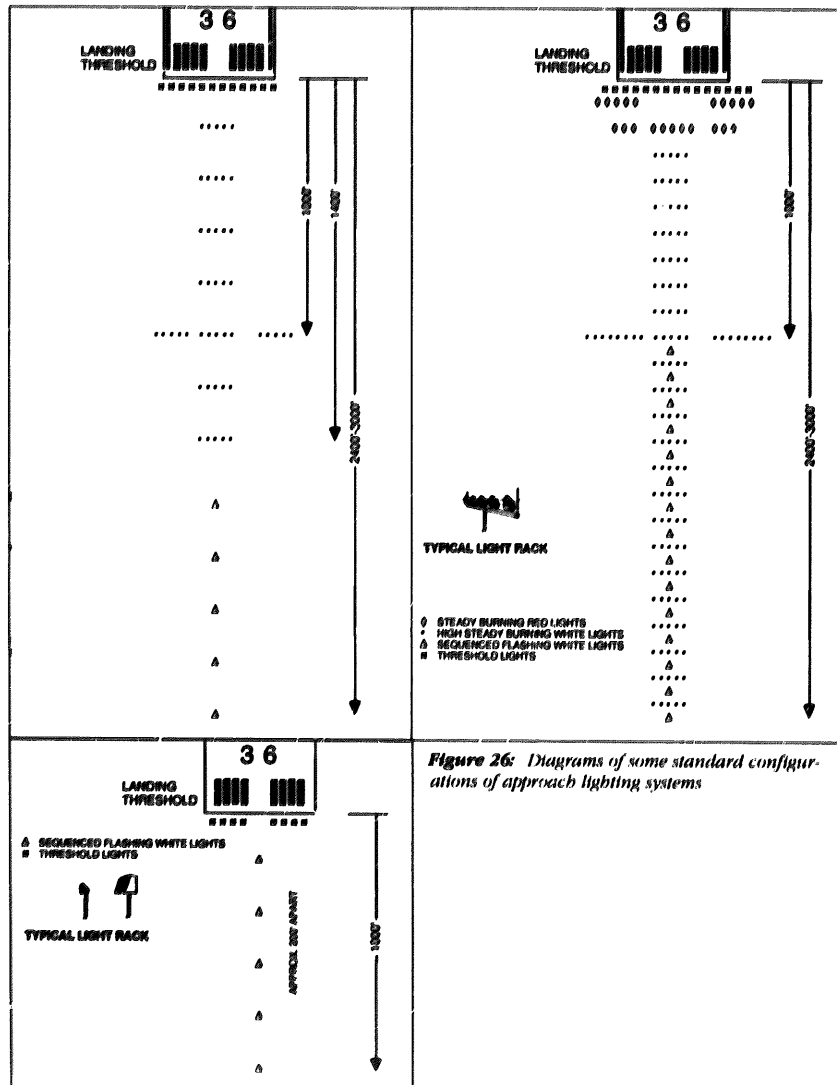


Figure 26: Diagrams of some standard configurations of approach lighting systems

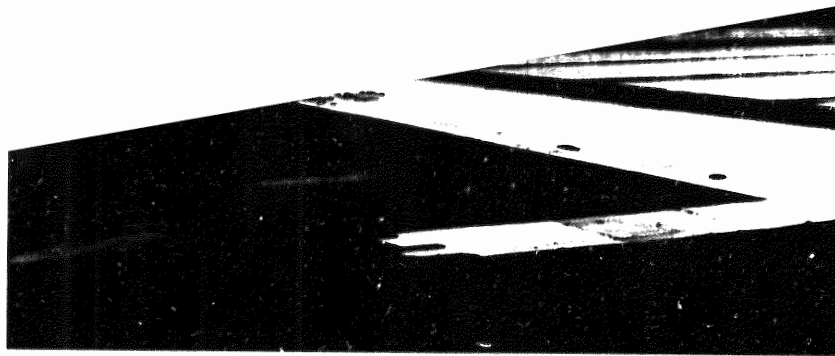


Figure 8: Concrete runway with markings painted on the surface

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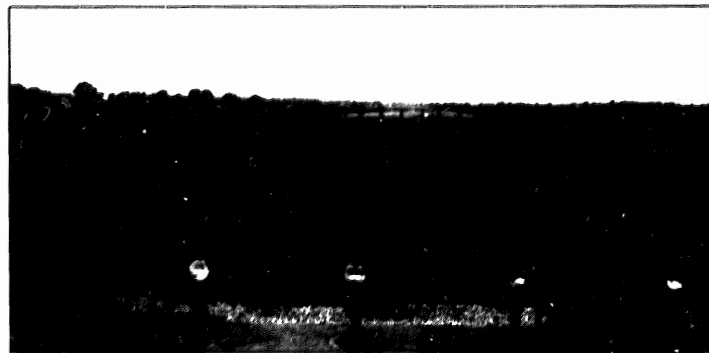


Figure 27: Approach light system near threshold, strobe light in box located in foreground

Some systems include sequenced flashing lights that appear to the pilot as a ball of light traveling towards the runway at high speed (twice a second).

Visual Glideslope Indicators

The angle at which an inbound aircraft approaches the runway is critical to safely landing the aircraft. The ideal point on the runway where the aircraft wheels touch ground is on the touchdown zone located just beyond the threshold. Landing an aircraft at the correct point without assistance from a controller or glide slope lighting system is a difficult task and an unpredictable procedure. If the approach landing angle is too high, there will not be enough runway remaining to accommodate the decelerating aircraft. Conversely, if the approach angle is too low, the aircraft will touch down before the runway threshold and become damaged by intervening obstacles, (trees, lights, fences, etc.). Visual glide slope indicators tell the pilot when the aircraft is on the proper approach angle (not too high and not too low) by a series of light signals that are visible from the air.

There are four types of visual glide slope systems, the Visual Approach Slope Indicator (VASI), the Precision Approach Path Indicator (PAPI), Tri-color systems and the Pulsating system. Of the four types of glide slope lighting systems, the VASI and PAPI are the most common and easiest to identify.

Visual Approach Slope Indicators (VASI)

The VASI is a system of lights arranged to provide visual descent guidance information during the approach to a runway. VASI lights are visible from 3-to-5 miles away during the daylight, and up to 20 miles away at nighttime. The visual glide path that a VASI provides, guarantees safe obstruction clearance to within 10 degrees of the runway centerline and 4NM of the runway threshold. Descent, using the VASI, should not be initiated until the aircraft is visually aligned with

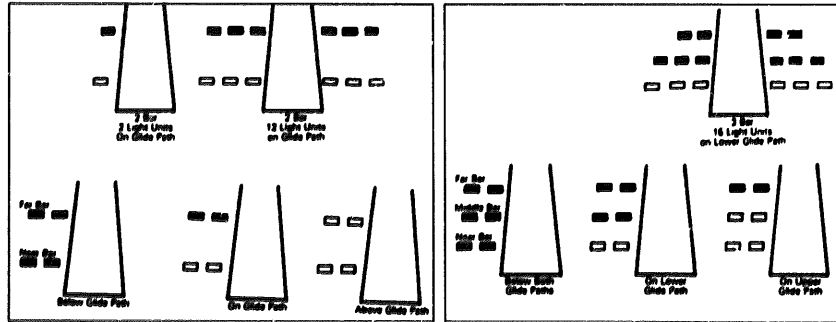


Figure 28: Various configurations of Visual Approach Slope Indicator (VASI) units

the runway. Lateral course guidance is provided by runway markers or runway approach lights.

VASI installations consist of either 2, 4, 6, 12, or 16 lighting units, arranged in bars, (two bar or three bar VASI's). The bars are located on the left side of the runway in the case of 2, 4, or 6 light units, and on both sides of the runway for 12 and 16 light units. The three bar VASI has a near, middle, and far bar, while the two bar VASI system has near and far bars.

The VASI lighting units consist of boxes that project a multi-colored beam of light having a white segment in the upper part of the beam and a red segment in the lower part of the beam. When the aircraft is at too low of an altitude for a given



Figure 29: Visual Approach Slope Indicator (VASI) light units

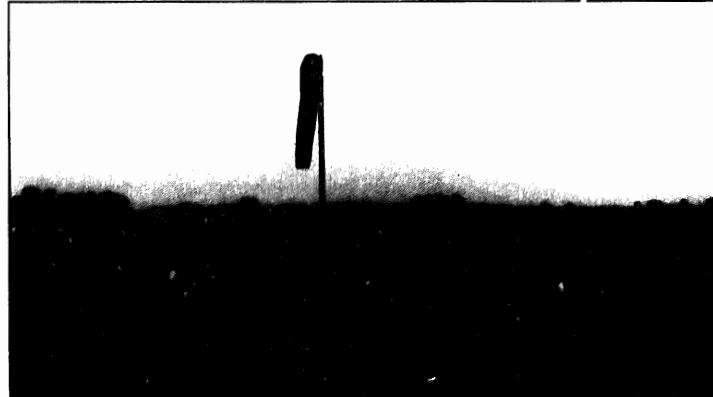


Figure 30: Quarter view of PAPI light units and windsock. The position of the windsock indicates a lack of surface winds or a "zero" wind condition.

range, only the red beam of light will be visible to the pilot. Landing in this situation would cause the aircraft to touch down before reaching the desired landing zone. If the aircraft is too high for a given distance from the touchdown zone, only the white light will be visible to the pilot. In this instance, the aircraft will land way beyond the landing zone and probably miss or roll off the runway. The lighting units are carefully positioned and their angle is periodically checked so that the pilot using the VASI during an approach will always see the correct combination of red and white lights.

Precision Approach Path Indicators (PAPI)

The PAPI uses multi colored beam of light similar to the VASI. Each lighting unit is installed in a single row of either two or four separate lights. The PAPI system has an effective visual range of 5 nautical miles during daylight and up to 20 nautical miles at night. The single row of lighting units is normally installed on the left side of the runway. Each light faces the aircraft at a different angle, when the aircraft is "on slope" the pilot sees two white lights and two red lights.

Tri-Color Systems

Tri-color visual approach slope indicators normally consist of a single light unit projecting a three color (red-below, amber-above, green-on, slope) visual approach path into the final approach area of the runway. These types of indicators have a useful range of

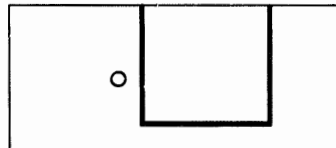


Figure 31: Diagram showing the relative position of the light on either a tri-color or pulsating light system

approximately one-half to one mile during the day and up to five miles at night depending upon visibility conditions.

Pulsating Systems

Pulsating visual approach slope indicators normally consist of a single light unit (located near the runway end) projecting a two color visual approach path into the final approach area of the runway. A below slope approach is indicated by a pulsating red light, above slope is indicated by a pulsating white light and on slope is shown by a steady white light. The useful range of this system is about four miles during the day and up to ten miles at night.

Alignment of Elements Systems

Alignment of Elements Systems are installed on some small general aviation airports. They are a low-cost system, made of plywood panels, painted black and white or fluorescent orange. Some of these systems are lighted for night use. The useful range for these systems is approximately three quarters of a mile. To use the system the pilot positions his aircraft so the elements appear to be in alignment.

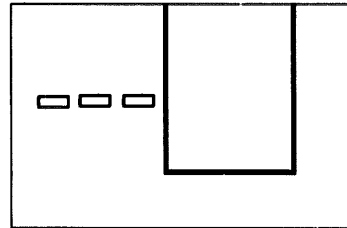


Figure 32: Diagram showing the relative position of the panels in an alignment of elements system

Runway End Identifier Lights (REIL)

Runway End Identifier Lights are installed at many airfields to provide rapid and positive identification of the approach end of a particular runway. The system consists of a pair of synchronized flashing lights located laterally on each side of the runway threshold. REILs may be omnidirectional or unidirectional facing the approach area.

REILs are used for:

1. Identification of a runway surrounded by a preponderance of other lighting.
2. Identification of a runway that lacks contrast with the surrounding terrain.
3. Identification of a runway during periods of reduced visibility.

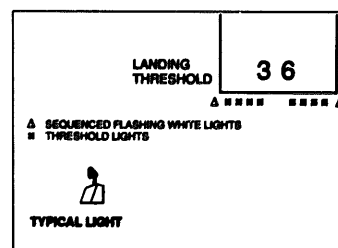


Figure 33: Diagram showing placement of Runway End Indicator Lights (REIL) and threshold lights

Figure 11: Runway overrun and barrier net

An **arresting gear** is a type of barrier system device consisting of an elevated cable connected to reels mounted on both sides of the runway. It is used for the purpose of stopping tail hook and non-tailhook equipped aircraft. A cable is stretched across the runway and is caught by the tail hook or landing gear of the inbound aircraft, as the cable is stretched the energy of the aircraft is reduced thus preventing the aircraft from going beyond the overrun. Arresting gear cable systems are usually located just beyond the designated wheel touchdown zone.

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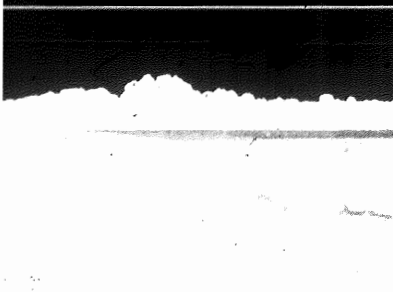


Figure 34: Runway End Identifier Light (REIL) system approach end of an asphalt runway

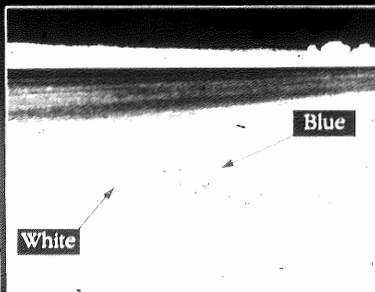


Figure 35: A runway edge light and a taxiway light

Runway Edge Light Systems

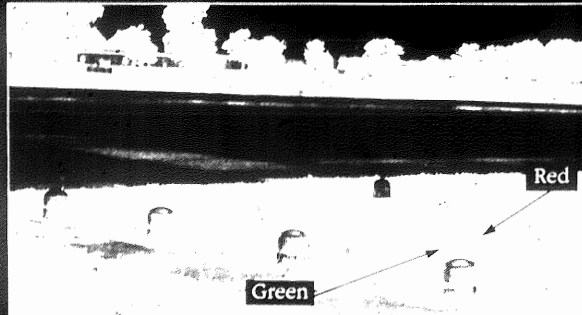
Runway edge lights are used to outline the edges of runways during periods of darkness or restricted visibility. Runway edge lights are white, except on instrument runways where amber lights indicate the last 2000 feet of the runway or the last half of the runway thus forming a caution zone for landings. Taxiway edges are marked by blue edge light fixtures.

Threshold Lights

Threshold lights marking the runway ends emit a two colored directional beam which is used to distinguish the runway threshold from the runway end. The red portion of the beam faces inward, indicating the runway end to a departing aircraft, a green light facing outward from the runway indicates the threshold end for inbound aircraft. Runway edge lights and threshold lights are usually 12 to 18 inches tall.



Figure 36: Threshold Lights



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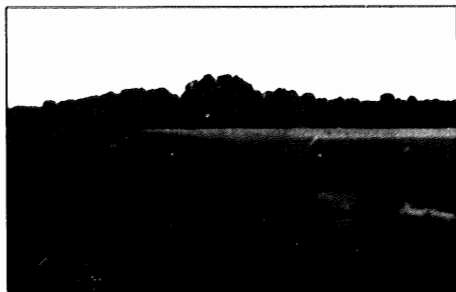


Figure 34: Runway End Identifier Light (REIL) system on the approach end of an asphalt runway

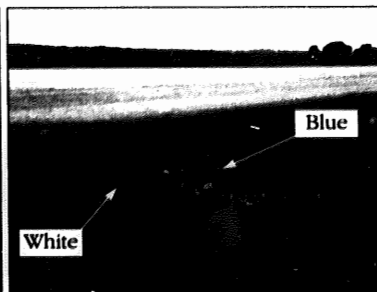


Figure 35: A runway edge light and a taxiway light

Runway Edge Light Systems

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Figure 36: Threshold Lights



In-Runway Lighting

Touchdown zone and centerline lights are installed on some precision approach runways to facilitate landing in adverse visibility conditions. Taxiway turnoff lights may be added to expedite movement of aircraft from the runway. The lights are flush mounted at or below the runway surface and are seldom detectable unless viewed from above in low light conditions.

Threshold Lights Touchdown Zone Lighting (TDZL) consists of two rows of transverse light bars disposed symmetrically about the runway centerline in the runway touchdown zone. The system starts 100 feet beyond the landing threshold and extends to 3000 feet from the threshold or to the midpoint of the runway, whichever is the lesser.

Runway Centerline Lighting Systems (RCLS) consist of flush mounted centerline lights spaced at 50 foot intervals beginning 75 feet from the landing threshold and extending to within 75 feet of the opposite end of the runway.

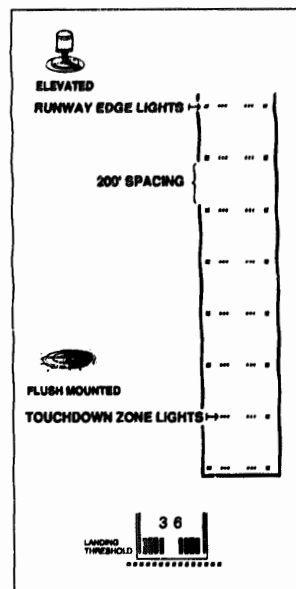


Figure 37: Touchdown zone lights and runway edge lights

Taxiways

Although there are different types of taxiways, the main purpose of a taxiway is to provide a dedicated surface for the orderly movement of aircraft to and from the runway. Taxiways are paved with as many types of surface materials as are runways, however taxiways are not always paved with the same material as the runway they serve. The width of the taxiway is considerably more narrow than the runway (usually just wide enough to allow the landing gear to roll on pavement), and the overall thickness of the pavement is thinner than the runway. Taxiways are marked differently than runways, but in some instances they are mistaken for the runway itself. There are five primary taxiway types: parallel, loop, perimeter, dispersal, and link.

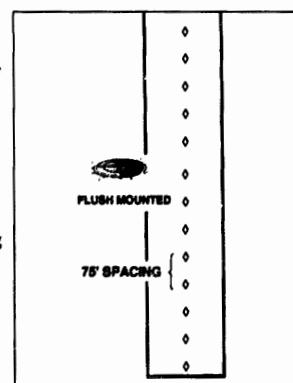


Figure 38: Runway centerline lights

Parallel Taxiways

As the name implies, the parallel taxiway is oriented along the same axis as the runway. This taxiway permits aircraft roll to the appropriate end of the runway (for take off or exiting runway), without obstructing the runway.

Parallel taxiways are sometimes mistakenly identified as parallel runways because of their similar orientation. To reduce the frequency of this common mistake, the analyst should remember that taxiways are more narrow than runways, and they lack approach markings and approach lights. Parallel taxiways are connected to the runway by link taxiways located at both runway ends, and at selected points along the length of the runway.

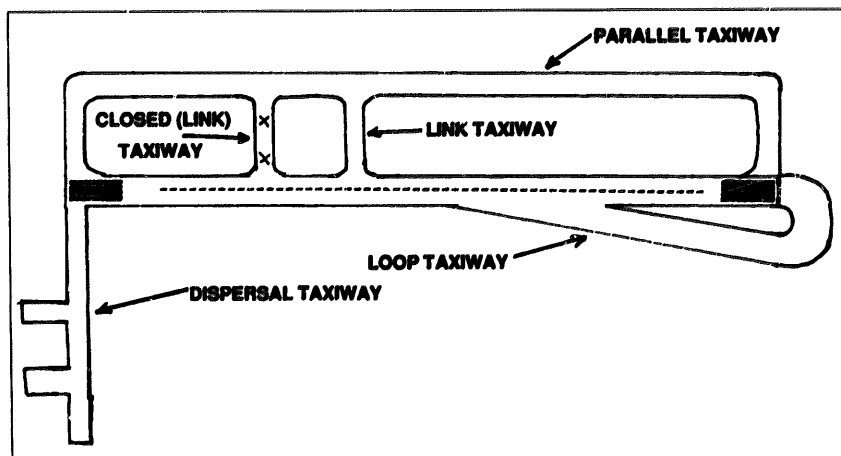


Figure 39: Diagram of a small airfield showing the relationship of the various types of taxiways

Link Taxiways

Link taxiways, (also called connecting links) are used to connect runways, parking facilities and other taxiways. Link taxiways have the same marking, lighting, measurement and pavement types as do all other taxiways.

Loop Taxiway

Loop taxiways are located at one or both ends of the runway, and look just as the name describes. The turning loop allows aircraft to taxi to the runway end, and turn around into the wind before take off. When landing, aircraft roll to the runway end, enter the loop taxiway, then follow the taxiway across the runway or to a parking area.

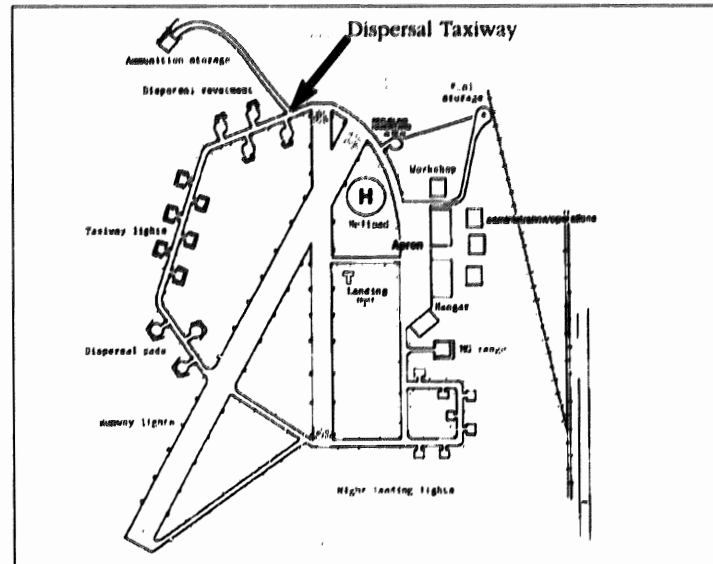


Figure 40: Diagram of a larger military airfield showing the relation between the taxiways, runways and other facilities.

Perimeter Taxiway

The perimeter taxiway connects the runway with maintenance, cargo, munitions, parking, and passenger areas on non-consolidated airfields that have service facilities spread over a large area. Because this taxiway is not located in the immediate vicinity of the runway and does not always follow a straight line, it is sometimes mistaken for a service road. Perimeter taxiways are wider than service roads and do not connect with main thoroughfares.

Dispersal Taxiways

The dispersal taxiway is only found on military airfields, it provides quick access to the end of the runway for departing aircraft and connects the runway to dispersal parking areas where alert aircraft are normally parked. Dispersal taxiways can be straight or curved, with numerous links connecting dispersal parking areas with the taxiway. Dispersal areas are located at one or both runway ends.

Taxiway Markings

Taxiway centerlines are marked with a painted, continuous yellow line. Taxiway edges are marked with a continuous double line that is separated by six inches.

Holding Lines

Holding lines are found on taxiways, and are used to indicate where aircraft should stop and wait before entering an active runway. They serve a similar purpose as the white lines found at automotive traffic light crossings. Holding lines are placed a sufficient distance from the runway edge to prevent inbound landing aircraft from making physical contact with waiting outbound aircraft.

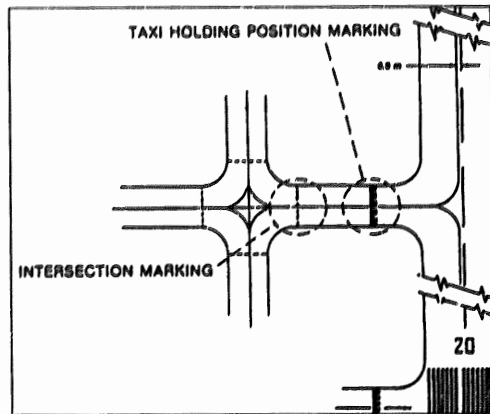


Figure 41: Taxiway markings

Taxiway Lighting

Taxiway edge lights are used to outline the edges of taxiways and are illuminated during periods of darkness or restricted visibility conditions. These fixtures emit blue light.

Taxiway centerline lights are used to facilitate ground traffic under low visibility conditions. The flush mounted lights are steady burning lights that emit a diffused green light.



Figure 42: Elevated Taxiway lights

Aircraft Parking Areas

Aircraft parking areas are connected to the runway by taxiways. There are two types of aircraft parking areas, the apron and the hardstand. Each type provides a stable area for aircraft to park while involved in a variety of non-flying functions such as fueling, cargo/passenger services, maintenance, etc. The function or specific activity performed at a parking area is described in its name. The parking area name describes the appearance or functional design of the aircraft parking site.

Apron Parking Areas

Apron parking areas are associated with both military and civilian airfields. They are rectangular or square shaped areas, and are paved with a wide variety of surface materials. The paving material selected will vary depending upon the climate, the amount of traffic, the wheel load weight of the aircraft using the airfield, the size of the parking area and the specific type of surface material. Apron parking areas are subdivided into nine different types, named for the design or function performed at each apron. They are: general field parking, alert, operational, hangar, base flight, pad, transient, depot and stub aprons.

General Field Parking

This type of facility consists of a natural surface area (usually sod) for parking aircraft safely away from the operational areas at the airfield. Field parking areas are not easily identified; at their worst they closely resemble grass areas found on the surrounding airfield. Fortunately there are a few subtle signatures at some field parking areas that will aid in their identification.

Designated parking spaces, visual tie down points and grounding rods are sometimes present at field parking areas. The spaces are defined by the average wing tip to wing tip length of the aircraft that use the airfield. Each space is separated

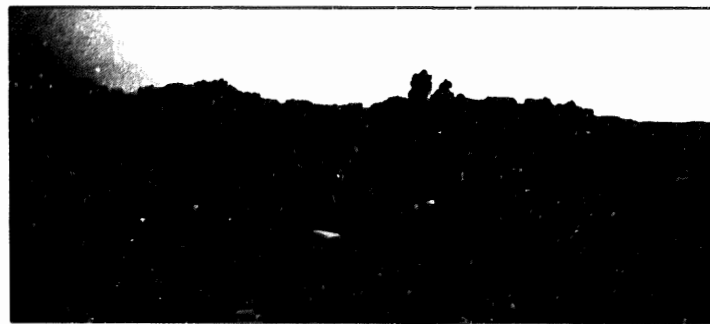


Figure 43: General field parking (grass surface) with aircraft tie downs

by enough distance to prevent damage to other aircraft when an aircraft is moved in or out of a parking space. At field parking, aircraft parking spaces are sometimes outlined with used aircraft tires that have been painted white. The tires are placed on the ground at regular intervals to define the appropriate tie down points.

At air shows or large deployments of a temporary nature, the perimeter and entrances of field parking areas are often defined as rectangular areas and are delineated by surveyors tape or lime powdered lines. Parking spaces in these areas are not defined, each aircraft is parked next to the other.

A method of identifying general field parking areas is by comparing the height of the grass at the airfield. On parking areas and runways the grass is mowed closer to the surface than the grass that covers the non-operational open areas of the airfield. The mowing pattern and smooth texture of the shorter cut grass forms a smooth textured, clean rectangular shape when contrasted against the rough, unmowed background.

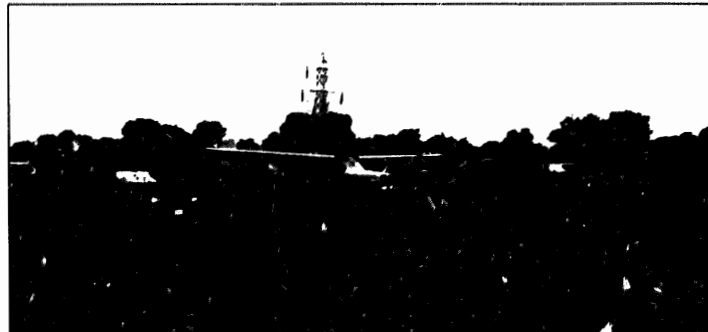


Figure 44: General field parking with aircraft tied down

Identification of taxiways that connect field parking areas with the airstrip can sometimes be made by detecting aircraft tire tracks that have been worn into the turf or surface material. Repeated aircraft crossings and wet conditions increase the tire tracks in the taxiway and field parking area.

In the absence of the above mentioned indicators, field parking areas cannot be distinguished from open grass areas.

Alert Aprons

Alert Aprons exist to provide a separate parking area for military combat aircraft. Alert aircraft are continuously kept loaded and ready for combat with aircrews on twenty four hour standby, to fly the aircraft in the event of war. The general appearance of the alert apron is vastly different from other parking aprons.

Alert aprons are located near the runway ends and are surrounded by a cleared area with security fencing. They are usually occupied with combat aircraft parked in a well dispersed, sequential manner and are served by a single taxiway. The presence of an alert bunker or ready room for the aircrews is a characteristic of the alert apron.

Fully loaded alert aircraft remain parked for long periods of time in the same location on the alert apron, thus resulting in continuous stress on the apron pavement. This type of wear and tear can only be sustained by the application of a paving material that remains stable under load, during wet weather or high temperatures. The two most commonly used paving materials for alert aprons are cement and pierced steel planking.

Apron floodlights are used to illuminate alert aprons and their security fence lined perimeter.

Operational Apron

The operational apron is the most commonly found apron type. Its only distinct identifying characteristic is the presence of rows of parked aircraft. The operational apron is used to temporarily park aircraft that are not engaged in any activity. Operational aprons are paved with all types of paving materials, or may have non-paved natural surfaces. They are well illuminated by apron floodlighting and are usually served by more than one taxiway.

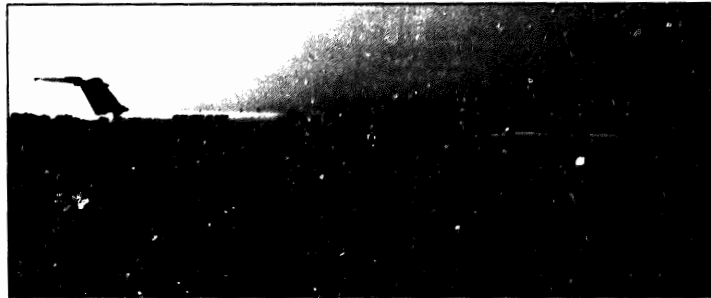


Figure 45: An operational apron at a major military airfield

Hangar Apron

The parking area located immediately before a hangar door opening is the hangar apron. This type of apron serves as a temporary parking area to store aircraft that have completed or are awaiting servicing/storage in the hangar. The hangar apron is usually illuminated by hangar floodlights. Entry stripes are marked on the apron to enable the aircraft pilot to safely enter or exit the hangar with adequate clearance.

Figure 25: Approach Lighting System as viewed when facing oncoming aircraft.

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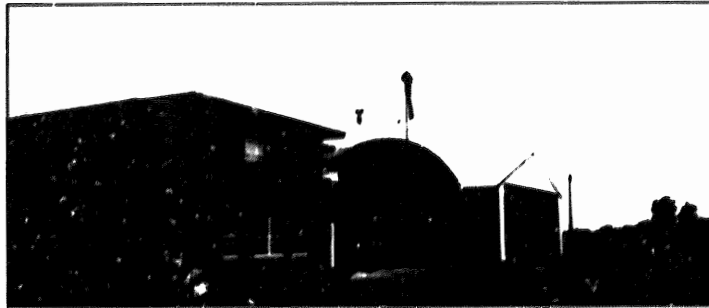


Figure 46: Hangar apron in front of two single bay hangars

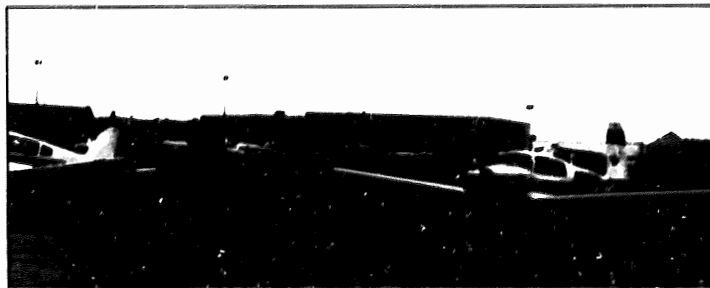


Figure 47: Base flight apron

Base Flight Apron

The base flight apron is the apron with the most activity at the airfield. Incoming and departing flights stop there to transfer passengers and cargo. Aircraft on this apron will usually occupy the area for a very brief time. Multiple taxiways serve this apron and apron floodlighting is always present. The paving surfaces for this apron are usually made of cement or pierced steel planking, however exceptions to this are found at less improved airfields.

Transient Apron

Transient aprons are similar in appearance to other parking aprons. Located away from the main activity area of the airfield, they are occupied by aircraft that are not permanently home-stationed at the airfield. Aircraft refueling is usually accomplished by trucks on this apron and security services are provided when necessary. At military airfields, the transient apron may contain aircraft types that are noticeably different from the majority of the aircraft normally found there. This is the best signature for determining the presence of a transient apron.

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Figure 4B: Military aircraft refueling at a transient apron

Pad Apron

A pad apron is a simple apron that is not associated with any structures. It is alone and not connected to the runway by a taxiway. The pad apron can be used for a wide variety of activities and is only identified by the absence of any adjacent structures. The surface materials used to pave a pad apron cover the whole range. Apron lighting on pad aprons is not essential.

Depot Aprons

Depot aprons are co-located with cargo handling facilities. The presence of specialized off-loading equipment, warehouses, and delivery trucks are the primary features that differentiate the depot apron from other parking aprons. Because most cargo flights arrive and depart at nighttime, the presence of apron flood-lighting to assist the transshipment of cargo is a necessity. Compared to passenger terminals, depots have noticeably less civilian vehicle parking.

Stub Apron

The stub apron is a parking apron that is directly attached to the runway without the benefit of a taxiway. Stub aprons can be found along the edge of the runway or on either end of the runway just beyond the threshold. Stub aprons are used for a variety of purposes, and they provide a safe place to exit the runway when another plane is coming in for a landing.

Hardstand Aircraft Parking

Hardstands are improved parking areas that are found predominantly on military airfields. The presence of a parking hardstand at a civilian facility is very rare.

Hardstands are built to provide parking areas for military aircraft. Each hard-stand is separated from the other by an interval that is large enough to prevent an explosion in one from damaging aircraft parked in adjacent hardstands.

Hardstands are used for many specific types of aircraft activities and purposes.

There are ten types of hardstands to accommodate the various uses: alert, dispersal, pad, refueling, parking, operational, engine run-up, firing-in, compass rose and maintenance hardstands.

Finding an observable difference between the many hardstand types is sometimes difficult. The location, cleanliness, security, and quantity of hardstands provide clues to their specific use, thus giving the analyst enough information to classify them by type. Hardstand parking areas look much different from parking aprons. In general, the hardstand can best be described as a round or square asphalt or cement pad, connected to a runway or taxiway. From above they appear to have the same shape as an antique keyhole or a cul-de-sac street.

Hardstands can be built to accommodate all types of aircraft from large to small depending upon the size that is required. Although they are normally occupied by one aircraft, some have enough space to park two aircraft side by side. The materials commonly used to pave the hardstand parking pad are concrete, pierced steel planking (PSP), membrane, and occasionally asphalt over concrete.

Dispersal Hardstands

Dispersal hardstands provide separate parking spaces for military aircraft. They are separated by a distance great enough to prevent neighboring aircraft from sustaining damage due to fire and explosion in another. Dispersal hardstand parking areas were designed as a response to the lessons learned from the damage that was inflicted upon aircraft parked wing tip-to-wing tip at Hickham Airfield, (Pearl Harbor, Hawaii) in 1941.

Dispersal hardstands are located away from the runway, and are connected to the runway by loop taxiways. Loop taxiways permit aircraft to enter and exit the dispersal area without having to back up and turn around at a dead end. Entry/exit taxiways for dispersal hardstand parking areas are located off the runway ends, and at various points along the length of the runway.

Alert Hardstands

With only a few exceptions, alert hardstands have the same general appearance as dispersal hardstand parking areas. These facilities are purposely located at the ends of the runway to provide quick access to the take-off end of the runway for departing aircraft.

Because they contain numerous aircraft that are combat ready (loaded with conventional or nuclear ordnance), security measures at alert facilities are more restrictive than at dispersal hardstand areas. Multiple rows of security fences, lighting, guard towers and control points regulating the passage of aircraft and vehicles are all characteristics of the alert facility. Shelter for the ever-present alert aircrews and ground support personnel, is provided by an alert building or bunker.

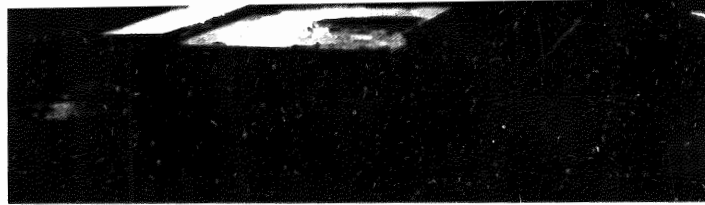


Figure 29: Visual Approach Slope Indicator (VASI) light units

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Taxiways serving the alert facility are predominantly of the loop type, and are not excessively long, thus minimizing the distance from hardstand to runway end.

The presence of aircraft at an alert facility is not a necessity for accurate identification of an alert hardstand area to be made. During an aircraft alert exercise it is common for all alert aircraft to depart the facility. Most of the time an operational alert facility is occupied by many aircraft, thus there will be many hardstands.

Operational Hardstands and Parking Hardstands

Operational hardstands and parking hardstands both serve as places to park aircraft and have nearly identical appearances. The only difference between them is distinguished by their location relative to other structures at the airfield. Usually only one or two of these hardstands exist at an airfield.

Operational hardstands

Operational hardstands provide temporary parking for single aircraft that regularly arrive at the airfield. They are usually located near hangars and cargo/passenger terminals.

Unlike dispersal hardstands, these hardstands are either connected to the runway by link taxiways, or are branches off other taxiways or parking aprons.

Parking hardstands

Parking hardstands are located away from other aprons, hangars, and similar high use areas at the airfield. Small groups of parking hardstands are used for temporarily parking single resident and non-resident aircraft.

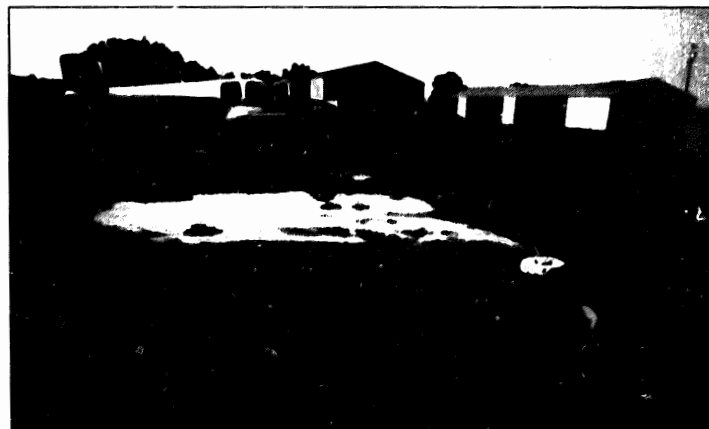


Figure 49: Parking hardstand on edge of apron (poorly maintained)

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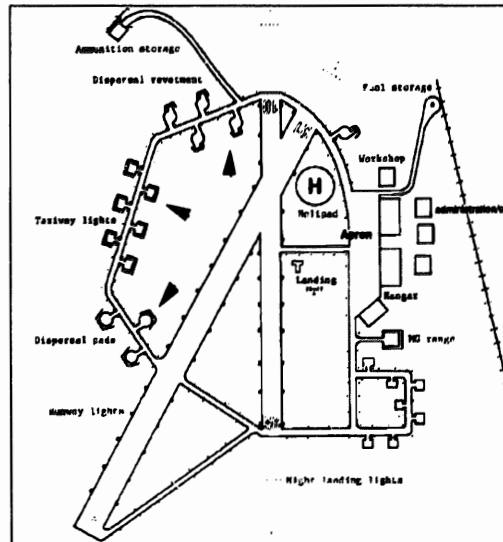


Figure 50: Diagram of a military airfield showing the location of dispersal hardstands.

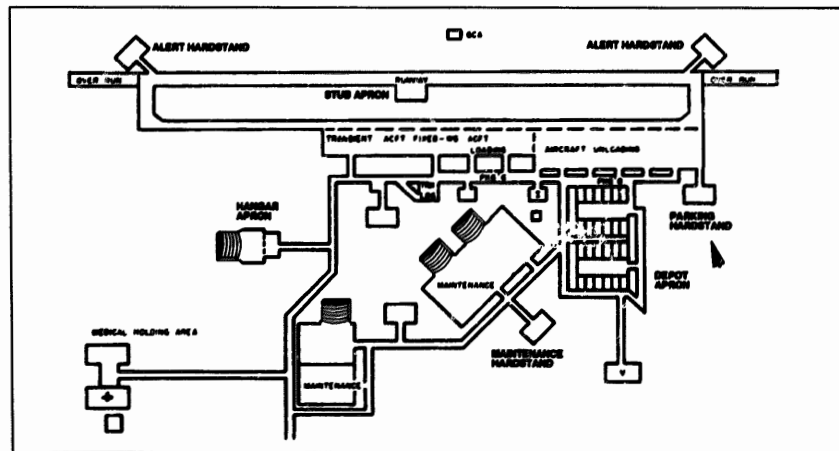


Figure 51: Diagram of a military airfield showing the location of various types of hardstands.

Engine Run-up Hardstands

Engine run-up hardstands have several characteristics that make them identifiable. Jet propelled and turbo-prop aircraft engines require occasional preflight stress testing at very high RPM ranges. The amount of exhaust and noise generated is significant enough to be a health and hearing hazard. One of the facilities that was designed to accommodate this activity is the engine run-up hardstand. Hardstands are located and oriented away from populated areas. They are equipped with blast deflectors that direct the resulting exhaust blast and noise up and away from the surrounding area. The engine run-up hardstand is usually located near a parking apron or next to the runway.

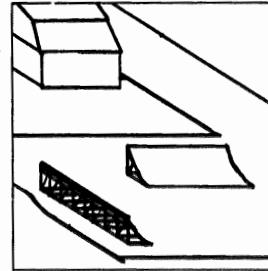


Figure 52: An engine run-up hardstand with blast deflectors

Firing-In Hardstands

Firing-In Hardstands are constructed at military airfields only. The sole function of a firing-in hardstand is to provide a parking pad for combat fighter aircraft while having their machine guns or nose cannon zeroed-in and aligned.

The firing-in site is essentially an aircraft parking area at the end of a firing range. When viewed from above, the site is rectangular in shape and consists of a circular parking pad set opposite from a tall and wide earthen-walled target area. Along each side of the range connecting the pad and target area, are two long, tall earthen walls that are separated by a distance equal to the wingspan of the aircraft using the facility.

The arrival of laser gun sighting systems and optical sight devices has all but eliminated the necessity to fire live ammunition at these facilities. Although new sighting-in technology has enabled incredible accuracies to be acquired, the need to sight in on targets while remaining shielded from outside disturbances is a prerequisite that the old sites still satisfy. Thus the need for firing-in hardstands continues.

There is only one firing-in hardstand per airfield, and they are only found at airfields built to support specific types of fighter aircraft.

Compass Rose Hardstands

This type of hardstand is associated with both military and civil airfields, it is one of the easiest hardstands to identify. The compass rose hardstand is used as a reference to calibrate the various compasses on board an aircraft. A compass rose that is subdivided into sections, is laid out and painted on the surface of the parking apron. Aircraft are taken to a reference point on the apron where the actual aircraft compass heading is compared to the figure inscribed on the

Figure 36: *Threshold Lights*

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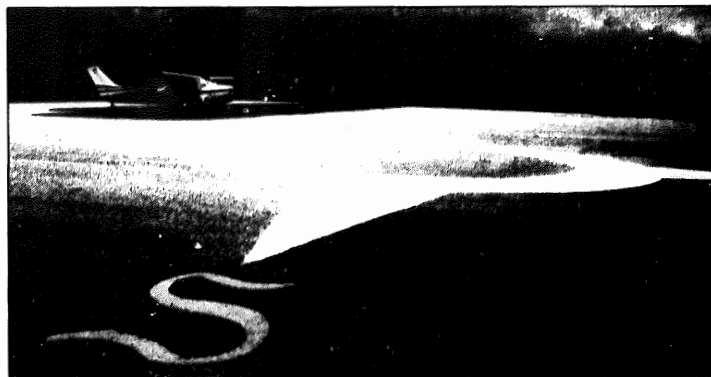


Figure 53: *A compass rose hardstand*

painted compass rose. The process of compass calibration is performed at all four cardinal directions. If minor differences between the aircraft compass reading and the ground truth figures are discovered the variation is noted and allowed, for more serious variations, the compass is replaced or repaired.

Compass rose hardstands are not associated with a specific area or location on the airfield. The only identifying characteristic of this hardstand is the presence of a compass rose painted on the hardstand surface.

Maintenance Hardstands

Various types of aircraft maintenance tasks are performed at the maintenance hardstand. Minor repair work such as fixing hydraulic fluid leaks, avionics box replacement, lubrication, tire replacement, and engine replacement are routinely performed outdoors on the maintenance hardstand. These hardstands are found at military and civilian airfields. At military airfields the maintenance hardstand is generally located within a dispersal hardstand area. When present at civilian facilities, a maintenance hardstand is generally located near an operational apron. The maintenance hardstand is characterized by the presence of special purpose vehicles, van-bodied trucks, noise abating equipment, oil stained pavement, environmental shelters and portable lighting units.

Refueling Hardstands

The refueling hardstand serves the purpose for which it was named. The primary characteristics that denote this feature are: stained pavement from fuel spills, the presence of fuel pumps or fuel vehicles, and lighting fixtures. At military and civilian airfields, refueling hardstands can be found within dispersal areas, alone near operational aprons, or near the base fuel storage facility.

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Revetted Hardstands

Although all hardstands that provide parking for military aircraft are subject to attack during wartime, the revetted hardstand is a somewhat hardened defensive structure. In order to protect parked aircraft from lateral blast damage, an earthen wall (revetment) is placed around the hardstand parking pad. The revetment surrounding a hardstand parking pad is tall enough to protect all parts of the aircraft from flying debris and shrapnel.

Revetted hardstands are usually found at dispersal and alert hardstand parking areas. To control erosion and aid in concealment, grass is planted on the revetment. When planted, mowed and cared for, revetments blend into the terrain. As a defensive structure, revetments work quite well, their height and varying orientation make them very difficult targets for low altitude attacking aircraft.

A common form of concealment employed at revetted hardstands involves stretching camouflage netting over the top of the revetment. This technique inhibits the ability of low-flying attack aircraft to detect and destroy parked aircraft on the hardstand pad. A common mistake made by analysts is to misidentify the net-covered, revetted hardstand for an aircraft bunker.

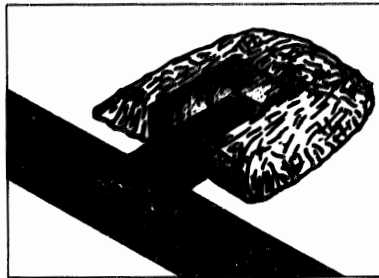


Figure 54: *Revetted hardstand*

Aircraft Bunkers and Hardened Aircraft Shelters

The aircraft bunkers and hardened aircraft shelters are defined as man made, reinforced structures that normally provide environmental shelter for one or more aircraft and provide a degree of protection from attack. These structures are only associated with military aircraft, and are found in dispersal areas and alert facilities. From above, three structural components are visible to the analyst, they are: blast doors, exhaust vents, and the shelter or bunker itself. At some sites multiple sets of blast doors are installed. The outermost set of doors act as a shield to absorb the explosive force of an incoming weapon, thus protecting the actual bunker doors from blast damage and penetration.

Aircraft Bunkers

Aircraft bunker construction begins by erecting a quonset or arch shaped structure (made of prefabricated arch shaped cement and steel segments), over a hardstand parking pad. After assembly of the inner structure and the addition of exhaust vents is completed, blast doors (sliding, hinged, or clamshell type) are installed on the opening of the structure. At this stage of construction the shelter can be considered complete. For airfields with requirements that demand a more

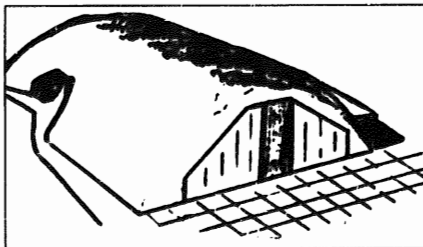


Figure 55: Aircraft bunker

hardened structure, the sides, back and top of the arch-shaped inner structure are covered with a 10 to 15 foot layer of earth. When left uncovered, the structure is referred to as a **hardened aircraft shelter**, when earth covered it becomes an **aircraft bunker**. Aircraft bunkers and hardened aircraft shelters both provide a highly blast resistant shelter for aircraft, and prohibit reconnaissance flights from detecting the number of aircraft present at the facility.

The taxiways leading to the aircraft shelter or bunker, and the blast doors are frequently camouflage painted, as is the surface of the hardened aircraft shelter. Some bunkers have bushes and other types of vegetation intentionally planted on them to make them more difficult to detect.

Occasionally, the blast doors on aircraft shelters are left in the open position to permit aircraft to enter and exit the structure. The ability to see the blast doors or look into the structure is dependent upon the orientation of the bunker entrance and the position of the observer. Dispersal areas and alert facilities are designed so that the entrance of each aircraft shelter/bunker faces a different direction thus making it impossible for an attacking aircraft to have a direct shot at more than one or two shelters per pass.



Figure 56: Side view of an aircraft bunker

Aircraft Shelters

An aircraft shelter is defined as a man-made structure with two or fewer walls, designed to provide overhead protection and concealment for one or two aircraft. Aircraft that are parked in these shelters are protected from small particles of falling debris and they are shielded from the environmental effects of rain, hail, snow, and sunlight. At military installations, concealment from overhead reconnaissance platforms is an on-going threat that is neutralized by parking beneath an aircraft shelter. An aircraft shelter is the airfield equivalent of the automotive carport.

Always built on top of hardstands or aprons, aircraft shelters are usually light-weight metal frame structures, covered by gable or flat, corrugated metal roofs. Other variations consist of arch or semi-hexagonal shaped structures made from prefabricated components.

An extra measure of blast protection can be obtained by adding an earthen, sandbag, or cement revetment around the outer edge of the open sided shelter.



Figure 57: Aircraft shelter (cantilevered roofs)

Aircraft Tunnels and Underground Complexes

Tunnels and underground complexes are the most difficult of all hardened facilities to detect. These facilities are buried completely below the ground, and even the ventilation shafts are sometimes camouflaged. The only way to find this type of structure is to locate the entrance by following all the taxiways and roads that leave the airfield and determine whether they lead to a tunnel opening. Because access to the runway is critical for flight take off, a pathway leading to the tunnel or underground entrance will always be present. The entrances are sometimes made more difficult to find by placement of natural vegetation, intentional concealment by shadowing, camouflage netting, or disruptive painting.

Construction materials used at these sites are reinforced concrete, metal arches, or layers of concrete. Steel blast doors may be built to protect the tunnel openings. When underground facilities are under construction, numerous dump trucks carrying rock and earth tailings can be observed going in and out of the construction site and area.

Underground structures are utilized extensively in Norway, North Korea, Taiwan, China, Switzerland, and Sweden.

Figure 42: *Elevated Taxiway lights*

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Hangars

The aircraft hangar is one of the first structures specifically designed for, and only associated with aviation. Early aircraft hangars were adaptations of existing structures (barns and agricultural buildings) that occupied the farm land where airstrips were first built. At ranches and farms with grass landing strips, modified barns and farm buildings still serve as hangars.

Hangars are associated with all types of fixed wing aircraft and helicopters, and are generally the largest and easiest to identify structures found at the airfield. Some of the largest hangars ever constructed were designed for lighter-than-air aircraft, blimps and airships.

Of the many aeronautical functions performed in hangars, the most common activities are heavy and light maintenance, aircraft storage, airframe assembly and construction, aircraft concealment, and airframe painting. Workshops, machine shops and parts storage/distribution offices occupy space within some aircraft hangars and usually take the form of shed type structures or appendages connected to the side of the main hangar structure.

Design Variations

Some aircraft hangar architects created designs that radically departed from the usual aircraft hangar. In recent years, folding quonset-shaped aircraft hangars for small aircraft have appeared. They are covered with waterproof, opaque fabric and have an appearance similar to inflatable gymnasium structures. The outer covering is made of waterproof fabric that is suspended by a rigid inner framework. Entrance into the hangar is accomplished by raising or lowering a semi-spherical, hinged flap type door located on either end of the structure.

Other unusual hangar types that may be seen are cylindrical hangars that resemble POL storage tanks. Access to the hangar is accomplished through a set of curved hangar doors mounted on tracks that curve around the side of the hangar.

Construction Material

The most commonly used building materials associated with hangar construction are concrete, masonry, wood, and steel. For strengthening the framework and covering the walls and doors, metal sheeting and masonry are most often selected. Asphalt shingles, metal sheeting, and tar and gravel roofing are the most common materials used for aircraft hangar applications. Hangars usually have arch or gable roofs. Occasionally shallow pitch or flat roofs are chosen for smaller hangars or in areas with little rain or snow.

Figure 4.3: General field parking (grass surface) with aircraft tie downs

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Signatures

The signatures that differentiate aircraft hangars from other structures at an airfield are: large sliding doors, hangar parking aprons, close proximity to the runway, and the presence of aircraft parked nearby. Hangars always have an attached hangar apron with a taxiway connecting to the runway. Hangars are usually the largest structures at an airfield.

Doors

The doors that are used in over 90% of all hangars are of the sliding door type. Sliding doors are mounted on an overhead rail or track that permits the door to slide open parallel to the face of the hangar. To create an opening as wide as the interior of the hangar, the doors must travel a distance equal to the opening. To accomplish this, overhead door rails that extend beyond the front sides of the hangar opening are added to the structure.

Hangar Door extensions are clearly visible when the door is in either position. With the door open, the hangar will appear to have one or two solid ears extending from the face of the hangar. In the closed position the overhead rail and vertical support members are visible and will cast prominent shadows across the ground.

A variation of the external sliding door is the internal sliding door. This door type differs mainly because the overhead rail and extensions are mounted on the interior of the hangar and each door is divided into segments. This type of hangar door assembly allows the door segments to stack upon themselves and occupy a smaller amount of storage space.

A type of door mechanism used on medium to small hangars is the horizontal bi-folding door. This type of door is made from a solid panel that is divided horizontally into two sections of equal size. The counterweighted and hinged upper and lower door sections are mounted on vertical tracks that allow the doors to fold outward and upward. They join and form a single section that is stored in the ceiling above the intended aircraft parking space, on the mounting track. For ventilation and lighting purposes this type of door is sometimes observed in the partially open position, not completely stored in the hangar ceiling. When the door is left in the partially open position and viewed from above, the hangar will appear to have a flat awning extending over the doorway opening.

Hangar Types

As time passed and aircraft designs changed, a wide variety of architectural solutions for aircraft hangar design also emerged. A simple system of hangar design classification was devised to name specific hangar types. Seven types of hangars were identified and named on the basis of their shape, capacity, and location (above or below ground), they are: multi-bay, open end, nose, underground, single bay, double bay, and T-shaped.

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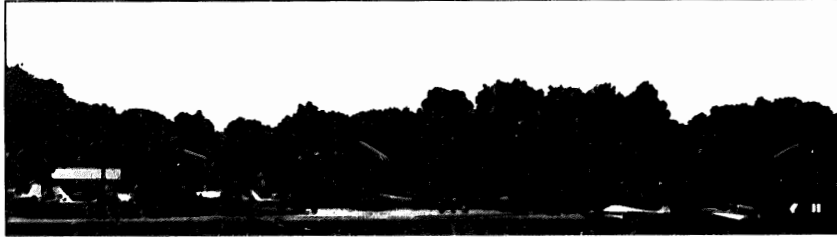


Figure 58: Multi-bay hangars

Multi-Bay Hangars

Multi-Bay Hangars are aircraft hangars that have three or more hangar door openings along the same face of the building, and are covered by a common or separate roof. Hangars with only two aircraft bays are not classified as multi-bay hangars. Each door opening delineates a separate open area or bay that accommodates a single aircraft. When a series of three or more hangars are joined and share common load bearing side walls, they are labeled as “multi-bay” hangars.

Single row multi-bay hangars usually have flat or shed type roofs and are covered with painted steel panels supported by a steel or wood interior framework. Each aircraft bay is joined to the next by an interior load bearing wall that is not visible from outside or above the building. Multi-bay hangars share a common roof, and outer wall covering. This hangar type is characterized by long and narrow proportions, whereas single bay hangars are nearly square in shape.

Multi-bay hangars can also be configured as double row structures. The double row configuration looks similar to the single row multi-bay hangar, however it is a structure formed by two rows of separate hangar bays that are joined side-by-side by load bearing walls, and connected back-to-back. The result is a hangar that opens outward along both long sides, onto two hangar aprons. The double row configuration is usually covered by a shared, low pitched, gable roof that is peaked along the long axis of the structure.

Overall, both configurations of the multi-bay hangar can give the impression of being a large warehouse type of structure, however the presence of one or two hangar aprons, separate hangar bay door openings, and nearby parked or taxiing aircraft reveal it's true identity.

Single Bay Hangars

The single bay hangar represents the most commonly used design for aircraft hangar construction. This hangar type is characterized by having a single door opening on one or both ends of the structure and hangar aprons on either side. The single bay hangar typically has a curved, gable, or flat roof.

Early structural engineers were asked to design a hangar with an open interior floor space, free of vertical support obstructions such as poles and uprights, the resulting effort yielded a hangar with unobstructed floorspace that permitted easy movement and parking of numerous aircraft. The structural engineering methods and solutions used to create these hangars utilized external devices such as buttresses and vertical support columns that are sometimes visible along the outer hangar walls.

The proportions of the average single bay hangar range from equal on both sides to being somewhat longer than wide. Each hangar is sized to fit the aircraft that will be using it, the proportions of wingspan width to fuselage length are close to equal for most non-combat aircraft. The height of single bay hangars varies from one to three stories tall, the only exceptions are blimp hangars that are sometimes as tall as six stories.

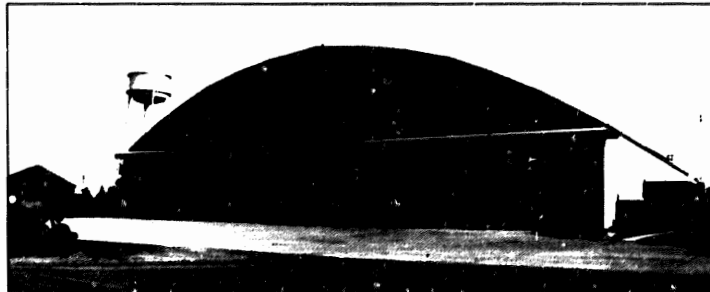


Figure 59: Large single bay hangar with internal sliding doors and arch roof

Double Bay Hangars

The double bay hangar is similar in appearance to the single row multi-bay hangar. Characteristics of the double bay hangar are the presence of two separate aircraft bays, and two separate hangar doors. Construction materials and roof types are the same as used on single bay hangars.

Nose Hangar

The nose hangar is a specially designed structure that provides sheltered parking for the nose portion, fuselage and wings of large aircraft. Most of the nose hangars in existence are modifications of single-bay hangars. When modern cargo and passenger aircraft were introduced to commercial use, their increased length and tail section height exceeded the interior capacity of most existing hangars. An economical solution to this dilemma was to park the nose, fuselage, and wing sections of the aircraft inside the hangar, and modify the hangar door such that when closed it would encircle the fuselage of the aircraft, leaving the tail section exposed to the elements. Fortunately, the portions of modern aircraft that are



Figure 60: Nose hangar

able to fit inside of existing hangars are also the parts of the aircraft that frequently require maintenance.

Positive identification of a nose hangar can be made only under two conditions:

1. When the tail section is visibly jutting out of the hangar,
2. when the hangar is unoccupied, with doors closed, and hangar door cut-out modifications are visible.

T-Shaped Hangar

T-shaped hangars can accommodate one aircraft per hangar, and are usually used to shelter small aircraft. The T shape design conforms to the proportions of the airplane. The narrow leg of the "T" accommodates the tail and fuselage, while the

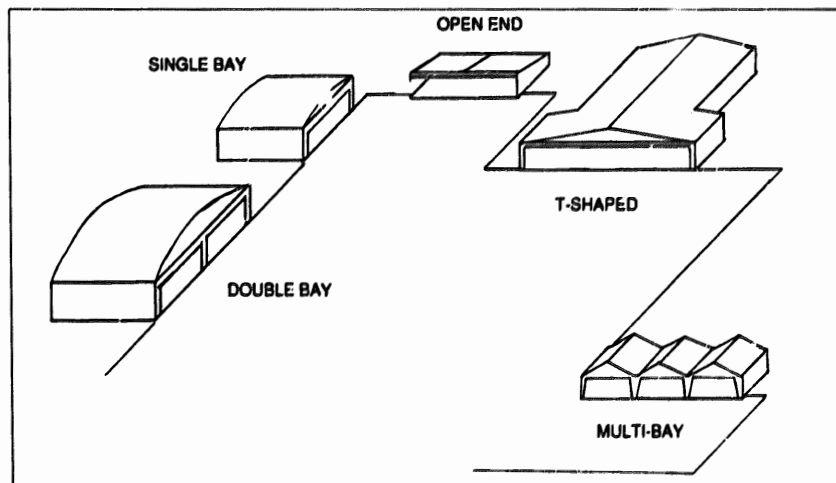


Figure 61: Hangar configurations

upper bar part of the "T" houses the wings and engines. The front of the T-shaped hangar, (the widest side) is where the hangar door is located, thus aircraft entering the hangar must be pushed in tail first. These structures are usually made out of steel sheeting over wooden pole interior frames. The door types associated with this structure are bi-fold, sliding, or outward opening hinge type doors.

The T-shaped hangar is usually a stand alone structure. Occasionally one or more T-shaped hangars are joined resulting in a structure that does not exhibit the characteristic "T-shaped" signature.

Open End Hangar

The open end hangar is characterized by low, long, narrow, rectangular, slanted-roof structures, that are open along one side and have no less than three walls. The open side, or hangar entrance extends along the entire length of the long side of the structure. Entrance to the hangar is made by backing aircraft in through the open side. These hangars are usually associated with small aircraft and provide environmental protection for one to fifteen aircraft.

Open end hangars are usually covered by sheets of steel or wood siding, and have metal roofs that are supported by a wooden pole internal framework. Like all hangars, the open end style is located near the flight line, and will have a parking apron in front of the hangar door opening.

Maintenance Shops and Facilities

Most airfields have facilities where maintenance activities are performed. The number and types of aircraft served at an airfield generally provide an indication of the level of maintenance activity performed there.

Small airfield maintenance facilities

Small airfield maintenance facilities that serve private, non-commercial and non-military aircraft generally have shops that perform routine maintenance activities. Small airfield maintenance shops require only a small amount of space and few,

if any specialized work or storage areas. The activities performed in a small maintenance facility are similar to those performed in neighborhood automotive repair shops. Correspondingly, there are few employees and the amount of floor space occupied is small. Workshop rooms and tool storage closets

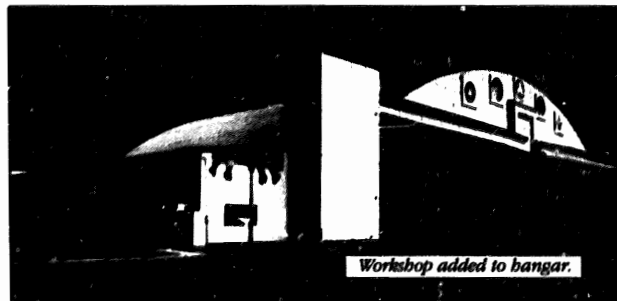


Figure 62: Single bay hangar with added maintenance workshop

are usually incorporated into the interior design of the hangar. Some are connected to the sides of the structure as appendages, wing additions, or sheds.

Medium and large airfield maintenance facilities

Medium and large airfield maintenance facilities that serve commercial or military aircraft have special buildings and storage areas where maintenance activity is performed. The difference between aircraft maintenance activities at medium and large facilities and that which occurs at smaller airfields, lies mainly in the amount of aircraft served and in the greater technical sophistication of the duties performed there. Maintenance of a higher order, such as engine swapping, minor airframe repair, painting, parts inventory and warehousing are a few of the activities that take place at these facilities.

The need to serve greater quantities of customers and larger types of aircraft, creates the requirement to have bigger repair shops with more room to store replacement parts. Military regulations require a certain amount of engine spares and replacement parts to be on hand at all times, (a concept shared by many civil aviation organizations) thus the need for parts warehouses. At most facilities

there is an outdoor storage area for engine containers and crates containing large spare parts. Many specialized vehicles, such as lift equipment, handling vehicles, work platforms, "cherry pickers" etc., are commonly found parked throughout the maintenance facility. Air compressor buildings and high pressure welding gas storage bins are important "small dimension" features found at these facilities.

The presence of aircraft parked on oil stained maintenance aprons, left in various stages of disassembly and/or surrounded by environmental canvas shelters also denotes the aircraft maintenance area. Some hangars are designated as "maintenance hangars" and the maintenance activity is sometimes observed on the apron in front of the hangar.

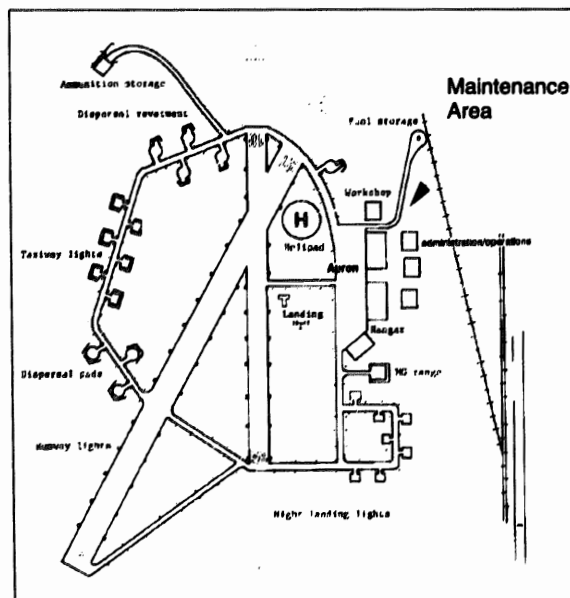


Figure 63: Airfield diagram showing relative location of maintenance facilities

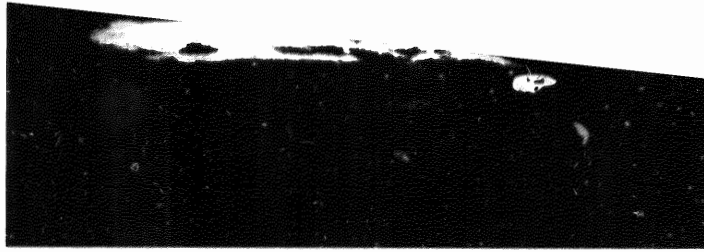


Figure 49: Parking hardstand on edge of apron (poorly maintained)

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Jet Engine Test Cells

Jet engine test cells and maintenance hardstands with blast barriers are usually present in maintenance areas where engine run-up tests are performed. There are several design variations of the engine test cell. Significant features that they share in common are:

1. a covered stand where the aircraft engine is mounted (or the aircraft is parked), and
2. an exhaust tunnel or duct that is connected to a deflector building. The roof of the deflector building is covered with openings that direct the resulting noise and exhaust blast upward and away from the immediate and nearby populated areas.

Another type of engine test cell is the "hush house," it allows the engine to be tested while it is still mounted inside of the aircraft. The hush house serves the same purpose as a test cell, but has a larger building at the cell front. It is served by a taxiway instead of an access road.

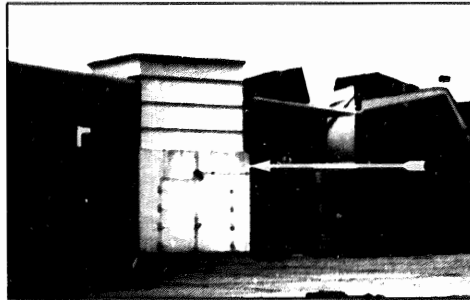


Figure 64: Engine test cell

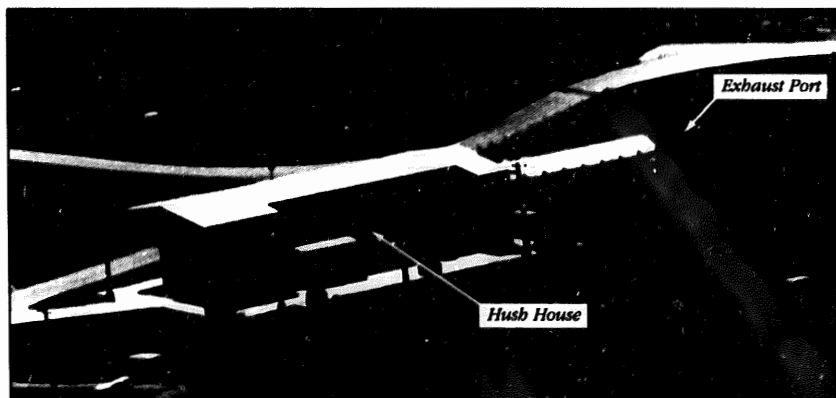


Figure 65: Jet Engine Test Cell

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Cargo and Passenger Handling Facilities

Cargo and passenger handling facilities and their related pieces of equipment constitute important parts of military and civilian airfields. Virtually every airfield, regardless of its size, receives passengers and cargo. At some airfields cargo and passenger facilities sometimes share a common building. Airfields that handle a high volume of cargo deliveries usually have a separate cargo handling area that is located away from the passenger terminal. In either case, it is relatively easy to distinguish the shared from the separated facilities.

Cargo and Air Freight Facilities

The unique characteristics that define cargo and air freight facilities are their location at the airfield, and the cargo handling and transportation vehicles that are associated with them. The cargo shipping and receiving building is a long, narrow single-story structure with a parking apron that is connected to the main runway by a taxiway. One of the long sides of the structure faces the aircraft parking apron and the other is bordered by a loading dock facing the cargo truck parking lot. The facility is road served with access to main highways. The overall appearance of the structure resembles a warehouse. The cargo that is handled in an airfield cargo facility is being transshipped and is only stored there for a short period of time.

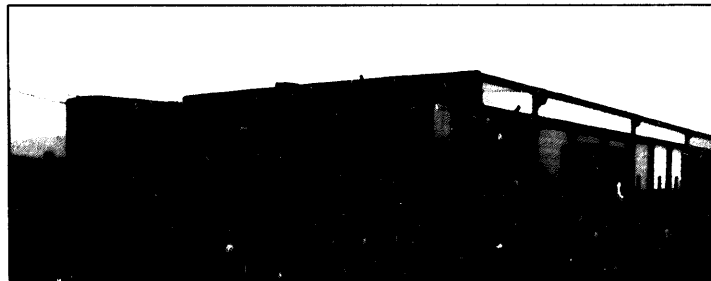


Figure 66: Cargo handling facility

On the airstrip side of the cargo handling facility, the parking apron is illuminated by apron floodlights, and is occupied by various handling vehicles such as forklifts, tow motors and trailers. Aircraft being loaded/unloaded are not always present on the cargo parking apron when it is observed. When not actively engaged in loading cargo aircraft, the transfer vehicles and handling equipment are usually parked on the apron's edge or inside of the warehouse structure.

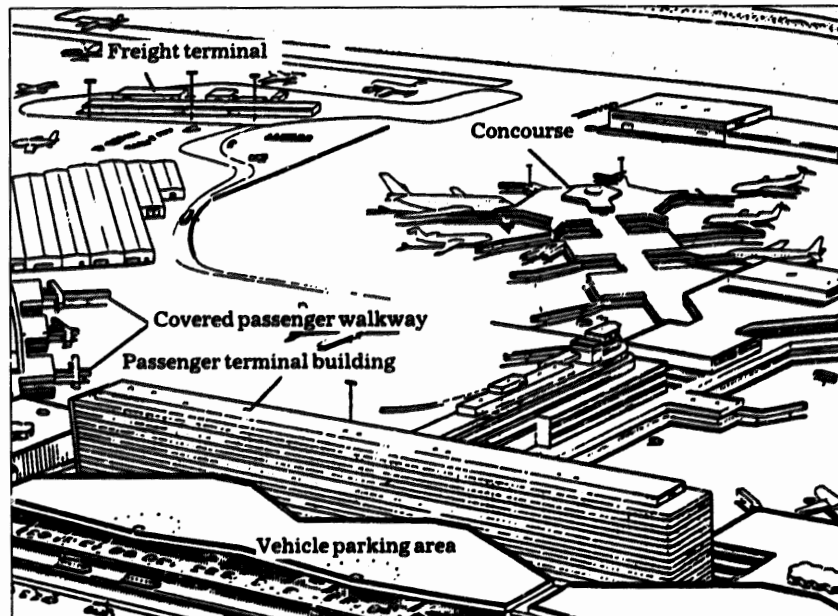


Figure 67: Diagram of a major civil airfield, showing passenger and freight terminals.

Passenger Facilities

Passenger facilities are characterized by passenger ramps leading to the aircraft, passenger handling vehicles, baggage handling trolleys, long and short term parking garages/lots, and the airport terminal building. Although activities such as cargo handling and passenger transfer take place at all airfields (regardless of their size), not every airfield has recognizable passenger facilities and equipment.

Passenger facilities at large and medium airfields have passenger ramps or "air stairs" that enable people to easily walk into the aircraft without having to climb ladders or negotiate other inconvenient devices. Baggage loading and unloading schemes at airfields range from complex to relatively simple. Two items that each unloading scheme has in common are baggage trolleys and conveyor belt vehicles. While in use, passenger access ramps and baggage transfer equipment are parked near the aircraft, otherwise the ramps are retracted and the equipment parked out of the way.

Terminal buildings at large airfields are usually the most conspicuous structure found at the facility. The airfield terminal is usually crowded with aircraft due to

the arrival, departure, and movement of passenger aircraft on the terminal parking apron. Large capacity automotive parking lots, parking garages, and road/rail access, are features that make the terminal building at a large airfield easy to identify.

At medium and small airfields, the passenger terminal is far less spectacular than those found at larger airports. Small airport terminal buildings sometimes share floorspace with other offices and functions at the airfield, thus the building may be larger than expected.

The identifying characteristics of most small and medium airfield terminal buildings are:

1. an awning covered walkway leading to the aircraft parking apron with mobile air stairs serving the passenger aircraft.
2. small automobile parking lots with a loop drive way for taxi or bus passenger pickup.
3. a single baggage trolley and
4. a small illuminated passenger aircraft parking apron.

Passenger terminal facilities at smaller airfields are much more difficult to identify because of their lack of easily defined characteristics. In such cases, the presence of automobiles parked in a lot near a roofed structure and the presence of a nearby patio or smoking gazebo may be the only clues to the presence of a passenger terminal.



Figure 68: Passenger terminal and operations building at a small airfield.



Figure 69: Passenger terminal at a military airfield, note the covered walkway to the parking apron.

Heliports

Heliports are airfield facilities that are exclusively used for helicopter operations and are most often associated with military rotary wing aircraft. Some heliports are part of an existing airfield and share the airspace with fixed wing aircraft, while other heliports are specifically designed for helicopter use.

The Federal Aviation administration defines a heliport as: An area of land, water or a structure used or intended to be used for the landing and takeoff of helicopters and including any buildings or facilities.

There are two categories of military heliports, temporary facilities that serve forward deployed military helicopters in wartime, and permanent facilities that are constructed to support military helicopters in garrison.

At airfield facilities that handle both rotary wing (helicopters) and fixed wing aircraft, the helicopter parking and landing area is always separate from the rest of the airfield.

Helicopters do not need runways or taxiways to take off and land, however to maintain order and safe aircraft movement at the airfield, they follow the same traffic rules and procedures as fixed wing aircraft. Except for a few minor differences in appearance, a heliport has the same features found at fixed wing aircraft airfields. The feature that is most noticeably different in appearance at a heliport is the helicopter runway. Compared to fixed wing aircraft runways, the heliport runway is very wide and short. Because very little or no runway length is needed for helicopters to initiate a rolling start take off, the long runways needed for fixed wing aircraft are not necessary.

Helipads are small designated landing and parking areas for helicopters. Helipads usually have a prepared surface and are found in groups at heliports, and airports, or alone at various locations such as hospitals, police departments, office buildings and in military complexes. Worldwide, helipads are marked with several different symbols, however the most common marking is a large letter "H" that indicates the center of the landing pad.

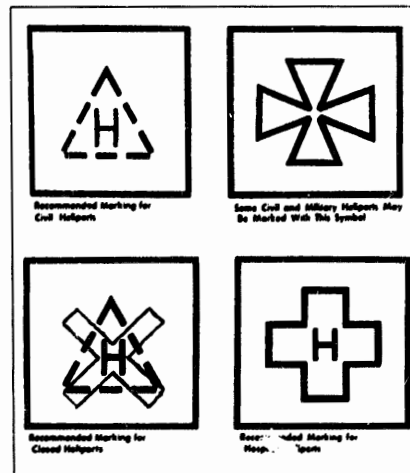


Figure 70: Helicopter pad markings

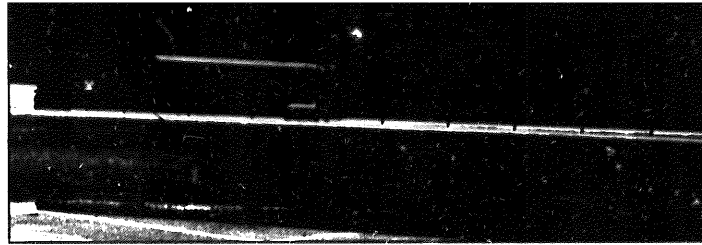


Figure 56: Side view of an aircraft bunker

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Air Operations and Flight Control Facilities

The flying and supporting activities of an airfield are directed and coordinated from the operations building and control tower. These functions may be located together or separately in permanent structures, or in vans and trailers at small or temporary airfields.

Air Operations Buildings

Air operations buildings are usually located on the perimeter of the landing area, often along the parking apron. The building is likely to be small or medium-sized in comparison to the surrounding hangars and shops. At civilian airfields the management and air operations functions are usually conducted in one building referred to as the terminal building. At military airfields the operations building houses the pre-flight briefing room, weather office, flight planning publications room and aircrew lounge. The size and variety of services offered at either a civil or military facility will depend upon the amount and type of air traffic using the airfield.

Control Towers

Control towers frequently sit atop the operations building, along with radio masts, radar antennas, windsocks, and weather measuring equipment. Some control towers are stand alone structures that are set away from the operations building.

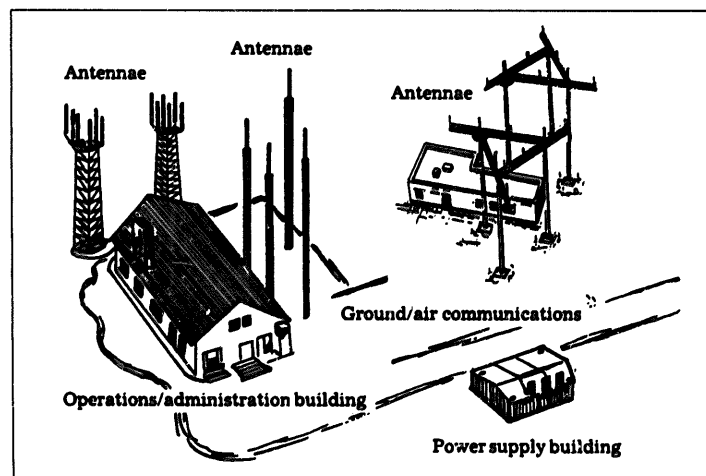


Figure 71: Air operations building and associated communications equipment

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Of the many functions performed by personnel in the control tower, their primary duties and responsibilities are:

1. Monitor, observe and direct air traffic on the ground to the appropriate runway or parking area.
2. Regulate use of the runways by inbound and outbound aircraft.
3. Ensure that aircraft are separated by sufficient distance to maintain safety.
4. Report runway and weather conditions to aircraft.

Airport control towers are normally metal or cement structures and are tall enough to observe all parts of the airfield where aircraft movement occurs. At air facilities that are spread out over a large area, auxiliary control towers are sometimes utilized to ensure that all aircraft movement areas are monitored and controlled.

Airport (Rotating) Beacons

The airport beacon is usually tower mounted, or installed upon the highest structure near the runway. The rotating beacon sends a color light signal that is visible up to 10 degrees above the horizon. It is used to indicate the

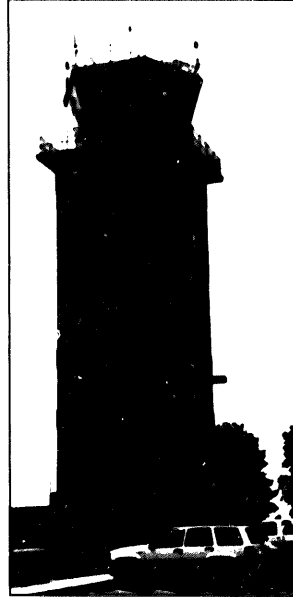


Figure 72: An airfield control tower at a military facility looks no different than one at a civilian airfield.

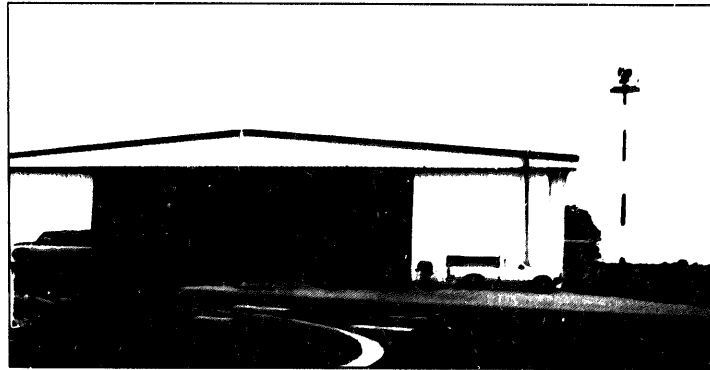
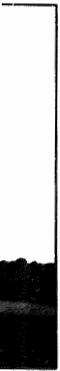


Figure 73: A rotating beacon located near a hangar at a civilian air facility



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Course

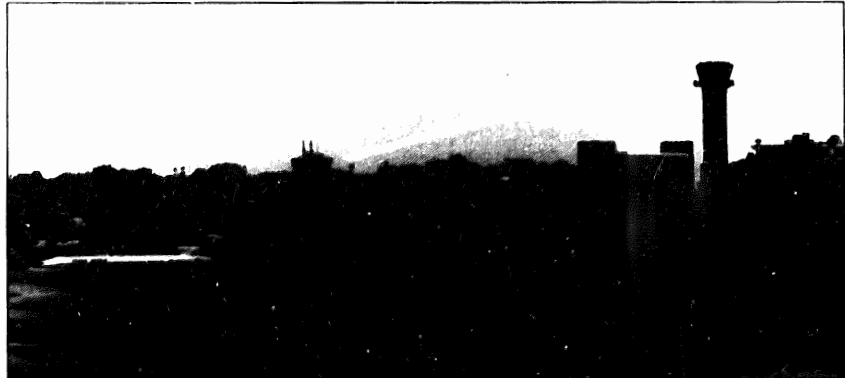


Figure 74: A joint use air facility with two control towers. Often several control towers will be used at large airfields or at joint airfields where ground operations/movement cannot be observed by one tower. A Surface Detection Radar unit is sometimes installed on top of the control tower and will appear as a large white dome.

presence and type of airport at that location. The beacon may be an omnidirectional flashing light or it may rotate at a constant speed that produces the visual effect of flashes at regular intervals.

Inland Waterways

Transportation by boat, barge or ship was man's first method of moving large quantities of people or supplies over long distances. Although roads and railways have largely supplanted ships for inland transportation, boats and barges are still widely used for transportation of bulk materials such as grain, coal and other non-perishable items. Although not as fast as other methods of transportation, shipping is still the least expensive.

Most inland water transportation is done by barges. There are two types of barges, the powered barges commonly used in Europe, and the unpowered barges (dumb barges) used in North America. In other parts of the world, one or both types may be used, in combination with various types of locally built boats. All are designed for use on inland waterways, where width and depth restrictions preclude the use of ocean-going craft.

Canals

Even with their narrow **beam** (width) and shallow **draft** (depth of hull below the waterline), barges require a minimum width of channel and depth of water in order to move freely. In addition the channel must be free of obstructions (rocks,

rapids, sandbars, tree stumps, etc.) and must have no sharp changes in course. In addition, the gradient of the waterway must be low, or the velocity of the current would preclude upstream movement, and make downstream movement hazardous. Only in the largest of natural waterways are these conditions met. Even in these, it is frequently necessary to dredge and clean the main channels to keep them clear for navigation.

Smaller waterways often require substantial modification to make them navigable. The course may be modified by straightening and rounding of curves. Shallow reaches may be dredged, or the depth of water may be increased using a combination of levees, dams and dredging. In areas with seasonal fluctuations in water level, additional modifications are needed to insure adequate water depth during the dry season. The greater the extent of the modifications, the less the **channelized river** resembles a natural watercourse. In some cases, difficult areas are bypassed entirely by construction of a short canal.



Figure 1: A channelized river

Sometimes it is necessary to dig an artificial watercourse to connect two navigable waterbodies. These **canals** enhance the movement of materials by providing access to a greater area without the need to transship cargo. Canals can also be found cutting across a large meander in a river to shorten the traveling distance.

Note: The term canal has been used to denote several types of artificial or modified waterways, including those used for irrigation or drainage. For this discussion, a canal is a watercourse expressly built or modified to accommodate shipping.

Because of the requirement for a low, even gradient, canals are almost exclusively found in areas of smooth, level terrain, such as coastal plains, deltas and marshes, and along river valleys in areas of higher relief. The cost of digging through or bridging over obstacles can be prohibitively high, so a canal will usually follow the low ground. Abrupt changes in the elevation of the watercourse are handled by the construction of locks or shiplifts to move vessels from one level to the other.

Characteristics of Canals

Canals and channelized rivers share many characteristics with other bodies of water. The water area is usually smooth and dark in color, except in certain combinations of sun and viewing angle, where the bright reflection is visible. (This reflection would only be seen in one image of a stereo pair.) Reflections from areas of disturbed water, such as the wakes of boats, will often be visible.

The surface is level and generally follows the lowest part of the valley. The difference between a natural and a channelized watercourse is gradational in nature, depending on the degree of improvements made. The decision to call such a watercourse natural or channelized should be tempered by the product specifications.

The artificial nature of canals, and to varying degrees, channelized rivers, is revealed by the straight to evenly curved alignment, the even width, and the regular shape and slope of the banks. Levees may be present as the canal passes through low areas, or it may be cut into the ground as its course deviates from the valley bottoms. Because of the even depth of water, the canal will exhibit a uniform dark tone, except occasionally in the shallows near the banks.

The presence of barges and other cargo vessels indicate that the waterway is used for transportation. Small pleasure craft may be found on many waterbodies not otherwise used for transportation, and the analyst should be careful not to confuse them with cargo vessels. The presence of one or more locks is the primary key in identifying a canal. When neither barges or locks are visible, look for high clearances under bridges or for moveable spans. In addition, the bridge pillars may be surrounded by barriers to protect them from damage by passing boats. These characteristics will aid in differentiating a canal from an aqueduct, ditch or non-navigable natural watercourse.



Figure 2: A canal as compared to an asphalt road

The dark, smooth surface of the water and the enhanced alignment of the canal may give it the appearance of an asphalt road. The presence of barges and locks, the absence of lane markings and the absence of connections to the rest of the road network help to identify the feature as a canal. In addition, canals are fairly wide when compared to roads. At least thirty meters is needed to allow two standard barges to pass.

Basins

Lay-by basins are found where a canal is so narrow that it will allow only one shipping lane. The canal bank is cut away at a convenient point to form an area of water where vessels can lay-by until traffic coming from the other direction has passed. These are analogous to passing tracks on single track railroads. Turning basins are areas on the channel or canal that have been enlarged to allow for the turning of vessels.

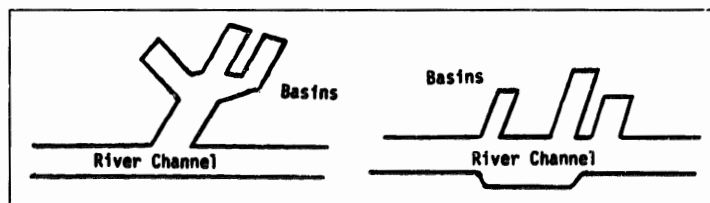


Figure 3: Examples of basins on an inland waterway. Note the turning/lay-by basin at the bottom of the right figure.

On larger waterways, loading and unloading facilities may be located directly along the banks, but frequently there are basins cut into the banks to bring the barges out of the main channel and closer to the facilities they serve. These are analogous to railroad sidings.

Locks

A lock is a narrow rectangular basin used for the raising and lowering of vessels between water bodies at different elevations. A ship enters the lock through gates at either end, and then water is either pumped into or out of the lock to bring it level with the other water body. On waterways with a high volume of traffic, locks may be paired to accommodate traffic moving in both directions.

Lock widths and lengths will vary depending on the size of the vessels expected to use the canal. Most are between 17 and 33 meters in width and the usable length is anywhere between 120 and 370 meters. The vertical lift distance varies from one meter in some tidal canals to over 30 meters in major rivers such as the Columbia and the Snake.



Figure 4: A single lock with miter gates. Upstream is toward the bottom of the figure.

The locks are usually made of concrete and will appear white in tone. The lock gates are usually metal and will have a darker tone. In addition, some of the mechanisms for opening and closing the gates will be visible, as well as a control building. Often there will be a guide wall before and after the lock on rivers.

Several different types of gates may be used on locks. The most common is the **miter gate**, a two-piece gate that, when closed, forms a "V" pointing upstream. This configuration uses the upstream water pressure to hold the gates closed. (The analyst can often



Figure 5: Twin locks with miter gates. As in the previous figure, upstream is toward the bottom.

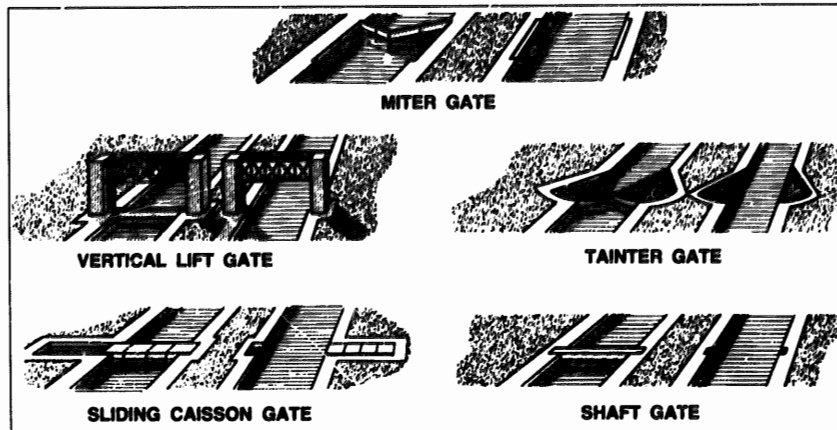


Figure 6: Five types of lock gates shown in the closed (left) and open (right) positions.

use miter gates to determine the direction of flow in a watercourse.) Other types of gates include **vertical lift**, **tainter**, **sliding caisson** and **shaft gates**.

Where rivers and canals connect to the sea, there may be a substantial tidal variation in water depth. To accommodate these changes, and maintain a navigable water depth in the waterway, tidal locks are constructed. If the **tidal locks** have miter gates, they can be identified by the fact that the gates point outward from the lock at both ends, instead of in the same direction. If other types of gates are used, only the lock's position near a coastline would indicate that it is a tidal lock.



Figure 7: Tidal lock

Dams and weirs are often constructed on rivers or canals to maintain navigable water depth, to reduce gradient and current velocity, for flood control, or to impound water for irrigation or other uses. In

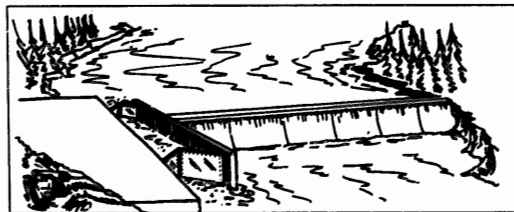


Figure 8: A single miter lock used to bypass a low dam

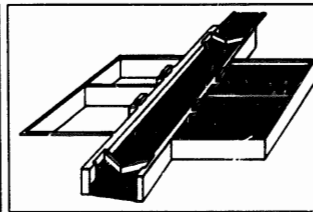


Figure 9: A thrust basin

these areas, the locks are used to allow ships access past the dams. If the change in elevation is large, a series or **flight** of locks may be required. In other cases, locks are used along canals connecting waterbodies at different elevations.

Basins are often built parallel to the lock chambers to use for water storage (thrift basins) in areas where an adequate water supply is not available, or for use as lay-by or turning basins.

Shiplift

A **shiplift**, like a lock, is a structure which moves ships between waterbodies at different elevations. A ship will maneuver into a water-tight tank-like basin with gates at both ends. The entire basin is then raised or lowered like an elevator.

The mechanism may be either mechanically or hydraulically operated. Shiplifts are used in locations

where there is a substantial change in elevation, and construction and operation of a shiplift is more economical than a flight of locks. They may also be used where there is an insufficient supply of water to operate a lock.

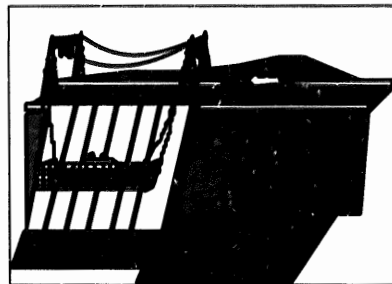


Figure 10: A side lift shiplift

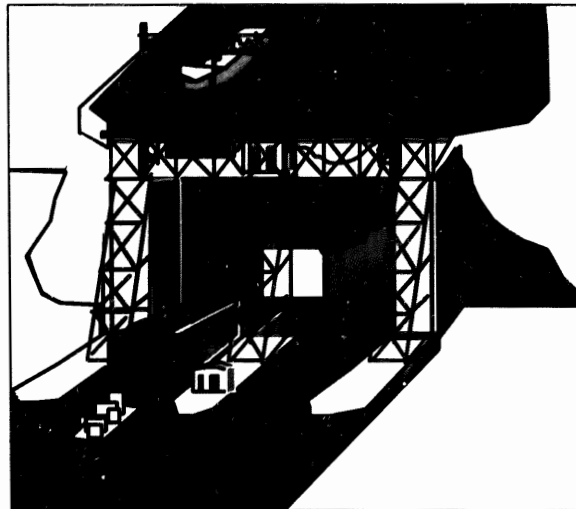


Figure 11: A front lift shiplift

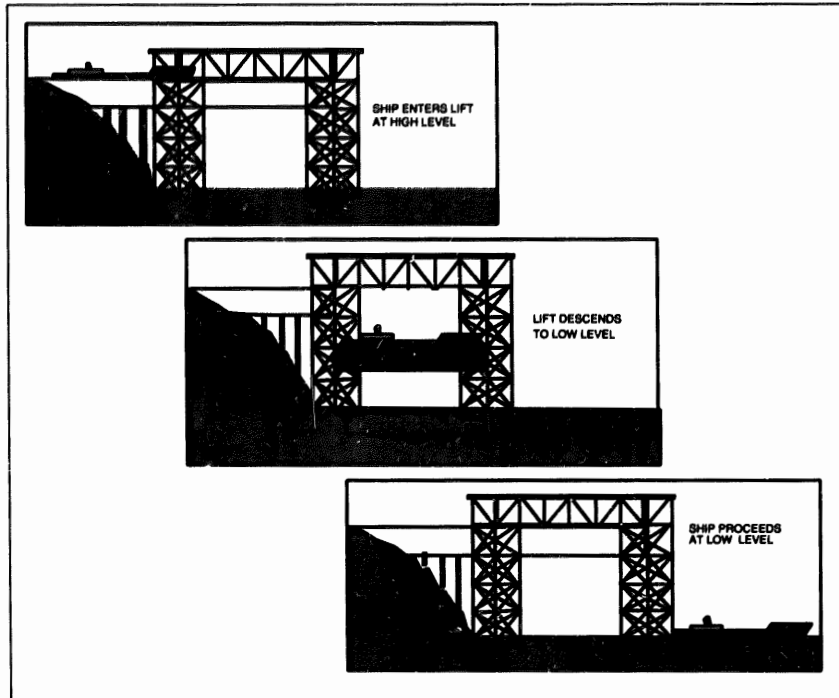


Figure 12: A front lift shiplift being used to lower a vessel.

A shiplift will be large enough to hold one ship only, usually thirty to forty meters long. Shiplifts consist of a light-toned concrete base upon which the steel truss framework for the lifting mechanism is built. The large size of these structures, as well as their position in between waterbodies of differing elevation makes them easy to identify.

Gates

A **sluice gate** is a gate, not associated with a dam, used to regulate the flow or level of water, whereas a **weir** is a fixed structure with the same purpose. They can be found on both navigable and non-navigable waterways. Along coastal areas, tidal sluice gates are used to maintain a suitable water depth in basins and canals during periods of low tide, or to protect areas from inundation during high tides. On navigable waterways, locks are used to bypass the sluice gates.

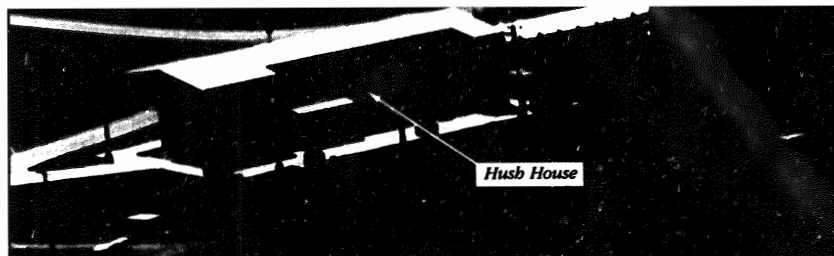


Figure 65: Jet Engine Test Cell

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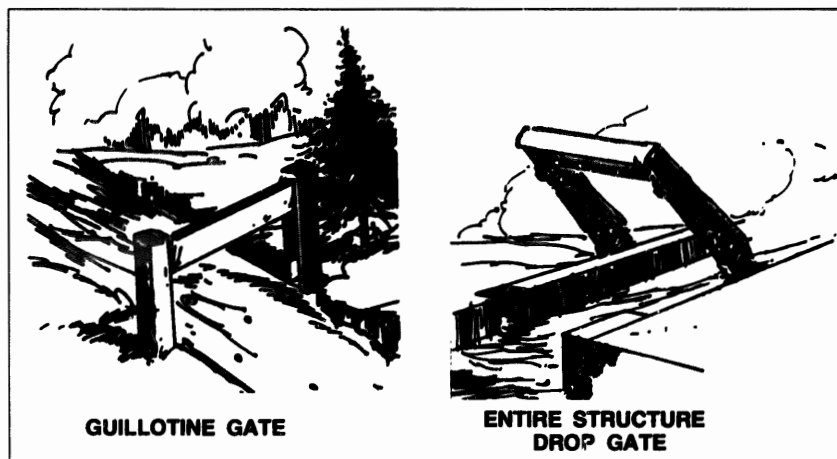


Figure 13: Safety gates

Safety gates seal off a section of a waterway in the event of a breach. They are most frequently found near an intersection with another waterway. The most common type of safety gates are large plate-girders suspended in a massive superstructure. They may operate either on the guillotine principle, where the plate girder is dropped into place, or the entire girder and supporting structure can be lowered into the water. Their massive construction makes them easy to identify from the air.

Terminals

Inland waterways generally do not have large port facilities, such as those associated with maritime shipping. Cargo is normally loaded and unloaded from individual facilities, either directly on the watercourse, or in a basin attached to it.

The historical reliance on shipping for transportation led to the construction of many industries along inland waterways. Therefore, those that still rely on barges for delivery of raw materials are ideally situated to have the materials delivered directly. Since raw materials are not so conveniently located, they must be delivered to a transshipment facility by truck, train or pipeline. Some materials, such as refined petroleum products, are also delivered to transshipment points for distribution to users not located near the watercourse.

These terminal facilities can be identified by the presence of moored barges, conveyors, cranes or other cargo handling equipment and storage facilities.

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Figure 66: Cargo handling facility

On the airstrip side of the cargo handling facility, the parking apron is illuminated by apron floodlights, and is occupied by various handling vehicles such as forklifts, tow motors and trailers. Aircraft being loaded/unloaded are not always present on the cargo parking apron when it is observed. When not actively engaged in loading cargo aircraft, the transfer vehicles and handling equipment are usually parked on the apron's edge or inside of the warehouse structure.

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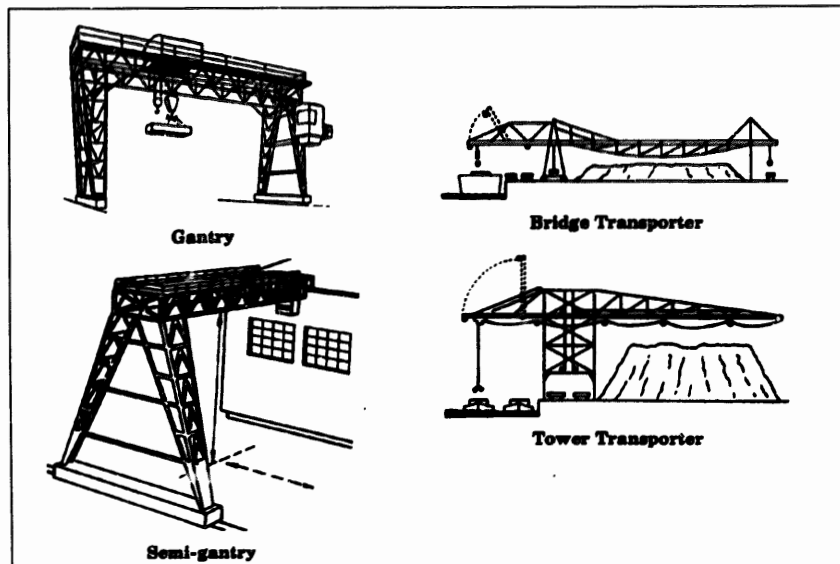


Figure 14: Some of the various types of cargo handling equipment found at inland waterway terminals.

The storage facilities may consist of tanks, elevators, warehouses or open storage areas. If the materials are being transhipped, a rail or truck loading/unloading facility will also be present.

PORTS AND HARBORS

General

Ports

Ports are settlements with installations for handling waterborne shipping. Principle port facilities consist of berthing space, storage space, cargo-handling equipment, cargo transshipment facilities, and vessel-servicing facilities. Ports are classified on an area-wide rather than a worldwide basis. Mearing, a principal port in a small maritime nation may be equivalent to a minor port in the more extensive port system of another country. In wartime, principle and secondary ports and bases are prime targets for destruction, and the relative importance of minor ports increases.

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Harbors

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Figure 69: Passenger terminal at a military airfield, note the covered walkway to the parking apron.

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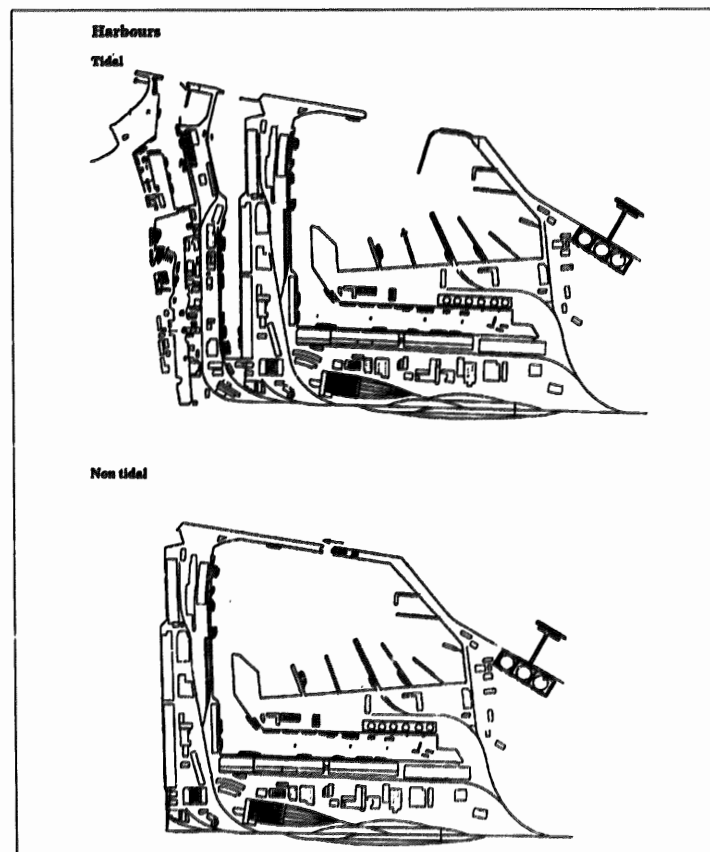


Figure 2: Layout of a harbor, shown as a tidal or non-tidal harbor. Note the presence of a gate between the two breakwaters in the non-tidal harbor.

enough space to accommodate large numbers of vessels, and a shoreline that can be developed as a port and as a site for industry. Harbors may be situated on the sea, estuaries, or inland lakes and rivers and may easily be recognized by abundant waterborne traffic and port facilities.

A natural harbor is one that can be used without harbor works or improvements of any kind. Relatively few strategically located natural harbors are large enough or safe enough to be valuable to shipping. The improved natural harbor is one

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whose utility has been enhanced by the addition of artificial works and improvements. The artificial harbor is one that is created and maintained largely or entirely by human efforts. Many of the important harbors of the world are man-made.

Harbor Works

Harbor works, including protective works, are the structures designed to provide shelter, to control water flow, and to regulate erosion for the improvement of the navigability of a harbor. The principal categories and types of structures are; breakwaters, jetties, groins, sea walls, bulkheads, dikes, locks, and moles. Harbor works do not include port facilities that are designed specifically for the transfer of cargo and servicing of vessels.

Breakwaters

Breakwaters are structures protecting a harbor or beach from the forces of the sea. They may be located on the seaward boundaries of a harbor or can be located within the harbor itself. They may also be located just offshore, protecting the harbor or possibly a beach. If the breakwater is connected to the land, it is called peninsular, if it is entirely offshore, it is called insular.

Breakwaters are narrow, linear structures that extend across or at an angle to the entrance of a harbor or appear as linear offshore features. If a portion of the length of the breakwater is above the water's surface while

the remainder extends underwater, the end of the exposed portion could appear to be pointed due to the angle of the feature and the water's surface. The "point" will be towards the underwater section.

When a portion of the breakwater is not wet it will generally have light tones on an aerial photo, but darkens when it becomes wet. Careful examination of the texture will assist the analyst in determining the material composition. One

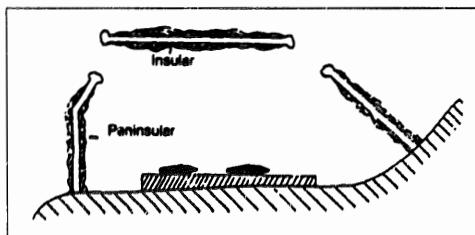


Figure 3: Aerial view of insular and peninsular breakwaters

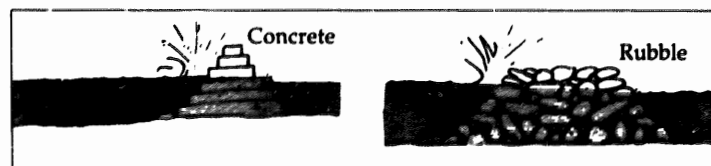


Figure 4: Cross sections of two breakwaters of different construction materials

made from rock will be relatively rough, while a masonry breakwater will have smooth edges.

An observer may actually see how the breakwater works by paying attention to the surface wave patterns. The breakwater will considerably dampen wave propagation with calmer water in the harbor.

Mole

A mole is a massive breakwater (tens of meters in width) with freight transfer facilities on it. A mole is constructed on the seaward side of a harbor and is not necessarily connected to the shore (insular). The mole is used for its protection against current and wave action, drifting ice, sanding up, and winds just as a breakwater does. Moles are large enough to accommodate freight transfer equipment that is part of a wharf or along a quay wall. They usually have roads or even railroads on them if the feature is in a peninsular position.

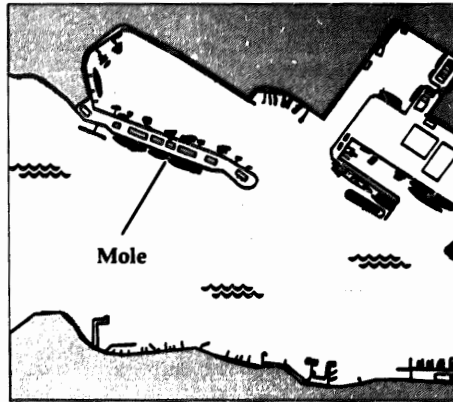


Figure 5: Mole diagram

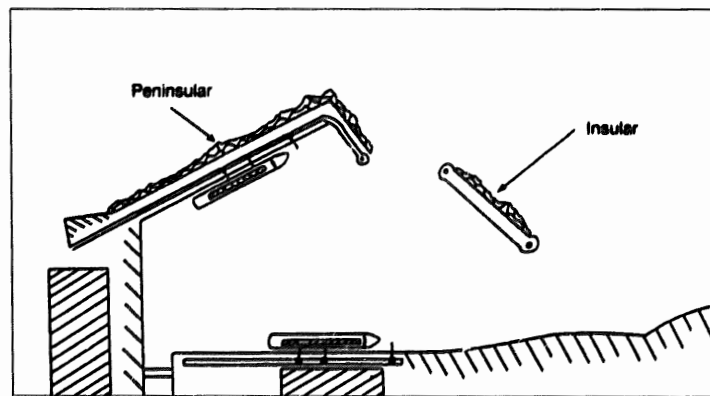


Figure 6: Aerial view of insular and peninsular moles

Figure 73: A rotating beacon located near a hangar at a civilian air facility

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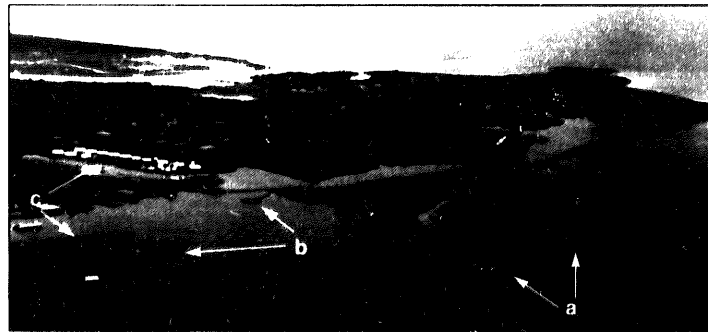


Figure 7: Two jetties (a) where a river empties into a body of water. Note also the POL bunkering piers (b) and POL storage tanks (c) on the left side of the picture.

Jetty

A **jetty** is a solid linear structure of stone, concrete or other material that projects out at an angle from the shore. Jetties are usually found in pairs, and are located at the entrance of a harbor or the mouth of a river. Their purpose is to restrain or control the direction of currents and to maintain the channel opening and depth from silting. Commonly, a light is placed at the end of the jetty out in the water for safe navigation. This feature looks similar to a breakwater, but its location is a key to identify it as a jetty.

As mentioned, jetties are usually found where a river empties into a body of water (see Figure 7). This will give the appearance of the river extending into the open water. Jetties are long narrow linear features exhibiting light

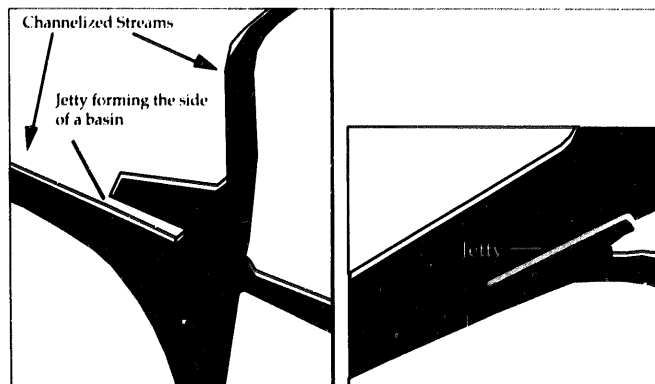


Figure 8: Examples of how a jetty may be used where two watercourses intersect

tones when made of masonry or concrete, however, it will appear darker in tone when wet. If the construction material is rock, then the tone is usually darker. The perception of texture will be dependent on the scale of the photos. One comprised of rocky material will be relatively rough while the jetty

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composed of masonry or concrete will be smooth and may have a sharp edge if a wall is present.

Jetties may be found when two watercourses intersect in an area that has been built-up. In some of these situations, the jetty may form the side of a tidal basin.

Groin (Gryone)

This structure (usually one of a group) extends usually perpendicular from a shore to protect the shore from erosion by tides, currents, or waves or to trap sand for making a beach. The resulting pattern may give the shoreline a sawtooth or scalloped appearance because of sand being deposited on one side of the structure. Groins are found along coastal shorelines, or along the banks of inland waterways.

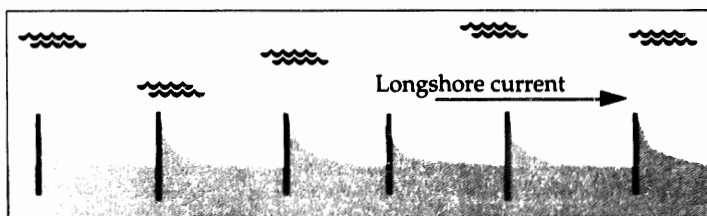
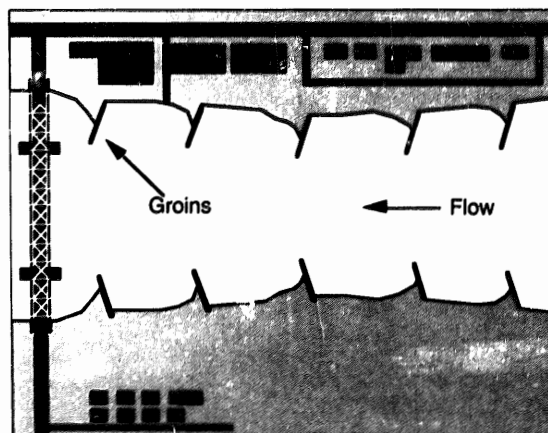


Figure 9: A series of groins along a shoreline. Note the build-up of sediment on the side of the groin which is down current.



Training Wall

The training wall is a structure built along a channel in order to direct the stream or currents through the channel. This funneling of the water movement helps to increase the current thus promote a scouring action to keep the channel from silting up. During high water, training walls are often submerged. On the down stream side of the walls, sediment accumulates and eventually a sawtooth or scalloped appearance of the channel shoreline appears just as with a groin.

Figure 10: These groins (training walls) are placed along a channel to increase the speed of the current thus, reducing the amount of deposition in the main channel

Sea Wall

This is a structure built along the shoreline to protect the shore from erosional forces. The sea wall is a long linear feature that is only a couple of meters wide. They are constructed of concrete, rubble, or masonry and will usually exhibit a bright photographic tone. The sea wall is constructed at varying locations on the shore. It may be right at the land-water interface always protecting the shoreline from the sea or it could be built on the shore for protection during high tide or during storm surges (Figure 12). In this case, when viewing aerial photos, the sea wall will usually appear as a light toned linear feature up on the beach away from the land-water interface.

The sea wall should not be confused with what is known as a quay wall, that is used for berthing of vessels. Quay walls are covered in a later section. Another feature that

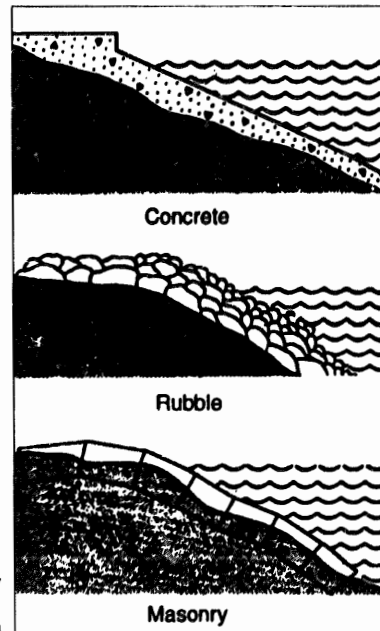


Figure 11: Seawall construction

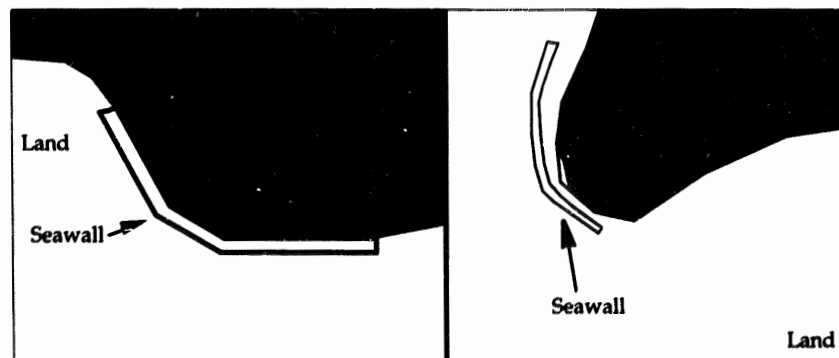


Figure 12: On the left is a seawall as a solid linear feature currently at the land-water interface and on the right the seawall is onshore for protection at high tide or during storm surges

acts similar to a sea wall is the bulkhead. The difference is that a bulkhead is constructed of piles or sheet metal erected vertically along the shoreline.

Berthing Facilities

A variety of berthing facilities are used within the modern port. Each is designed for a specific purpose. The purpose of the vessel's visit and/or the nature of the cargo will determine the type of berthing facilities.

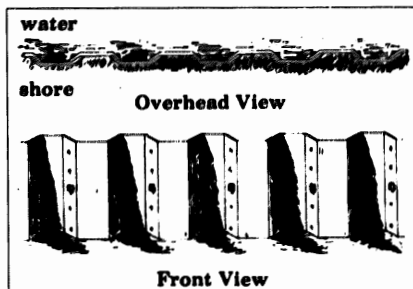


Figure 13: Bulkheads

Berthing Buoys

Berthing buoys, or mooring buoys, are provided in harbors where space restrictions prohibit free-swinging anchorage, where the number of accommodations is limited, and as a more secure berth than can be provided by a ship's own anchors.

Several types of berths can be provided by mooring buoys: a) free-swinging (one buoy), ship's head secured to buoy, b) bow and stern (one buoy), ship secured ahead by own anchors and astern to buoy, or ship secured ahead to buoy and astern to bollards ashore, c) bow and stern (two buoys), ship secured to buoys ahead and astern. Buoys may be held by a single anchor, but generally, two or more anchors laid at varying angles are used for greater holding capacity and more precise positioning of the buoy. When more than one anchor is employed each may connect independently with the buoy. However, ground chains from each anchor converging at a heavy sinker and secured by a pendant chain is more common.

Mooring buoys (particularly those used by naval craft) may be fitted with submarine cable connections for telephone, electricity, and water.

Mooring buoys vary in design depending on their intended use. On aerial photos, the resulting shapes may range from simple circles to that of a four-leaf clover, all of which vary in size up to several meters across.

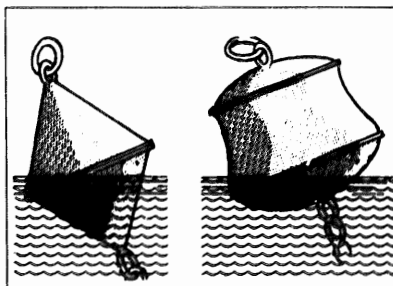


Figure 14: Berthing or mooring buoys

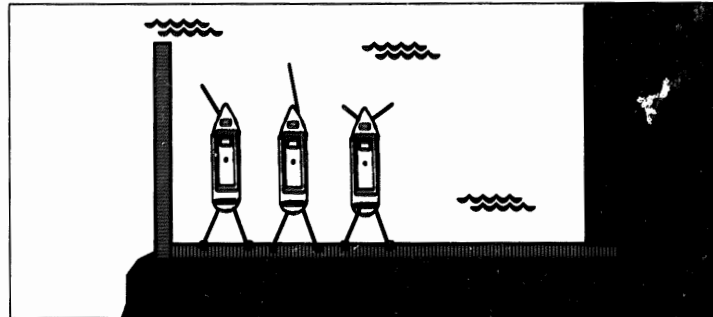


Figure 15: Mediterranean mooring

Fixed Moorings

Mediterranean Moorings

Ships may lie in fixed moorings without buoys in a variety of ways. The simplest method is that of mooring with one or both anchors ahead and stern lines to bollards ashore. This is used where facilities are limited, and is commonly employed in Mediterranean ports. With the Mediterranean moorings, ships lay stern to and off at right angles to a quay wall or wharf.

Dolphins

Dolphin moorings usually consist of a group of posts lashed together at the top, measuring around one to three meters (3-10 feet) across. Dolphins are located off the shore and are used singly for breasting into or hauling out of a berth, and in a series for mooring a ship fore and aft alongside. They conserve space in a stream and are used either for idle berthing or for working cargo by lighter. Dolphins are often associated with a wharf either as a protective device at a wharf's corner and face, or as means of increasing the length of berthing space provided by a wharf face. Dolphins are usually cylindrical or square shaped and will exhibit a light tone, in contrast to the much darker tone of the surrounding water.

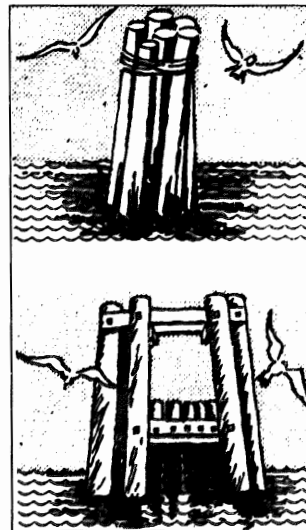


Figure 16: Different styles of dolphins

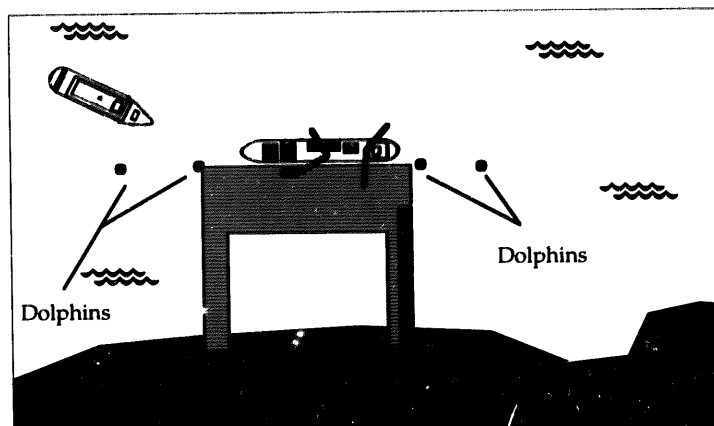


Figure 17: Dolphins extending the berthing space of a wharf

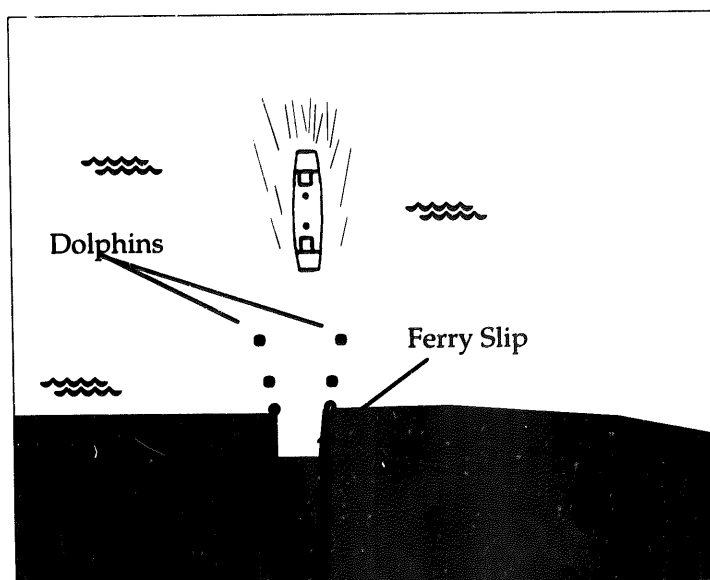


Figure 18: Dolphins at a ferry landing slip

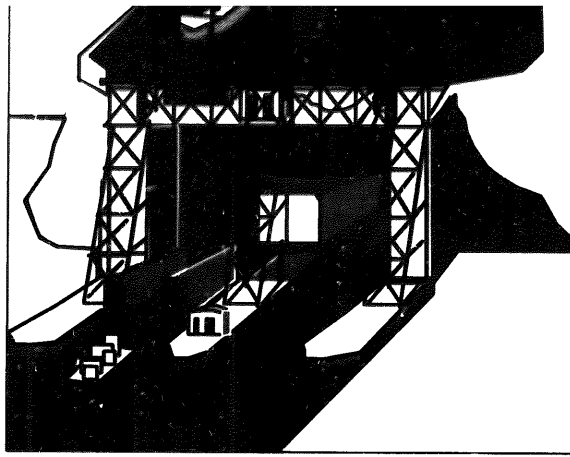


Figure 11: A front lift ship lift

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Piling

Another type of mooring device is the piling that consists of just a single post. These are much smaller than the dolphin and would be utilized by smaller boats.

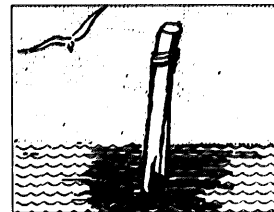


Figure 19: Piling or post

Bollard

A bollard is a post (usually steel or reinforced concrete) firmly secured on a pier, wharf, quay, etc., for mooring vessels by means of lines extending from the vessel and secured to the post. They are usually a meter (3 feet) or less in diameter, and are difficult to discern on all but very large scale imagery. However, they may be located when a vessel is docked and the securing lines are visible leading to the shore. It is at this location on the wharf or quay where the bollard is located. Bollards are usually not shown on charts.

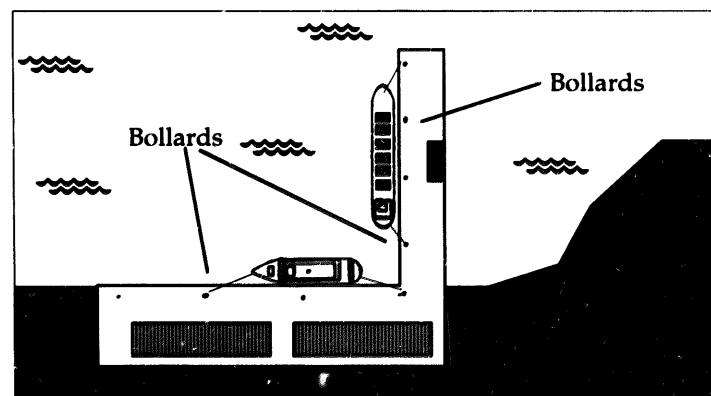


Figure 20: Bollards as they may appear on a wharf and pier.

Piers/Wharves

The majority of landing structures are either piers or wharves, and are defined as berthing places for vessels or decks for land based recreation. Piers project into the water at an angle to the shoreline. Berthage is usually available on both sides of the pier and at the head as well if the structure is wide enough. Variations of the simple straight pier are the T-head pier and the L-head pier, which are commonly used to transfer bulk petroleum, and berthage is generally confined to the pier head.

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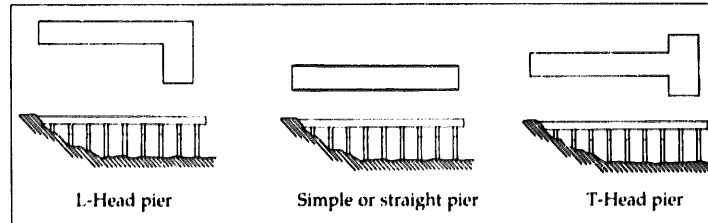


Figure 21: Three types of piers

Wharves form the pivot point for port operations, and detailed information concerning them is necessary to evaluate a port's capabilities. Generally, the term wharf includes all landing structures, even piers. Specifically, a wharf is a structure that parallels the shoreline and provides berthage at its face only. Wharf design is determined largely by its intended use and by local conditions and engineering practices. Variations in the names of landing structures cause considerable confusion, and analysts should be careful to use the proper term. The term dock is properly used in northwestern European countries to designate a water area; in the U.S., however, it is applied generally, but erroneously to any type of landing structure. The pier structure is commonly called a jetty in British and other foreign ports, and all marginal structures are called quays.

The wharf is classified as marginal, quay, or offshore. The marginal wharf and quay are both built parallel to and against the shore and differ only in construction type.

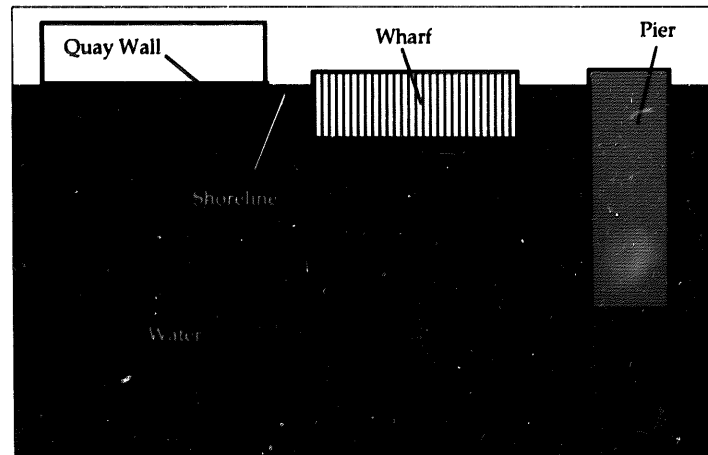


Figure 22: Pier, wharf, quay wall comparison

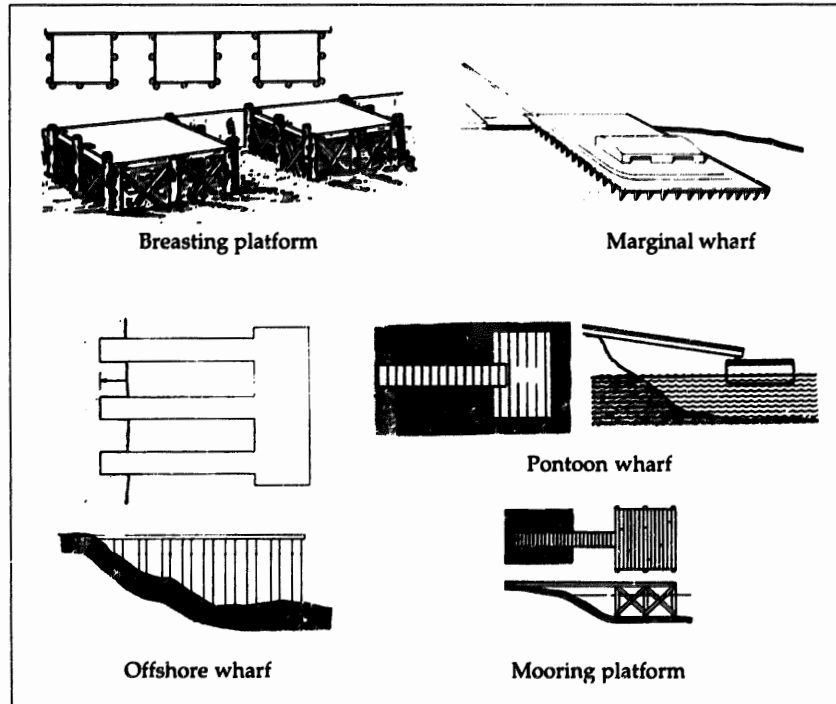


Figure 23: Wharf examples

The marginal wharf is constructed on pilings over the water and is in a peninsular position to the shore. The quay is a solid wall of masonry or other material and is back-filled with earth. The offshore wharf is a structure of open pilings built parallel to but in an insular position off the shoreline. It may be connected with the shore by one or more approaches, gangways, or pipelines. A variation of the offshore wharf commonly used in the Far East is the pontoon wharf, which consists of pontoons of various constructions moored in a fixed position offshore and connected with the shore by one or more adjustable gangways. This type is used where the water level fluctuates considerably.

Two special wharf types are the mooring platform and the breasting platform. The mooring platform is a small offshore wharf with a square platform or deck. It provides berthage for a ship but is too small for cargo transfer. Mooring platforms commonly are provided in groups of two or more, and ships are berthed across the heads. One or more of the mooring platforms is generally connected

with the shore by a narrow approach or trestle, and platforms may be connected by catwalks. The breasting platform is a small platform structure projecting from the face of the wharf bulkhead. Breasting platforms are usually provided in groups of two or more, and ships are berthed across the heads.

Wharf construction and materials vary greatly, however, most structures are either open or solid construction. Open construction is used for marginal wharves, off-shore wharves, and most piers. In its simplest and least permanent form, it consists of open-spaced wooden pilings supporting a wooden deck. Variations of design are numerous and contribute to the strength and permanence of the open structures. Substructures may consist of steel or precast concrete pilings. The superstructure or decking may vary from wooden joists and flooring to concrete and steel construction with an asphalt or other paved surface.

These different construction materials will create a variety of tones associated with the wharves or piers. The wooden deck has a tonal signature of light to medium gray where a deck constructed of concrete will generally have light tones. The asphalt or steel surfaces will be medium to dark gray, almost black in some cases. Piers and wharves used as a transfer point of freight can exhibit an array of tones due to cargo, cargo handling equipment, buildings, roads and railroads, etc., all on the deck of the wharf or pier.

Recreational Piers

Some piers are used for recreational purposes such as for pleasure craft and will be very narrow compared to their lengths. This type of pier usually has a deck constructed of wood or even aluminum. The aluminum will give off very light tones with the wood surface having light to medium tones. When grouped together with other facilities for small boats the location can be referred to as a marina. Promenade piers are used for leisurely, non-boating activities and may have buildings on them and possible even amusement park attractions on the pier.

This category of pier/wharf will typically be found away from industrial and cargo handling port areas and will be in marinas or along open shoreline. Usually, there is a repeating pattern of piers paralleling one another in a marina (Figure 25). Some associated features include recreational boats docked along the

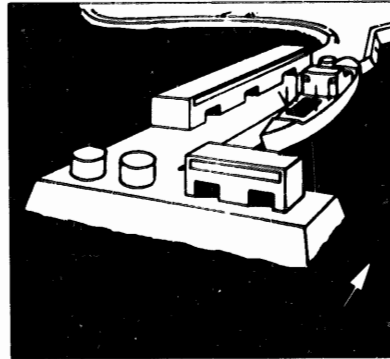


Figure 24: Mole (a breakwater that also has a wharf on it with a road or even a railroad)



Figure 25: Recreational piers

pier, exhibiting near white tones and nearly uniform sizes and shapes, ramps for off-loading and retrieval of boats, or a parking lot with vehicles, some with trailers attached to them.

POL Bunkering Pier

POL (Petroleum, Oil, and Lubricants) bunkering piers are large elaborate pier structures of varying shapes, equipped with facilities for loading and unloading of liquid cargo (usually crude oil or other petroleum products). Most of these oil bunkering piers are characterized by their extreme narrowness in comparison to wide dry cargo piers. This is because there is no need for temporary storage and handling areas.

The piers may be constructed using a modified T-head pier or may be constructed offshore and served by a submarine pipeline. In both cases, the pipelines from shore usually have their origin in a nearby petroleum complex or storage tanks. The unique construction of these types of piers can easily be recognized, as illustrated in Figure 27. The offshore POL bunkering pier, sometimes referred to as an offshore loading facility, usually has the capability to accommodate two vessels simultaneously.

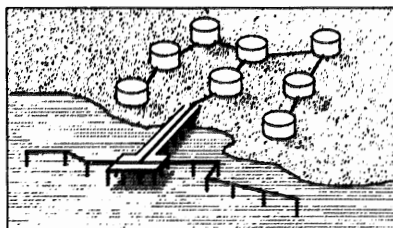


Figure 26: POL bunkering pier. See also figure 7.

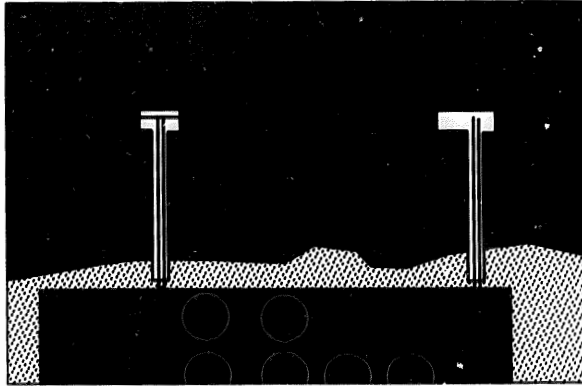


Figure 27: Two different styles of the POL bunkering pier. See also figure 7.

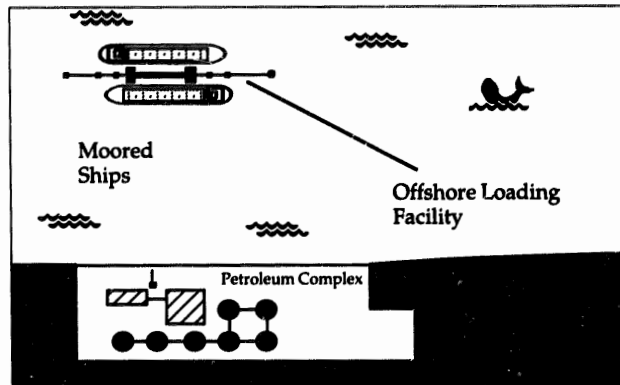


Figure 28: Offshore loading facility

Terminal Buoy

Another type of offshore facility which transfers cargo is the single point mooring (*terminal buoy*), which is much smaller than a POL berth. The terminal buoy is, as its name implies, a buoy, and is charted as such. The terminal buoy may have a variety of shapes and is substantially larger than the standard mooring buoy. It is positioned offshore in deep water with three or more chains attached to heavy anchors.

The terminal buoy has a revolving platform or swivel to which the tanker is secured as are the floating hose lines for cargo, bunker oil, and fresh water. The buoy's flexible hoses are coupled to the ship's system, permitting ship and hose lines to swing together a full 360 degrees with the wind or sea. Product transfer is conducted through submarine pipelines connecting the buoy and a shore installation. An ancillary source should be used to identify it as a single point mooring.

Quays

A quay is a structure of solid construction along a shore or bank, which provides berthing and normally cargo handling facilities as well. It consists of a retaining wall with solid backfill, covered with a surfaced decking. A quay wall may be a simple facing of interlocking sheet steel piling, a monolithic concrete wall, or a masonry structure built of stone or precast concrete blocks. Many quays abroad consist of large concrete caissons sunk in-line to form a wall, then back-filled with concrete or rubble and capped with a reinforced concrete deck.

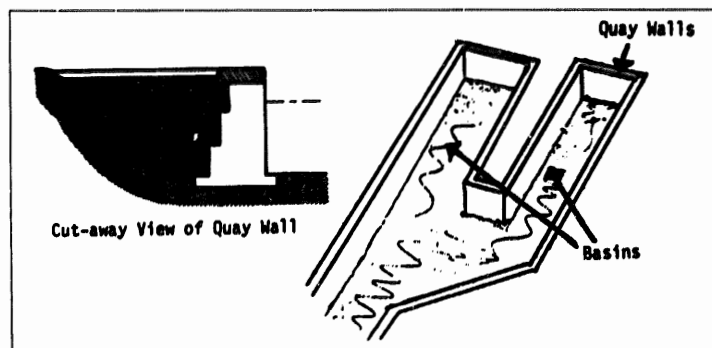


Figure 29: Quay wall construction

Basins

Basins are artificial, partially enclosed bodies of water that form a harbor or part of a harbor for the purpose of berthing vessels. They are usually bordered by wharf structures or quays. Gates or caissons may be constructed at the entrance, or at each end, to control the water level inside.

Tidal Basin

A tidal basin is a partially enclosed body of water that is affected by tidal influence. Vessels berthed within a tidal basin rise and fall with the tide, thus creating a problem for the transfer of cargo. Tidal basins are open to the sea, and have no structures to allow them to be closed off.

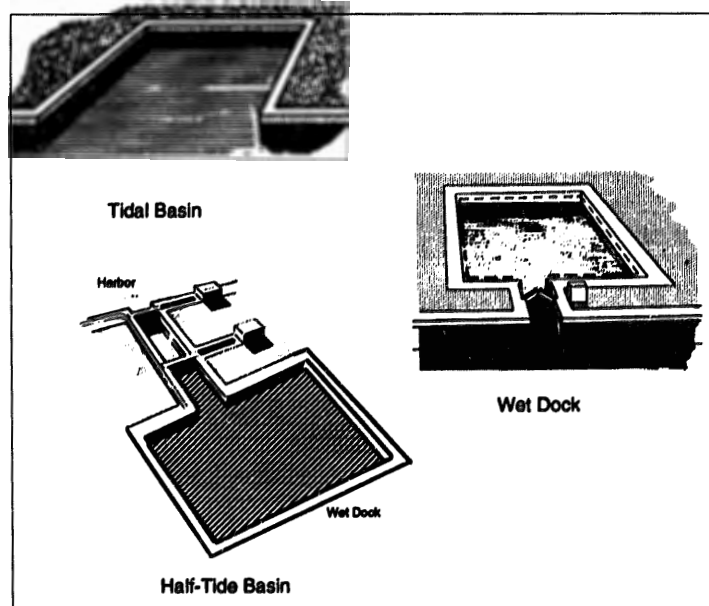


Figure 30: Three types of basins found in ports.

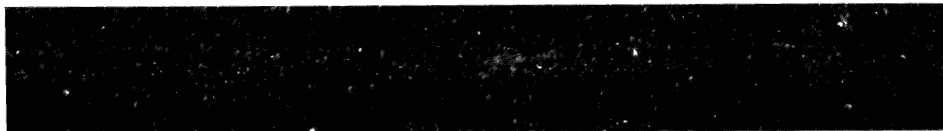
Half-tide Basin

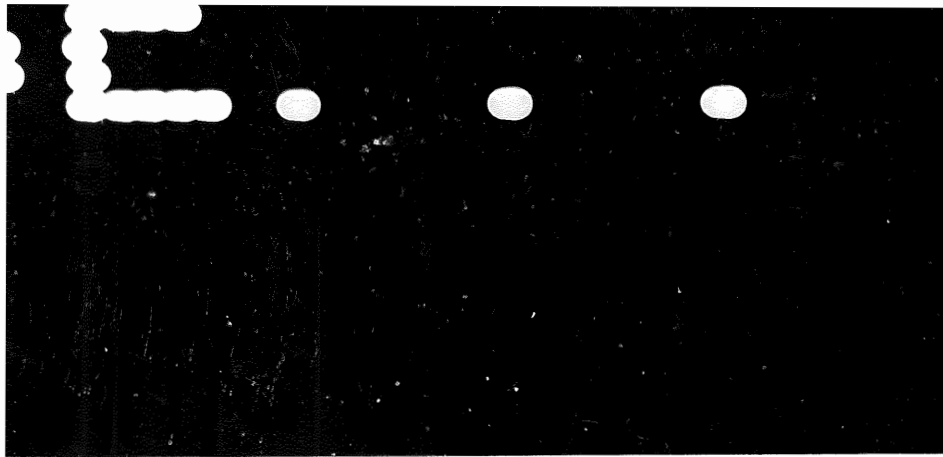
A half-tide basin is a lock large enough to handle freighters (which usually range in size of 75 to 150 meters (250 to 500 feet) in length). It operates with gates, which are kept open for several hours after high tide so that vessels may enter as long as there is sufficient depth over the sill. Vessels remain in the half-tide basin until the ensuing flood tide before they may pass through the gate to the inner harbor or wet dock that has quay walls along the boundary. If entry to the inner harbor is required before this time, water must be admitted to the half-tide basin from some external source. Owing to the enormous amount of water required to raise the water level it cannot be used at all states of the tide; hence its name, half-tide basin.

Wet Dock

The third type of basin is called a wet dock, or non-tidal basin, which is also a controlled level basin like the half-tide. This enclosed basin is separated from tidal water by a miter gate. Usually, ships are moved into the dock near high tide and the gates are closed when the tide begins to fall to maintain the water level.

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If necessary, ships are kept afloat by pumping water into the dock to maintain the desired level. A difference between a half-tide basin and a wet dock is that a wet dock allows vessels to pass in or out of the basin during any phase of the tide.

It should be mentioned that basins are not restricted to coastal harbors. They can also be found along water courses or inland shorelines.

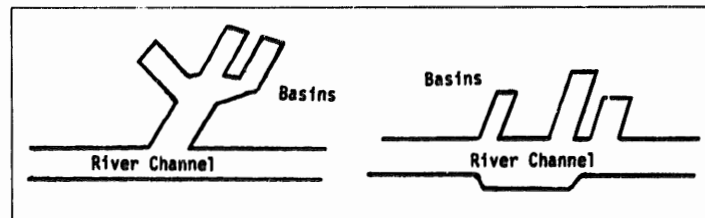


Figure 31: Basins along a river

Ramps

Ramps are partially submerged hard surfaced areas on a shoreline for launching and retrieving vessels or vehicles. They are primarily used in harbors near recreation piers. They usually are at the edge of a parking lot (small or large) and are identified on aerial photographs by the notch created by them in the improved shoreline. Ramps located outside of harbors are more difficult to identify, but can be located by searching for the hardened pad of the ramp.

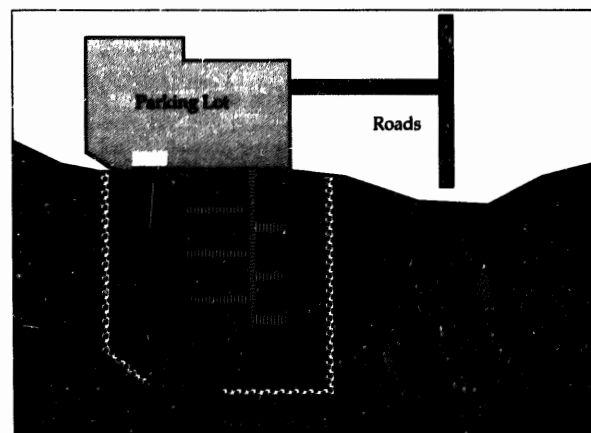


Figure 32: Ramps located in a marina.

This pad is constructed usually of concrete and will have a brighter return than the adjacent ground or parking area. The submerged portion of the ramp is usually visible because of the shallow water.

Cargo Handling Equipment

Cargo berthing space may be recognized by the presence of heavy handling equipment located on piers or wharves. However, very small ports may not have any such equipment, requiring vessels to supply and use their own. The equipment used for the movement of freight varies from manual labor to large cranes specifically designed for handling crates, containers, and heavy equipment.

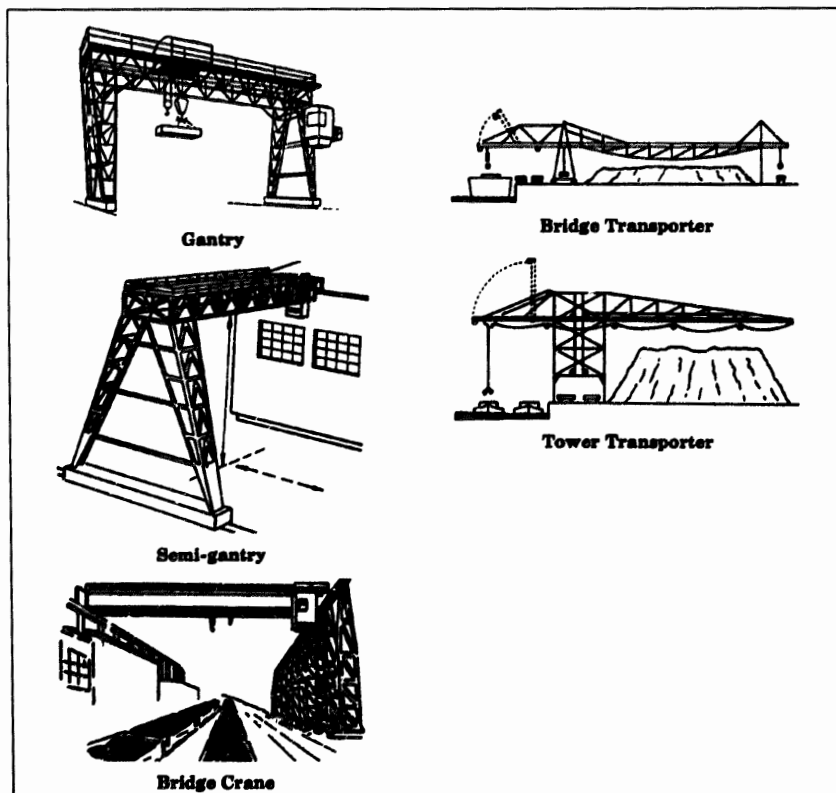


Figure 33: Gantry and transporter cranes

The variety of cranes is large and it is difficult to classify them systematically. Likewise, terminology dealing with cranes differs greatly due to the variation in local and national technical terms. Cranes can be classified either on a basis of function or generic type. The generic types of gantry, transporter, cantilever, jib, floating, derrick, and shearleg cranes will be discussed next.

Gantry Cranes

A gantry crane is a traveling crane on rails that consists of a hoist on a heavy cross girder, called a bridge, which is supported at two points. Hoisting is performed by a trolley or cab that moves transversely along the bridge. Gantry cranes occasionally serve as a base for a jib crane, the latter being mounted on and capable of transverse movement along the bridge member. Gantry cranes are used extensively in shipyards for hull erection and in various industrial yards and shops for heavy lifting. They are usually electrically operated. Depending on use, they may range up to 250 tons capacity. Hoisting capacity is constant regardless of the position of the cab or trolley on the bridge. Gantry cranes are sometimes referred to as "bridge cranes." An overhead crane differs from a gantry crane in that the supporting mechanisms do not move as they do on the gantry.

Transporters are cranes characterized by a long beam (bridge) of relatively light construction, supported by one or more vertical uprights, or towers. There are two types of transporters. The bridge transporter is similar to the gantry crane, but it is of light construction. The tower transporter has a bridge that is supported by a central tower. This type of transporter is usually located on a narrow pier. In both cases the crane is constructed so that it may travel beyond each supporting leg. They are normally used for handling loose materials such as coal or ores.

Cantilever Cranes

A cantilever crane consists of a base or tower structure on which is mounted a counter balanced, horizontal arm or jib. There is a trolley that can be racked along rails on the cantilevered jib that carries the hoisting sheaves. The trolley does not carry the hoisting mechanism but merely serves to support the fall, and its transverse movement is controlled by a system of sheaves and ropes. The entire machine may be mounted on rails for movement along the pier or wharf.

Cantilever cranes are most commonly found in shipyards, although they may be used for cargo handling in special instances where a large working radius is required. They are normally electrically powered and range up to 250 tons or more in capacity. There are three types of cantilevers. The giant hammerhead has a fixed base and is usually located at fitting-out basins in shipyards. Titans have low bases and are relatively rare. Third, is the tower cantilever that resembles a tower jib crane. The difference between these two is that the tower cantilever's arm is horizontal and the tower jib crane has the arms extending out an angle.

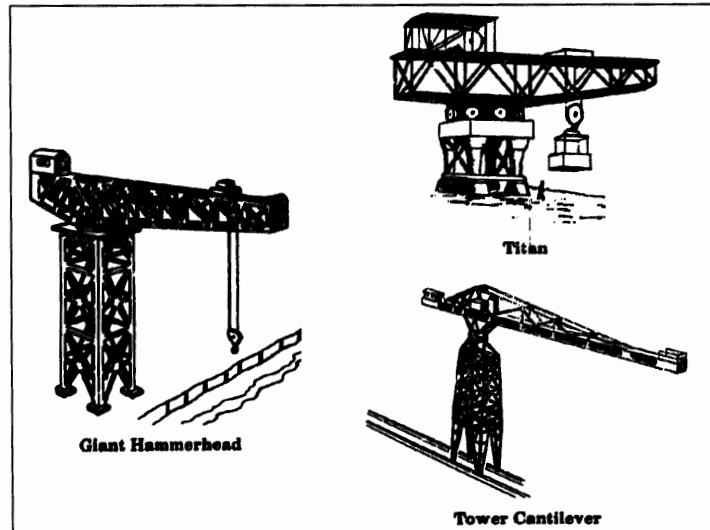


Figure 34: Cantilever cranes

Jib Cranes

A jib crane consists of the primary arm on which is mounted a shorter arm, or jib, extending at an angle. At the end of the jib are sheaves, which the fall runs through and where the load is suspended. The fall is raised and lowered by a hoisting mechanism built into the crane. Jib cranes are frequently mounted on gantry, bridge, or trestle bases, where they are capable of transverse movement. Because of their versatility, they are the most common cranes and have a wide range of uses. Various forms of the jib crane are common along wharves for handling general cargo and also for vessel construction in shipyards. They are usually electrically powered and range in capacity from 3 to 5 tons, but may have capacities of 100 tons or more.

Floating Cranes

A floating crane is almost any crane mounted on pontoons or barges. The float may range from a simple wooden barge to an elaborately constructed steel hull with built-in balancing tanks and pumps.

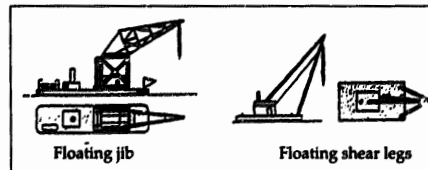


Figure 35: Floating cranes

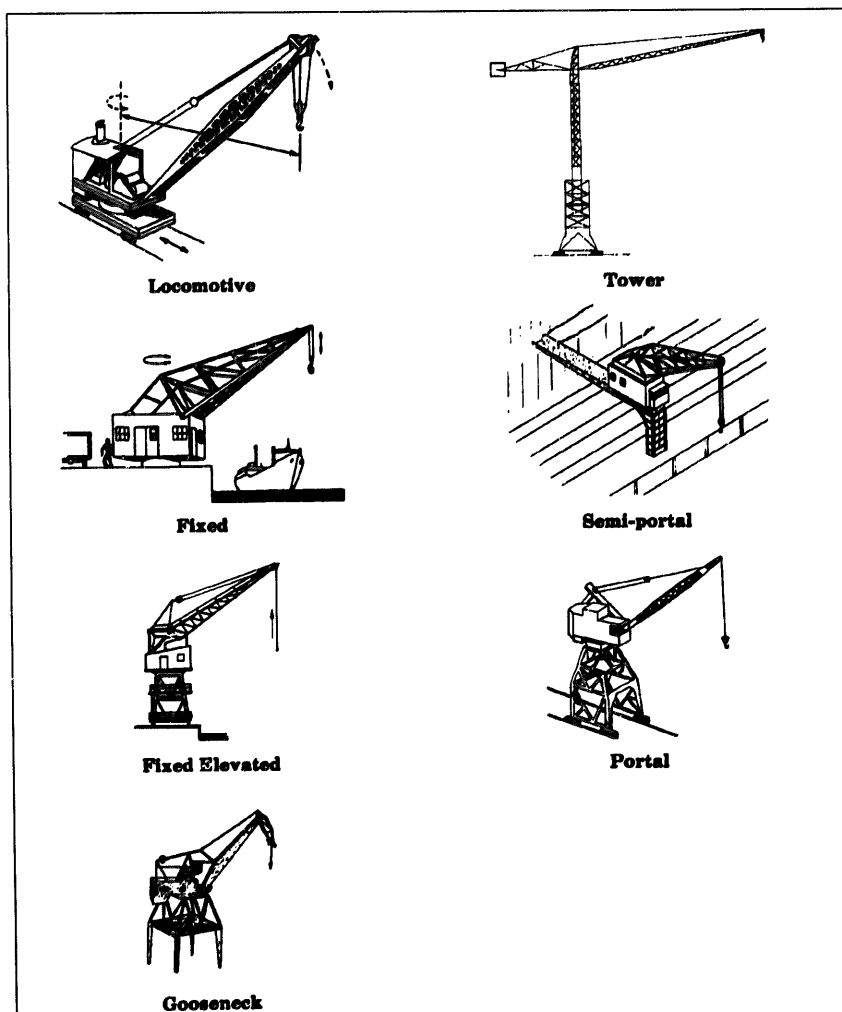


Figure 36: Types of jib cranes

Large floating cranes are commonly used in harbor construction, salvage operations, or transfer of heavy cargo to and from ships. Capacity may exceed 400 tons in some cases. Small floating cranes are driven by internal combustion engines or operated manually and are used for many lifting tasks.

Derricks

Derricks consist of a vertical mast supporting a pivoting jib or boom and appear as a maze of braces and masts on aerial photography. The mast may be stayed by cables or beams anchored to the ground, with the fall running through sheaves at the end of the jib. Large derricks are used for miscellaneous heavy-lifting tasks and run on steam, gasoline, diesel, or electricity. Small derricks are used for simple cargo handling and are operated manually or are driven by gasoline or diesel engines. Derricks and shearlegs are the simplest and least expensive cranes. Depending on size and type, capacity may range from 1 to 40 tons.

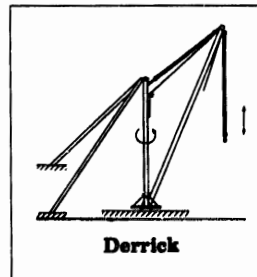


Figure 37: Derrick type crane

Shearleg Cranes

A shearleg crane is a fixed hoisting device with a leaning tripod supporting the system of pulleys and cables. Heavy shearlegs may range up to 150 tons capacity. In hoisting and lifting motions, the operating dimensions are comparable to those of the jib crane.

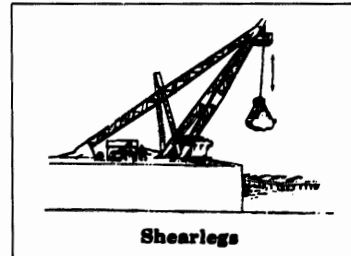


Figure 38: A shearleg crane

Ship Yards

Maritime shipyards are located at protected harbors or estuaries, both of which must possess a sufficient depth to accommodate the ships launched or repaired. Inland shipyards usually produce and repair smaller vessels for use on rivers or lakes, but may also construct submarines. Boat yards producing smaller craft, both maritime and inland, can be located at any protected waterfront. Some of these yards are capable of building small, high speed naval craft.

Slipways

Shipbuilding yards are recognized primarily by the presence of slipways, sometimes just called "ways." It is rare to find a single slipway; they are usually built in groups of at least three and may number over ten in a series along the

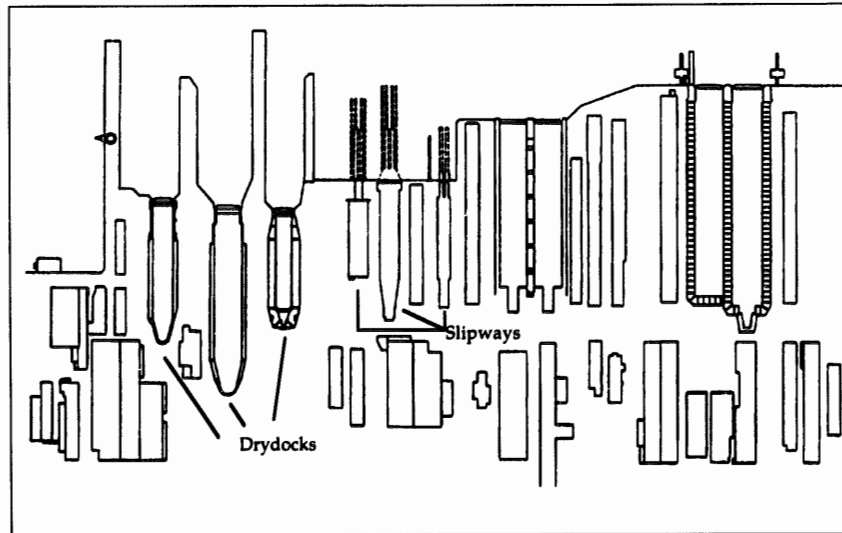


Figure 39: Layout of a large shipyard and how it may appear on aerial photos.

shore. Associated with slipways are huge steel frameworks and traveling cranes for handling the steel girders and plates. The majority of slipways are situated so that the completed vessel can be slid stern first into the water. The slipway is constructed with one end near ground level sloping down to the other end and into the water. This inclined bottom has an inclined rail (groundway), or a keelway leading from the head of the way, down into the water. It is this inclined bottom that helps identify the slipway and differentiate it from the drydock. The dimension of the area within a single set of frames limits the size of the vessels that may be constructed in the slipway. Occasionally two small vessels are built in a single slipway.

Slipways for submarines can be specially designed, narrow and have relatively low framed covered structures, or may be the standard slipway modified with the additions of two parallel keelways, one on either side of the regular keelway. In this manner, several submarines, depending upon their class, may be under construction in a single slipway.

Slipways may be more difficult to find in a military shipyard, because the slipway could have a structure over the entire length or just over portions of the vessel. This is done to prevent observation of the vessels within.

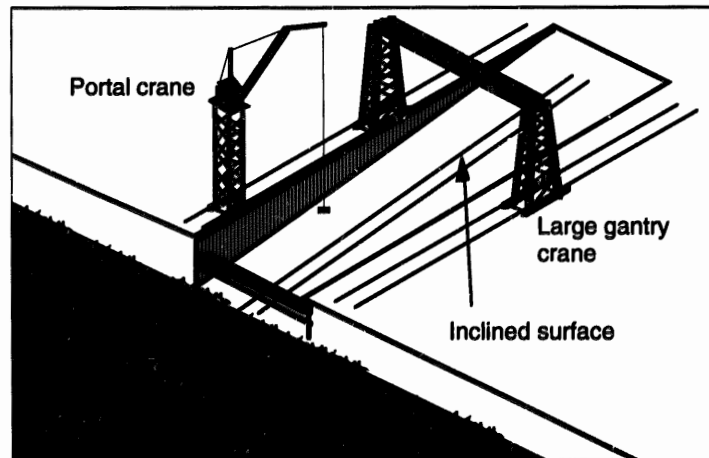


Figure 40: Slipway diagram showing the inclined surface

Ship Yard Shops

The essential operations in shipbuilding are: design and layout, fabrication, assembly, erection, launching, fitting-out, and engineering. Design and layout (drawing of detailed lines of the entire ship's hull and preparation of full-size templates of all structural parts of the ship) are done in a large, low rectangular building in well-lighted areas usually referred to as a mold loft. The mold loft is close to or built as a second story to the fabrication shop. The fabrication shop (cutting, drilling, punching, and forming steel plates to the size and shape of templates) is in a large, long rectangular factory-type building, usually the largest in the yard.

Launching is accomplished by sliding the hull of a ship from the slipway into the water with little of the superstructure and interior completed. This is done to clear the limited slipway area as soon as the hulls are seaworthy. The unfinished vessels are placed in a fitting-out basin or dock where they are completed. Fitting-out basins may be differentiated from cargo handling docks, by the variety of cranes, heavy handling equipment, and material shops and buildings present. Submarines are finished in fitting-out docks just as any other vessel. These docks, however, are often covered with a shed-like roof projecting out from the wharf and are called "screened docks." Yards designed for repair only have no mold lofts or building ways, but usually have marine railways for hauling small craft out of the water and/or graving docks or floating dry docks. A great deal of shipyard work is done in the open, and outdoor cranes of various types are conspicuous.

The raw materials for ship building consist of large quantities of steel plates, which are normally visible outside of the fabrication shop. Pipes, steel objects in a variety of shapes, large castings, lumber, and various types of ship equipment are visible. This type of industrial activity requires a large labor force consisting of many skilled workers as well as manual laborers.

Although the primary design of this facility is to build or repair ships, other types of products may be produced including dredges, cranes, floating drydocks, prefabricated houses, and a variety of small metal articles. Less frequently, rolling mills, hydraulic pumps, tractors, tanks, locomotives, and other heavy machinery are manufactured here.

Vessel Storage And Repair Facilities

Since there is a time lag between the unloading and reloading of a vessel, one area of the port that is removed from the main traffic lane is designated for the temporary storage of vessels. It may be part of the port complex or it may be located along a river bank next to the port complex when the port is on an inland waterway. Vessels are usually moored side by side and give a photo impression of a concentrated grouping of vessels in contrast with rest of the port area.

When repair facilities are present, they are frequently collocated with the storage facilities. Repair facilities are identified by marine railways, floating drydocks and graving docks (often called drydocks). In all of these facilities, the hull of the vessel can be exposed to accomplish the repairs.

Floating Drydock

Floating drydocks are large U-shaped structure of one or more sections, which can be partially submerged by controlled flooding of its hollow walls and base to receive a vessel. The floating drydock is raised by pumping out the water so that the vessel's hull can be exposed for repairs.

This type of drydock is not permanently attached to the shore and is out in the water. When no ships are in it and it has not been lowered to receive a vessel, the floating drydock is easily recognized on aerial photos by its rectangular shape and the high side walls rising up out of the water. If it is submerged, only the two long rectangular walls and gates would be visible. When there is a ship in the facility having repairs done, the side walls are parallel to

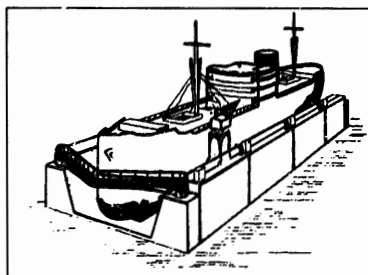


Figure 41: Floating drydock with a vessel in it

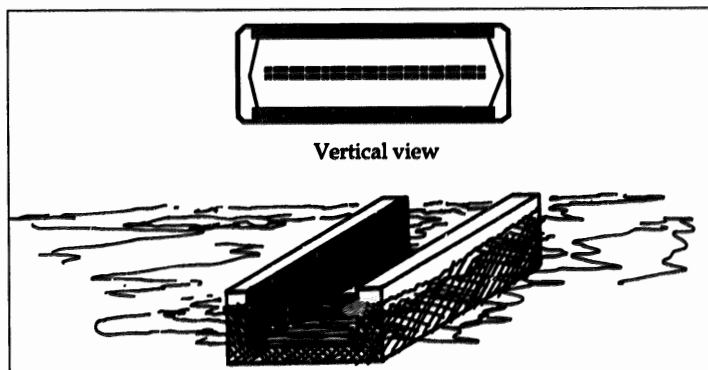


Figure 42: Plan view and a profile view of an empty floating drydock

and are much narrower than the vessel. On aerial photos, the vessel will usually overshadow the floating drydock making identification more difficult. Therefore, one must carefully analyze the vessels in a port for this feature. Also, look for the presence of cranes capable of traveling on tracks mounted on the walls of the floating drydock.

These types of drydocks are portable and therefore can be located anywhere, not just in a harbor.

Drydocks

A drydock, also called a graving dock, consists of an artificial basin fitted with a gate or caisson, into which vessels can be floated and the water pumped out to expose the vessel's bottom. The term "graving" is derived from the process of burning barnacles and other accretions from a ship's bottom.

This massive structure, is part of the repair facilities in a port situated along coastal shoreline, inland shoreline, or river banks

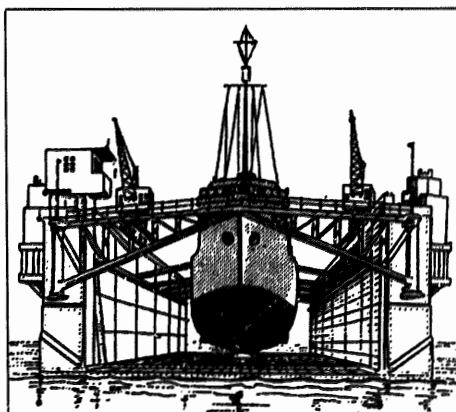


Figure 43: A floating drydock with a vessel in for repairs

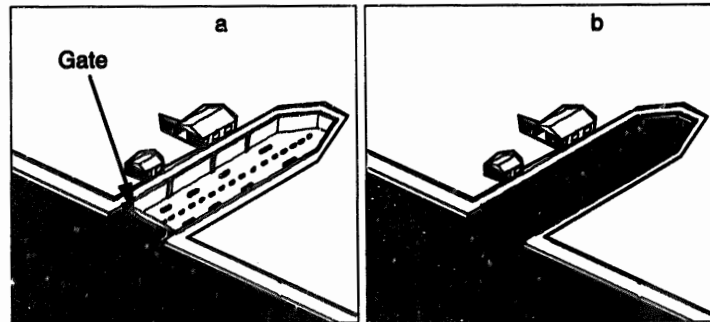


Figure 44: Drydock: (a) water has been pumped out. b) drydock is flooded.

and is constructed in the ground along the waterfront or off the end of a pier. The elongated shaped basin will vary in size depending on the port and the size of vessels to be repaired there. A drydock built to accommodate super tankers can be many hundreds of meters in length. When the drydock is void of water, the construction material may be determined from the tonal signature. Concrete and masonry material will have medium to dark gray tones. These materials can appear darker than normal due to the location in an industrial area. Any steel construction of drydock will exhibit very dark gray tones. If it is filled with water, with a vessel in it or not, the feature will generally have the same tones as the water just outside the gates.

The biggest clue to identifying drydocks is that they will appear as **depressions** along a shoreline. The top of this feature is at ground level, so any shadow of the drydock and most features within it appear in the interior of the drydock.

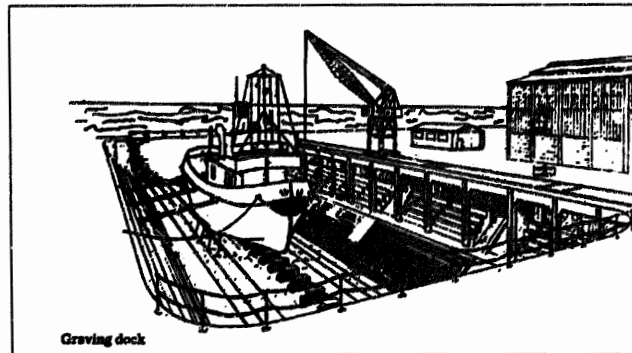


Figure 45: Graving dock

Other features that may help identify this are the presence of ships appearing out of the water onshore, cranes near and over the drydock, piers, wharves, etc. This feature may be confused with a slipway, but remember, a drydock has a level bottom and the slipway bottom is inclined starting from the surface farthest from the water.

Marine Railways

Marine railways are a single set of rail tracks or a parallel grouping of tracks that run perpendicular to the shoreline and extend from a point on shore down into the water. Overhead crane structures are usually present next to the marine railways. The facility consists of the tracks, cradles, and a winding mechanism for hauling vessels out of the water, so the bottom can be exposed. There are two types of marine railways, the end haul and the side haul. The end haul has the vessel approach the railway perpendicular to the shoreline and then the vessel is captured in the cradle and hauled onto shore (Figure 47). The side haul works by having the vessel parallel to the shoreline where it is captured on the cradle(s) and brought onto the shore. At this point the vessel is perpendicular to the tracks. In British terminology, the marine railway is called a *patent slip*.

When identifying this feature, look for the presence of a smooth concrete, masonry, or earthen surface, rectangular in shape, sloping down into the water. This surface is usually more square with side haul types and elongated with the end haul version. There will be a series of dark parallel lines on this smooth surface, these are the actual rails. One might be able to see the cradles and winch houses onshore. One obvious identifier in locating a marine railway is when a vessel is up out of the water. Marine railways are located in ports, shipyards, along inland shores, or rivers and associated with small vessel repair facilities.

Do not confuse this feature with a graving dock or a slipway. Remember, the marine railway is **not** below ground level.

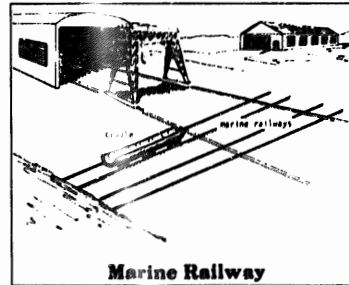


Figure 46: The marine railway as part of a small vessel repair facility.

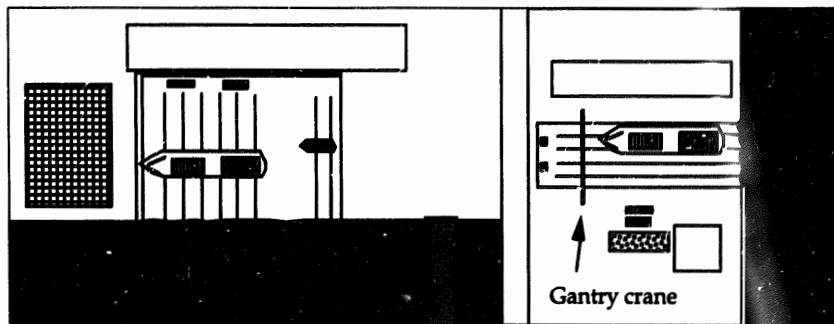


Figure 47: Side haul and an end haul marine railway

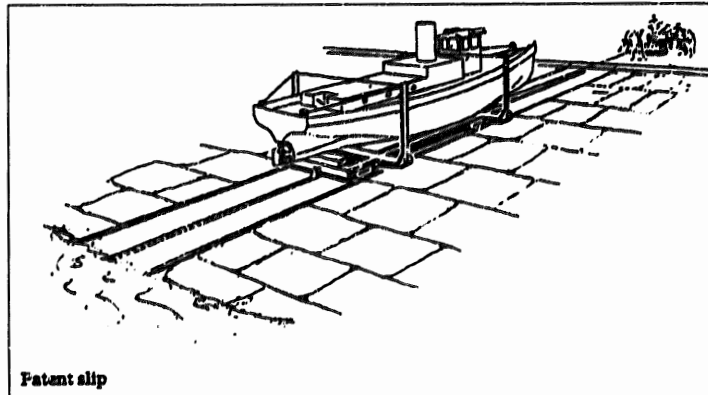


Figure 48: A vessel being hauled up onto the shore by way of a marine railway.

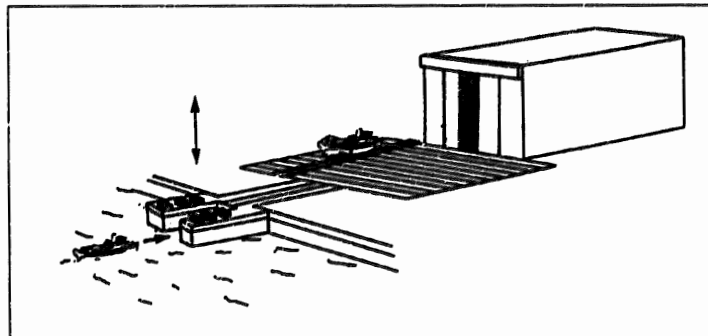


Figure 49: Ship Lift. This lift can also be used to raise vessels up to a level above the water, then hauled into a repair area.

Gridiron

Gridirons, or scrubbing grids, are the simplest of the repair facilities in construction and lack the associated heavy equipment. A gridiron consists of a flat frame, usually of parallel timber balks, erected on the foreshore so that a small vessel may dry out for repair or painting at low tide. The name comes from the fact that the timber beams are arranged such that they form a gridiron (network of crossing straight lines) pattern.

The operation of this feature utilizes the ocean's tides to place the small vessel on the gridiron. At high tide the vessel is maneuvered over the structure and held

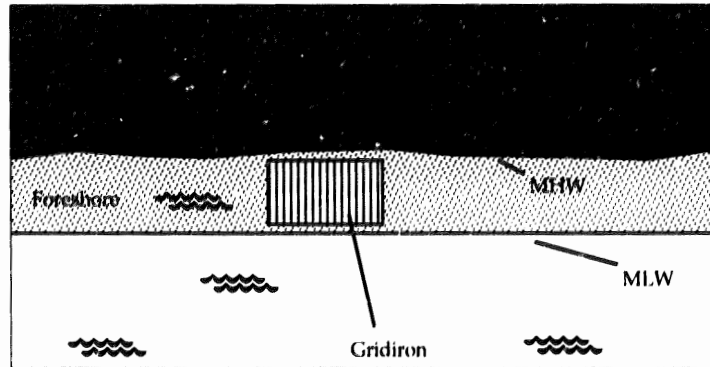


Figure 50: *Gridiron*

in place. As the water recedes, the vessel is lowered onto the gridiron. Not a common feature, the gridiron may be found on the foreshore near a fishing village or small harbor. The tonal signature is medium to dark gray. Identification is easier when the gridiron is occupied by a boat. The presence of a boat out of the water and a structure underneath it helps to identify this feature. Note, there are no railways associated with this feature.

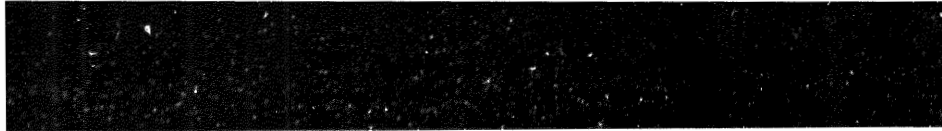
Military (Ports and Harbors)

Naval Bases

Naval installations are designed to support and further the mission of sea-going vessels, provide personnel training, support communications, contain repair facilities, and handle logistics support. Naval installations are the most fixed of the military installations, because they must be situated where the critical anchorages and channels for the navigation of warships are available. In addition, the necessary piers, drydocks, marine railways, shops and other repair facilities are usually of such permanence that moving them would be impossible. Because of its waterfront location, a naval base is seldom confused with army or air bases. It is often easy, however, to confuse naval bases with commercial shipyards as both may be equipped with quays, drydocks, extensive repair facilities, cranes, railways, etc. In addition, a number of different types of vessels may be present at commercial shipyards as well as naval bases, but the presence of warships, submarines, and service vessels will distinguish the base. Despite these similarities, naval bases will usually possess other characteristics of military installations such as housing, security fences and guard shacks, military equipment and recreational and training facilities. Naval stations located inland are usually engaged in basic military training or naval flight training. They tend, therefore, to resemble army

Figure 32: Ramps located in a marina.

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Transportation

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or air bases, unless the presence of ship-like structures indicate naval activity. Seaplane stations, which may be located on naval installations, are identified primarily by ramps, hangars and seaplanes in the water or onshore.

Vessels

During a war, the entire merchant marine of a belligerent nation may become a part of the armed forces of that nation. As such, each ship, regardless of its type, is of military interest. Thus, the photo interpreter is interested in every vessel capable of transporting men or supplies. Identification of vessels is of necessity, a specialty, but the general interpreter must still be familiar with the main types of merchant ships.

Passenger Ships

They are usually from 140 to 300 meters (450 to 1,000 feet) long and present a more streamlined appearance than other merchant ships. Fifty percent or more of their deck space is taken up by the central superstructure, and they have from 1 to 3 funnels (commonly known as smoke stacks).

Freighters

These vessels are the most numerous ocean-going merchant ships afloat. They are usually from 60 to 150 meters (200 to 500 feet) in length. They have blunt bows and sterns and parallel sides. Superstructure covers little area and may be split, but is usually in the relative middle of the ship. Freighters ordinarily have just one funnel that is located to the rear of the superstructure.

Tankers

Tankers used for transporting petroleum products are identified by a small bridge amidship, a single funnel near the stern, and a catwalk running the length of the ship. The bridge or superstructure is small in relation to the size of the entire tanker, which can be well over 300 meters (1000 feet) in length.

Warships

Warships are easily distinguished from merchant vessels by their shape. Major surface warships with the exception of aircraft carriers, have streamlined hulls when viewed on aerial photos. Cruisers and smaller warships have long streamlined hulls in relations to their width. In addition, naval vessels may also show a number of guns mounted in turrets or missile launching units on the center line of the ship and clustered around the superstructure. Aircraft carriers are easily identified by the large flat deck, aircraft on the deck, and deck markings. The carrier's superstructure is generally is mid-ship along the side.

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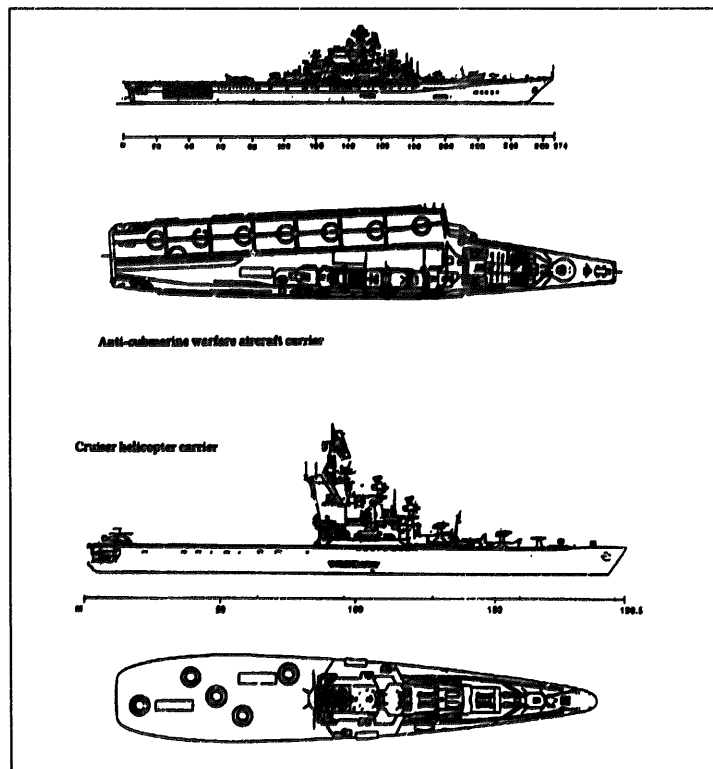


Figure 51: Helicopter carriers

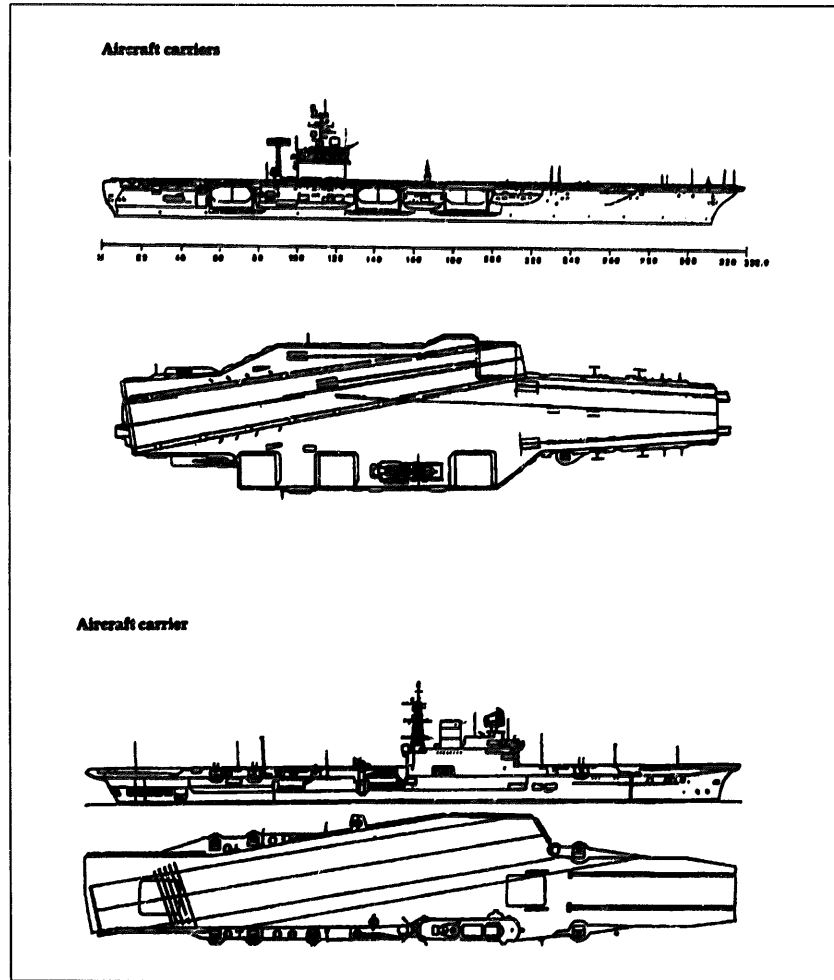


Figure 52: Aircraft carriers

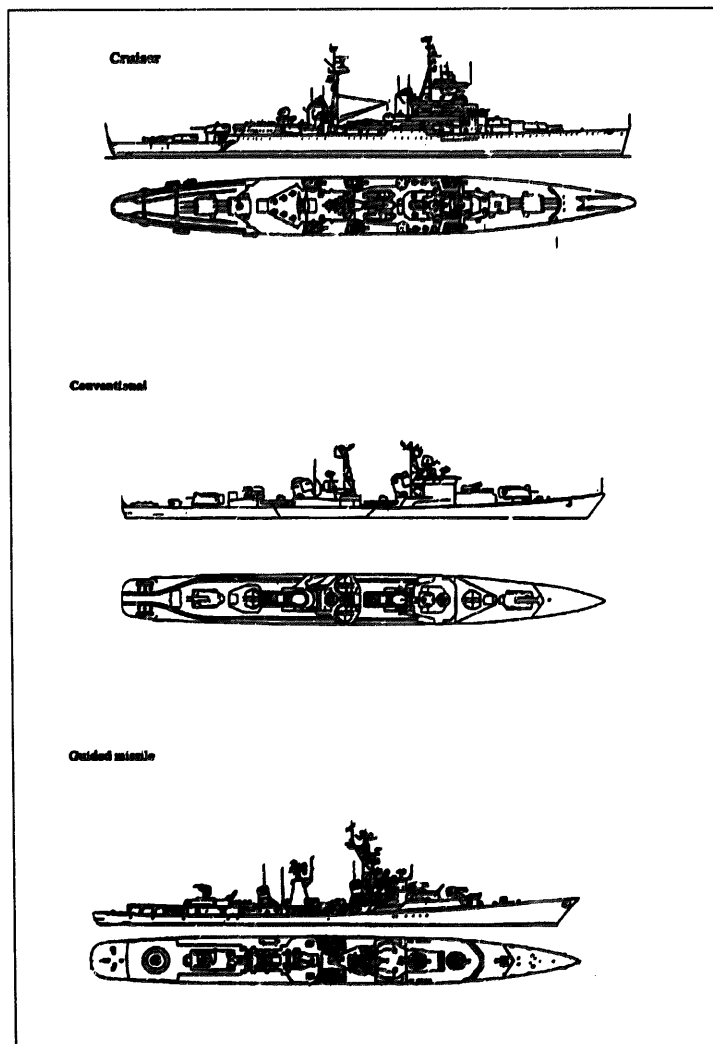


Figure 53: Examples of a cruiser and destroyers

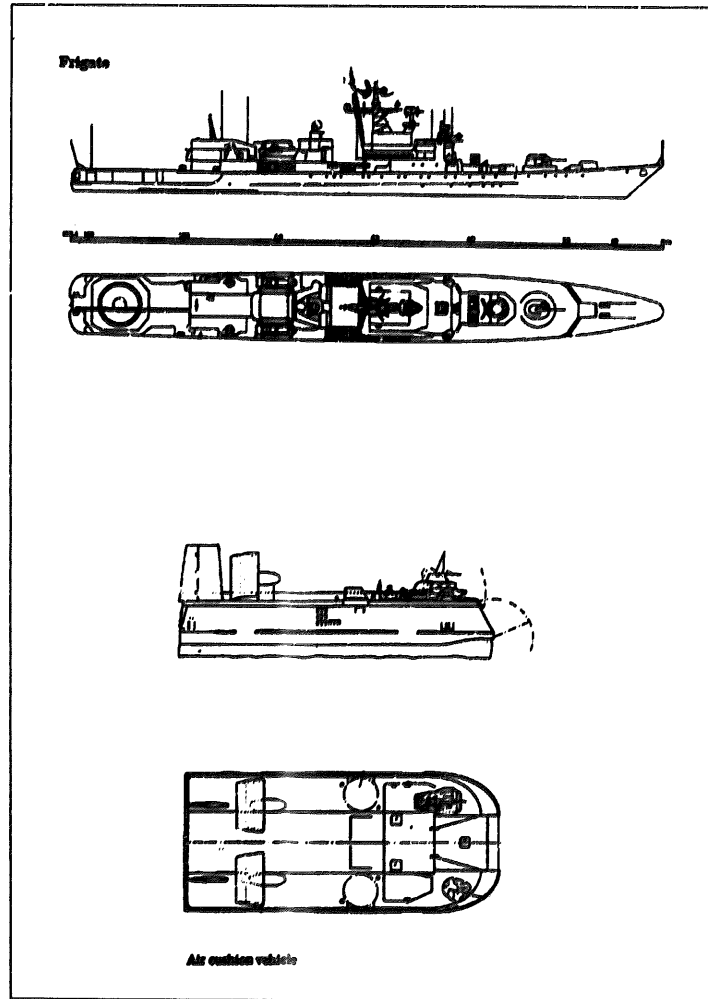


Figure 54: A frigate and an air cushion vehicle

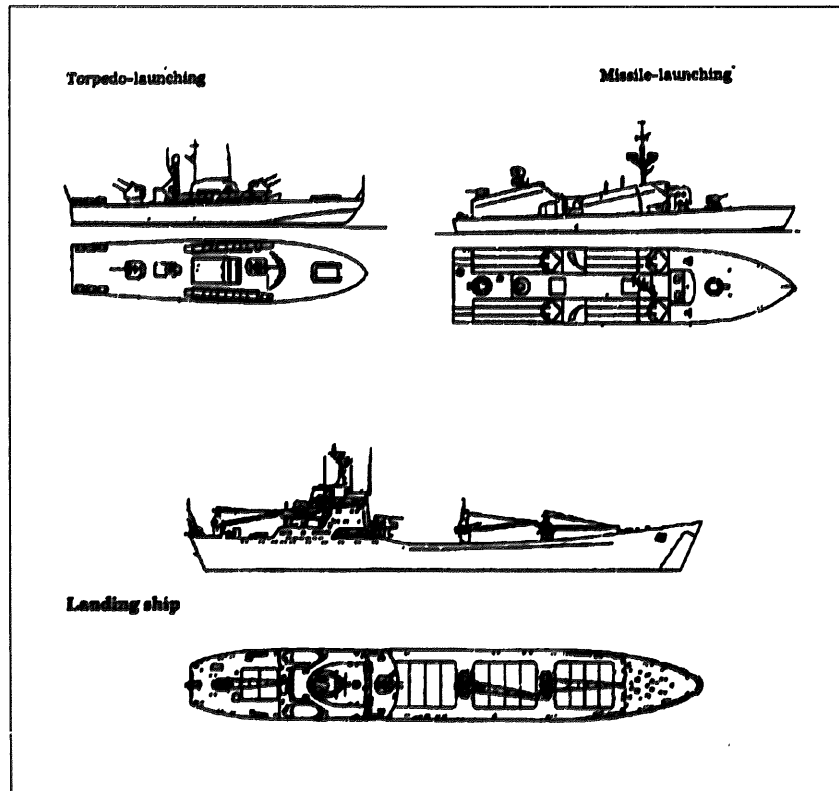


Figure 55: Fast patrol boats and a landing ship

Harbor Defenses

A variety of defense installations may be detected around a harbor and in a port area, not only for naval bases but also for commercial ports. Anti-aircraft guns and sea coast artillery may be present with land mines, beach obstacles, trenches, and casements, as part of local defenses. Underwater submarine nets and booms may be found at the harbor entrance to prevent entrance of unauthorized vessels and within the harbor to protect exposed points from torpedoes launched by aircraft, submarines, or torpedo boats.

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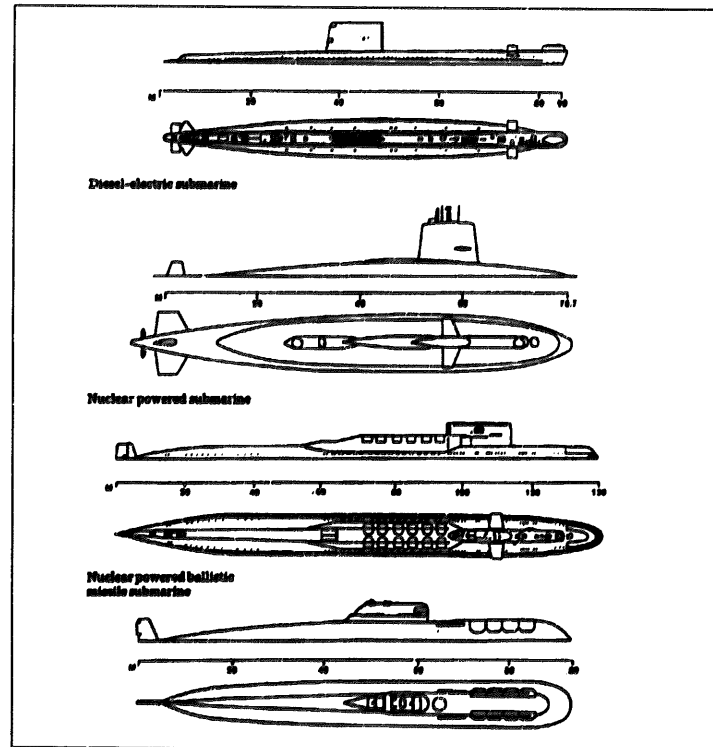


Figure 56: Submarines

Other Port And Harbor Features

Aids to Navigation (NAVAIDS)

The term *aid to navigation* means any device external to a vessel intended to be of assistance to a navigator. Assistance that is provided will aid in the determination of position, charting safe courses, or provide a warning to dangers or obstructions to navigation. This term includes lighthouses, beacons, sound signals, buoys, marine radiobeacons, racons, and the medium and long range radionavigation systems. The discussion of the aids to navigation in this section, however, will be limited to lights and buoys.

Lights

Lights on fixed structures can vary from the tallest lighthouses on the coast flashing with an intensity of millions of candlepower, to a simple battery-powered lantern on a wooden pile in a small creek. Located in fixed positions, which enable identification and accurate charting, lights provide navigators with a reliable means to determine their position in relations to the coastline and hidden dangers during daylight and darkness. The structures that house the light are often distinctively colored to facilitate their observations during daylight.

A major light is a light of high intensity and reliability exhibited from a fixed structure or on a marine site (except range lights). Major lights include primary seacoast lights and secondary lights. Primary seacoast lights are those major lights established for the purpose of making landfalls and coastwise passages from headland to headland. Secondary lights are those major lights, other than primary seacoast lights, established at harbor entrances and other locations where high intensity and reliability are required. Major lights are usually located at manned or monitored automated stations.

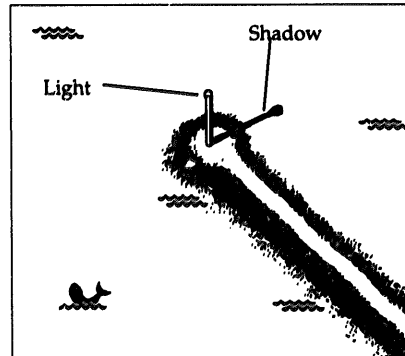


Figure 57: Light (secondary) at the end of a breakwater marking the entrance to the harbor.

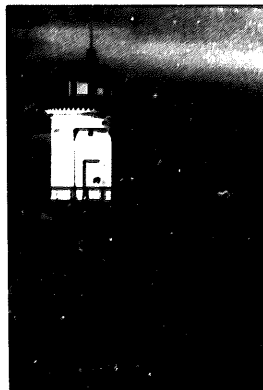


Figure 58: A secondary light at the end of a breakwater.



Figure 59: A minor light powered by a battery, recharged through the use of a small solar panel.

A minor light is an automatic unmanned (unwatched) light on a fixed structure showing usually low to moderate intensity. Minor lights are established in harbors, along channels, rivers, and isolated locations.

Lighthouses

Lighthouses, all of which exhibit major lights, are placed where they will be of most use: on prominent headlands, at entrances, on isolated dangers, or at other points where it is necessary that mariners be warned or guided. Their principle purpose is to support a light

at a considerable height above the water. In many instances, sound signals, radiobeacon equipment, and operating personnel are housed in separate buildings located near the tower or building. Such a group of facilities is called a light station.

For many lighthouses the most obvious identifying feature is the tall, cylindrical tower with the light positioned at the top with a walkway around the glassed-in light. As previously mentioned, some may have distinctive large painted patterns on the tower that can also be used to identify this feature. Keep in mind that all lighthouses are not of this design, but the light on the top of the structure is usually discernible. Use of an ancillary source (i.e. Notice to Mariners) may be needed to locate some of these features.

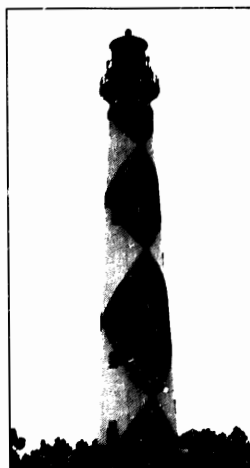


Figure 60: Lighthouse with very distinctive markings

Range Lights

Range lights, or harbor beacons, usually consist of self-supporting, tapered lattice towers with lights on top and, in some cases, radar reflector panels on the sides. They are placed onshore in a manner as to sit in-line with the center of a deep-water channel or an entrance to a harbor. This line of sight may be visible on aerial photographs because of a clear cut

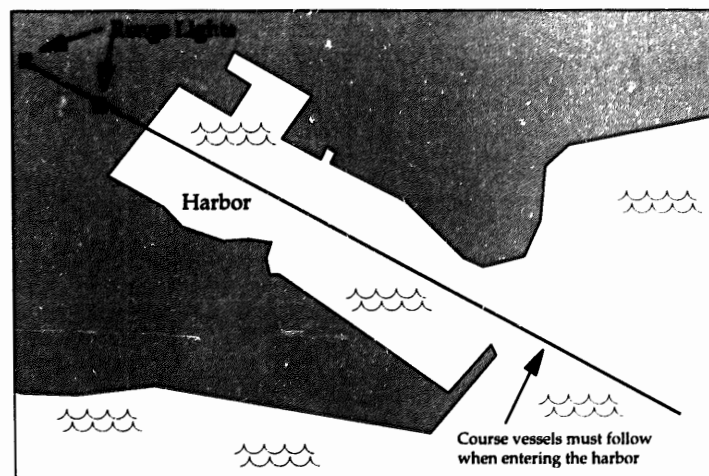


Figure 61: This is a graphic representation of the placement of range lights for this harbor.

from the rear light to the front beacon and down to the water. When these beacons are placed within a cultural area they may be lost within the clutter of features. The rear light is higher than the front light and at a considerable distance apart (this distance is variable depending upon the specific layout for the location). Thus, enabling the mariner to use the range by keeping the lights, structures, or radar returns in line during the progression up the channel. Range lights are sometimes used during daylight hours through the use of high intensity lights. Otherwise, the range light structures are equipped with day marks for ordinary daytime use.

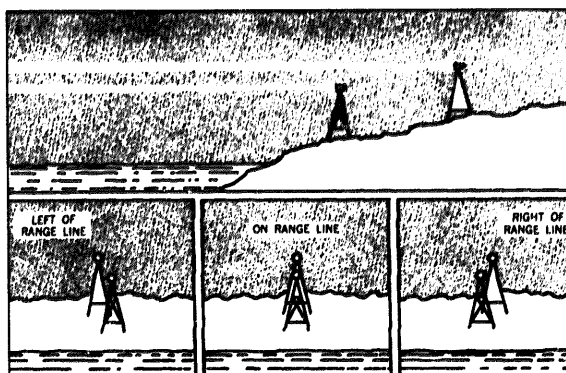


Figure 62: Range lights

The lights discussed here are just a few of the many different types of lights used by vessels for navigation. Much more information is required about a light than just its location derived from the interpretation of aerial photographs. Therefore, refer to *Chart No. 1 United States of America Nautical Chart Symbols and Abbreviations*, prepared jointly by NOAA and DMAHTC; and DMA's *Pub. No. 9 American Practical Navigator, Bowditch*; or *Chart Specifications of the International Hydrographic Organization (IHO)* for discussions and symbology on the characteristics of lights and other hydrographic information found on charts.

Pipelines

General

In spite of the high initial setup costs, pipelines are still the most economical means of transporting liquid or gaseous materials, particularly when large quantities are involved. For this reason, pipelines are extensively used for the shipment of water, oil, gas, and other materials, as well as the movement of waste materials to disposal or treatment sites. Even solid materials, such as coal, can be pulverized and mixed with water to form a slurry, which can then be pumped

through a pipeline. Cities and industries could not exist in their present size and form without pipelines.

A pipeline exists to transport a large quantity of material from a producer to a customer, from a source to a destination. Movement along a pipeline is almost always in one direction only. If a return flow is needed, a second pipeline is utilized. This is different from the other transportation systems discussed, where movement in both directions is common. In this section, we will concentrate on pipelines used to carry materials between source and destination points. Pipelines internal to various facilities will be discussed under Chapter 4, Industrial Components.

Gases and liquids are fluids, that is they have no definite shape and conform to the shape of their container. They move or flow in response to gravity or other forces. Gases expand to fill the space they are contained in, and can be compressed into a smaller volume. Liquids are essentially incompressible, and will maintain a level, free surface if their volume is less than that of their container. It is these similarities and differences that dictate how gases and liquids must be handled. Liquids, because of their greater density and fixed volume, flow downhill readily, while gases need to be introduced into the pipeline under pressure in order to induce flow. For uphill grades, both fluids require pressurization. For short pipelines, such as those internal to a facility, the initial pressurization is sufficient to carry the material to its destination. For longer pipelines, a series of **relay stations** (**compressor stations** for gases and **pumping stations** for liquids) are required to overcome frictional losses and to move the material through uphill grades.

There are three types of pipelines, **feeder lines**, **trunk lines** and **distribution lines**. In any pipeline system, one, two or all three types may be present. Feeder lines are small diameter lines that collect the fluid from source areas, such as oil and gas fields, and transport it to a processing site, a storage site, a point of consumption, or to a trunk line. The trunk line is of larger diameter and transports the fluid to a processing or storage facility, a point of consumption, or to a system of distribution lines. The distribution lines are small diameter lines that divert part of the flow in the trunk line to a particular point of consumption.

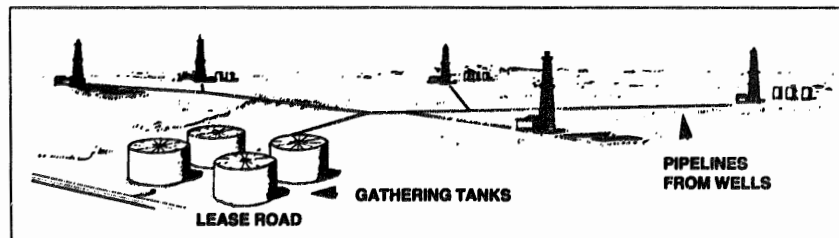


Figure 1: Feeder pipelines in a small oil field. The oil is stored in the gathering tanks and sent through a gas/oil separator before being sent through the trunk line to the refinery.

Figure 47: Side haul and an end haul marine railway

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Chapter 3

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The appearance of the pipeline does not provide much of a clue as to the material being transported. The best clues to this information are the terminal and storage facilities, and relay stations associated with the pipeline. These facilities may be the only clues to the presence of a buried pipeline. The association of the pipeline with features such as oil fields, urban areas and reservoirs will also give an indication of the materials being transported.

Pipeline Routes

The location and appearance of a pipeline are determined by two main factors, the relative location of the source and destination, and the environmental conditions along the route. The relative locations of the source and destination dictate the type of terrain to be crossed. The environmental factors determine the specific route, whether the pipeline is placed under, on or above the ground's surface, and other special engineering adaptations.

Pipeline Route Location

The most important factor in determining the route of a pipeline is economy. First, the construction costs must be minimized. Therefore, whenever and wherever possible, the pipeline will follow level terrain and gentle slopes, and will be laid in straight lines. It will stay in open areas, rather than going through brush or forest, and will avoid hard to excavate soils if it is to be buried. The pipeline will go around rugged terrain and other adverse areas, if this does not significantly increase its length. There are no grade limitations on a pipeline. Increasing uphill gradients will increase the number of relay stations required along the route.

Second, it must be economical to use. This means moving the maximum amount of material through the pipeline with a minimum number of relay stations. These relay points are expensive to operate and are subject to breakdowns which would interrupt the flow of materials. Economy of use also means that it must be possible to tie in new feeder lines from new sources, or distribution lines to new customers. Where the pipeline is subject to deterioration, by electrolysis or other means, special adaptations must be made to protect the system from damage.

Finally, the pipeline must be economical to maintain. All points along the route of the pipeline must be readily accessible. For this reason, pipelines are often placed along the right-of-way of other transportation systems, such as roads, railroads and powerlines. This also allows the pipeline to use existing bridges to cross over rivers and other obstacles. The route must be kept clear of any vegetation other than grass. The resulting cleared way can be readily observed on imagery of even medium to small scales. Hazards to the pipeline, such as freezing, flooding, erosion, deterioration, earthquakes, vandalism, etc., must also be taken into consideration.

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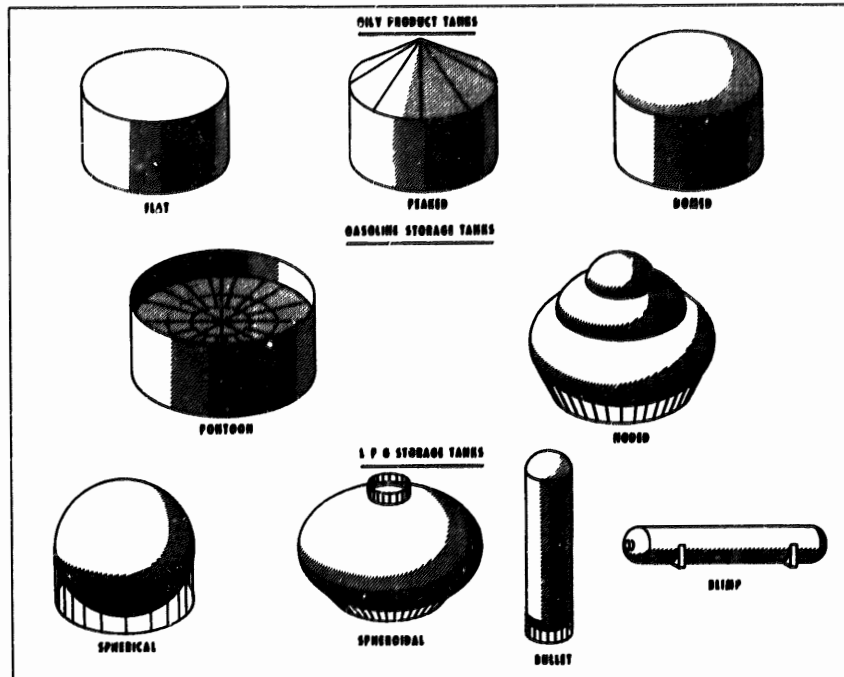


Figure 2: Tank types and the petroleum products associated with them

Pipeline Placement

The most inexpensive method of laying a pipeline is to set it on the surface of the ground. This minimizes excavation to that extent required to provide an even surface to support the pipeline. In most cases, the pipeline does not actually sit on the ground, but is supported by a series of small piers which compensate for irregularities in the ground's surface. As well as minimizing construction costs, this also leaves the entire length of the pipeline readily accessible for maintenance. Setting the pipeline on the ground's surface leaves it exposed to the weather, and to accidental damage or vandalism. It also becomes an obstacle to any vehicles traversing the area, and special accommodations must be made where the pipeline crosses a road or railroad. Therefore, pipelines are normally set on the surface only in sparsely populated areas with warm climates, or for expedient and temporary pipelines, such as collection feeder pipelines in oil fields, and those associated with military operations. Pipelines are also set on the

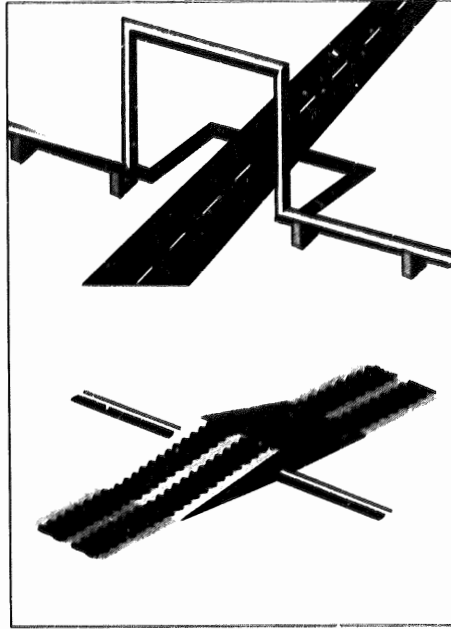


Figure 3: Two types of pipeline crossing points

surface in areas with little soil cover or hard to excavate soils.

Crossing points must be constructed where surface pipelines cross roads or railroads. At one type of crossing point, the pipeline is simply buried underground for a short distance, allowing the road or railroad to pass over it. These are easily recognized, as the pipeline disappears at the crossing point, and there is no discernible change in the road. An other alternative is to elevate the pipe a sufficient distance to allow traffic to pass under it. This is accomplished by placing a vertical jog or loop in the pipeline. The shadow of the elevated section of pipeline is very distinctive. A third method is to build a ramp over the pipeline. This is used extensively in oil fields where feeder lines are placed on the ground's surface. The ramp is usually easy to spot, as the pipeline is covered for only the width of the ramp. The shadow of the ramp may be visible. Frequently, several tracks or loose surface roads will converge at the crossing point.

In some cases the pipeline must be elevated above the ground's surface. The

Alaskan pipeline, for example, is set above the ground in order to prevent heat from the warm oil in the pipeline from melting the permanently frozen ground. Pipelines may also be elevated for short distances when crossing areas subject to flooding, or in areas of electrolytic soils, where contact with the ground would cause rapid deterioration of the pipe.

Many pipelines, particularly in the more industrialized countries, are buried underground. This protects them from damage and the weather. Placing the pipelines underground avoids interfering with other uses of the surface. This also makes detecting and identifying pipelines on imagery much more difficult.

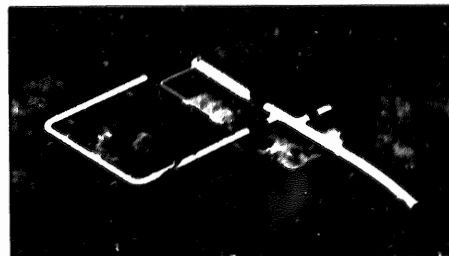


Figure 4: function manifold with valves where a distribution line exits the trunk line.

Although most of the pipeline is buried, some parts must remain exposed for operational and maintenance purposes. These, along with the cleared way, can be used to locate and identify both buried and above-ground pipelines.

Components

A **manifold** is a connection point, where two or more pipelines meet, or where a valve, regulator, meter or other control device has been installed. **Valves** are used to control the flow of fluids through a pipeline, and to shut down the pipeline in case of a leak or break. **Regulators** reduce the pressure of the gas as it enters distribution lines. Valves and regulators are frequently controlled by microwave radio, so that emergencies can be controlled immediately, rather than waiting for a crew to reach a remote location.

Relay stations, storage facilities and terminals are also located on the surface. In addition, pipeline route markers are placed at intervals along the pipeline, especially where the pipeline crosses a road or railroad. These markers serve as a warning to anyone who is excavating in the area that their activity may damage the pipeline.

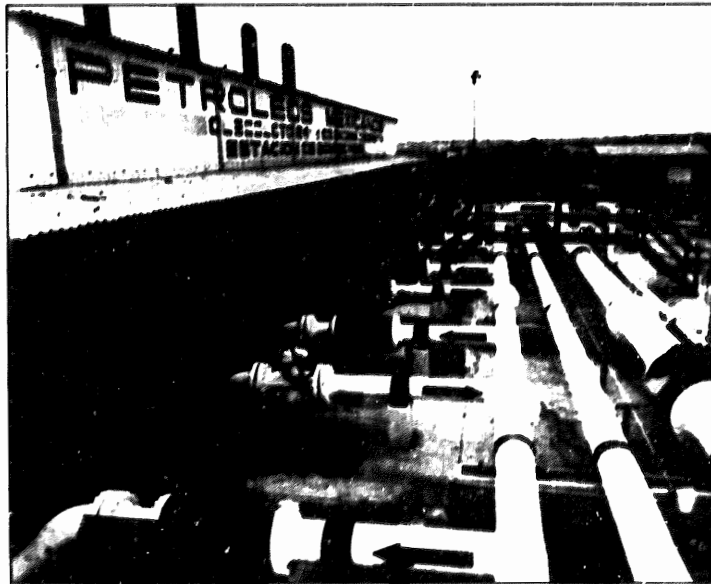


Figure 5: Large pipeline manifold at an oil pumping station

Steel and cast iron are the dominant materials used for oil and gas pipelines. Concrete is often used for larger water systems and some sewer systems. Masonry and tile pipes have been used, particularly in older systems. Bamboo and flexible hose have been used locally for small systems, and plastic piping is becoming more common. The smaller, lightweight, "primitive" pipelines may look much more irregular than their larger counterparts.

Identification of Pipelines on Imagery

Surface pipelines will appear narrower than roads or railroads, and will have regularly spaced angular jogs (**expansion loops**) that compensate for expansion and contraction of the pipeline due to temperature changes. Expansion loops are found on all pipelines, but they are much more closely spaced on steam pipelines. The closely spaced expansion loops are the key to identifying steam pipelines.

Above ground pipelines are distinct from and darker than the surrounding ground. Buried pipelines may be revealed by the scar in the earth, and their trace may be discontinuous.

Pipelines are straight, with angular bends, but may be very gently curved. Junctions and branchings are rare (except around oil and gas fields and urban distribution systems), and are normally angular, but may be tangential. Although the alignment is straight, there will be little evidence of cuts and fills, as pipelines follow the surface of the ground. A cleared way will be present whenever the pipeline passes through a forested area. Pipelines are more likely to cross the drainage pattern than to follow it.

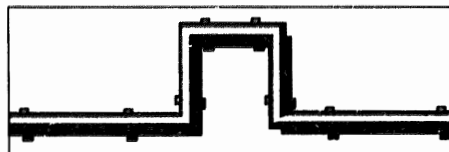


Figure 6: An expansion loop on an above ground pipeline. Note the small pedestals upon which the pipeline rests.

When a pipeline crosses a body of water, it is normally placed on the bottom, in which case there will be no visible indicators of its presence. A surface pipeline will be observed entering the water. A buried pipeline may have route markers placed along the shoreline at the point of entry. Occasionally, the pipeline may be suspended from floats, and remain on the surface. The contrast between the water and the pipeline and its floats will make it easy to locate and identify. The floats can be as elaborate as a set of small barges or pontoons, or as simple as a series of empty 55 gallon barrels. Floating pipelines would only be used in areas where they would not interfere with maritime traffic.

Relay Stations

As a fluid passes through a pipeline, friction slows down its movement. Uphill grades along the route require the fluids to be boosted up the grade. For this purpose, relay stations are placed at intervals along the pipeline route. Relay

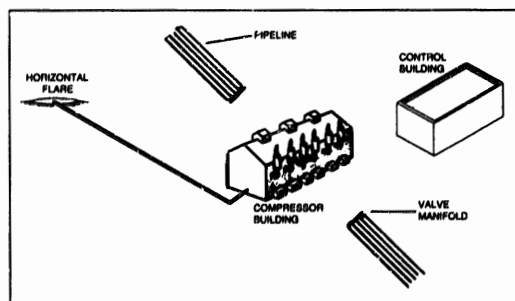


Figure 7: Diagram of an oil pumping station

stations consist of pumping stations (for liquids) or compressor stations (for gases) along with pipe manifolds, regulating tanks, storage tanks, and other associated features. Relay stations propel the fluid through and regulate flow in the pipeline. The spacing of the relay stations depends mainly on the topography, but is also influenced by the size of the pipe, the speed of movement and the type of material being moved. Over similar terrain, pumping stations will be more

closely spaced (16 to 100 km) than gas compressor stations (80 to 160 km).

Both pumping and compressor stations have a small, narrow, rectangular building which houses the pumps or compressors. It may have a gabled or flat roof, but will always have ventilators spaced along the length of the roof. If the pumps are powered by internal combustion engines, the exhaust pipes, with mufflers, will be visible along one side of the building. The number of pumps or compressors, and thus the length of the building, are proportional to the size and capacity of the pipeline.

An oil pumping station will usually have two or three small, regulatory tanks with cylindrical, flat or peaked roofs nearby, as well as a pipe manifold. A gas compressor station will usually have a pipe manifold, and a gasometer may or

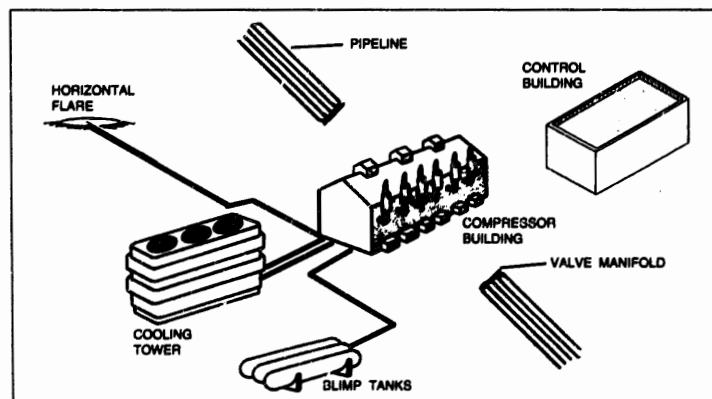


Figure 8: Diagram of a gas compressor station. Note the presence of the cooling tower and blimp tanks.

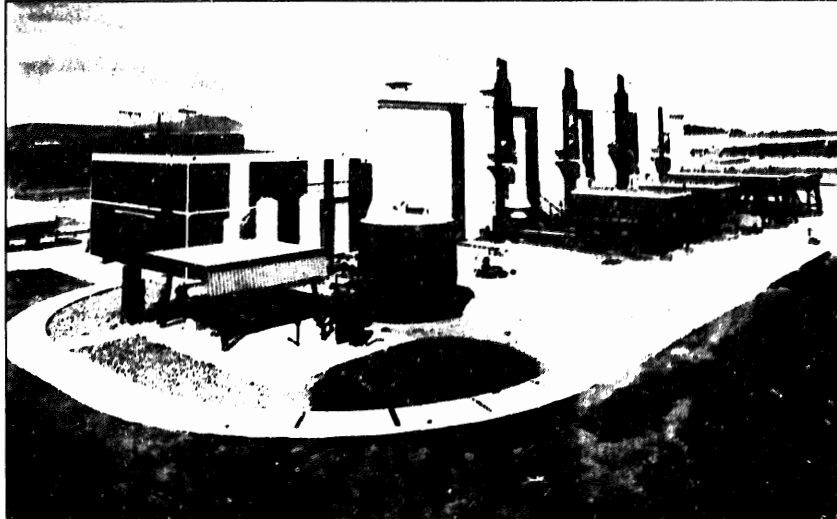


Figure 9: A typical gas compressor station. Blimp tanks are located at the far left of the picture. Individual coolers for the compressors are on the right side of the building. Note the shadow of a water tower in the foreground.

may not be present. Water pumping stations consist of a small building housing the pumps and an elevated or tower-mounted regulatory tank. Sewage pumping stations are small, plain buildings with no associated tanks. The sewer line will not be visible. Within an urban environment, the small sewage pumping station will be hard to detect.

A "city gate" is a station on a natural gas pipeline, located near a major point of consumption (such as a city) where the pressure is reduced and the flow is metered. The gas then flows along a branch line to the point(s) of consumption. The station consists of a manifold with valves, meters and regulators. A small building may be associated with the manifold.

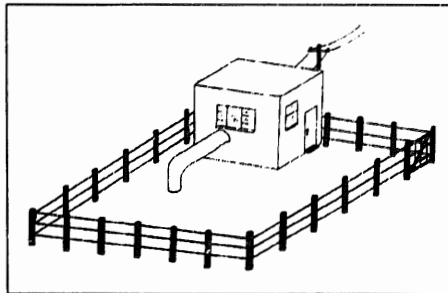


Figure 10: A pumphouse typical of those associated with water wells. Sewage pumping stations are similar in appearance.

Terminals

The large size and distinctive appearance of terminal facilities make them easy to identify. The storage facilities associated with the terminal are the best indicators of the contents of a pipeline, as each product has distinctive storage requirements. Since a pipeline is normally used for one-way transportation, there will be a source terminal and a destination terminal. Occasionally, a pipeline will end at a point of consumption, such as a manufacturing plant, where the obvious clues are absent. In these cases, a detailed examination of the components of the facility must be examined.

Source terminals can be oil or gas fields, reservoirs, rivers, storage areas, processing plants, or transshipment facilities. In any case, there will be a terminal pumping or compression station to propel the fluid through the pipeline. Terminal pumping stations are large buildings, substantially larger than relay stations. Destination terminals can be storage areas, processing plants, transshipment facilities or points of consumption. Storage facilities will also be present.

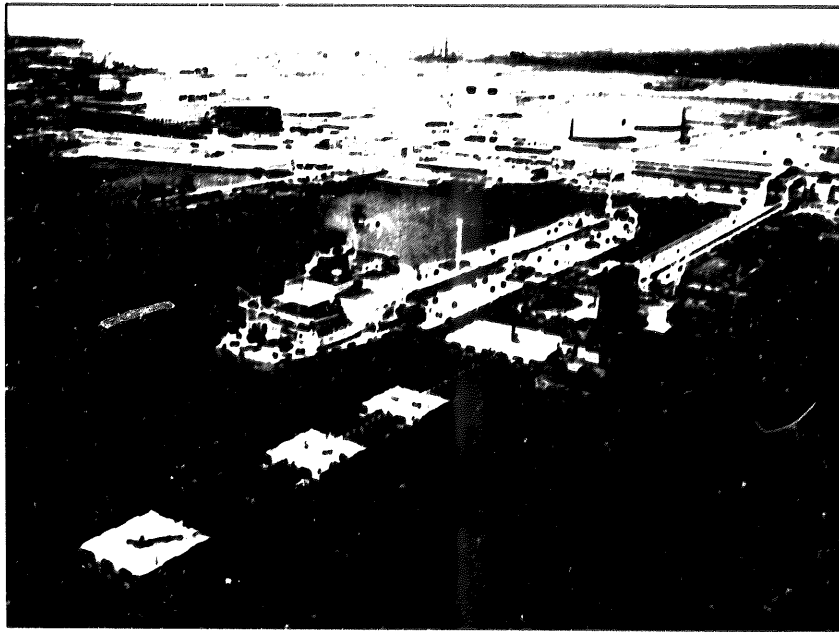


Figure 11: POI bunkering pier. Note the relatively narrow pier, the presence of pipelines and tanks, and the absence of cranes and other cargo handling equipment.

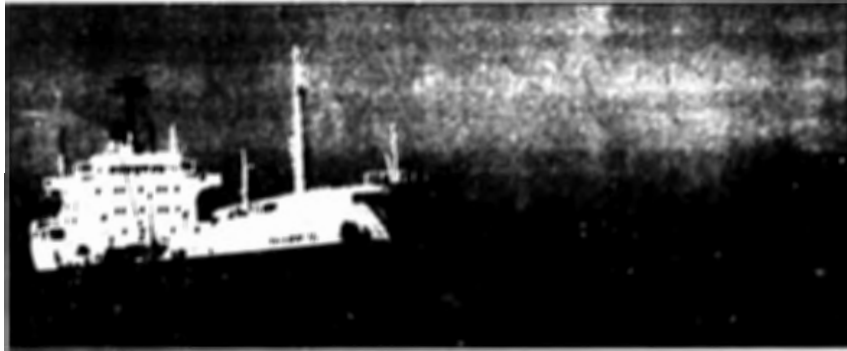


Figure 12: An oil tanker moored at a loading buoy. Note the relatively large size of the buoy and the pipeline emerging from the left side.

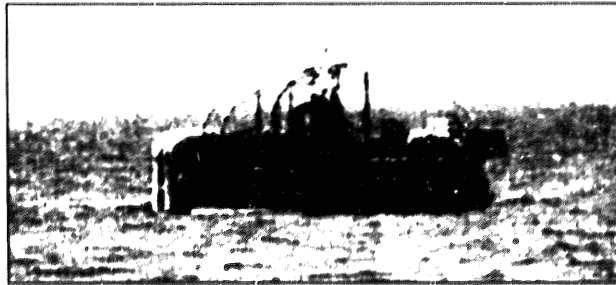


Figure 13: A closeup of the loading buoy from figure 12

An oil terminal pumping station will have a large pipe manifold, and a complex of pipes around the building. Storage facilities consist of cylindrical tanks, and occasionally spherical or spheroidal tanks. Open oil reservoirs are found at some oil fields.

A gas terminal pumping station will also have a large pipe manifold, but not as much pipe around the building. The building is high-roofed, and smokestacks are present. Storage facilities consist of wet or dry gasometers, but cylindrical, flat-roofed tanks may also be present.

Water purification plants are located near the urban areas which they support. Associated with the purification plant is a pumping station which sends the water to the elevated tanks and water towers that supply the area. The building is large, frequently more than 50 meters (150 ft) in length. If a pipe manifold is visible, it will be simple, with large diameter pipe. Several small tanks for chemicals

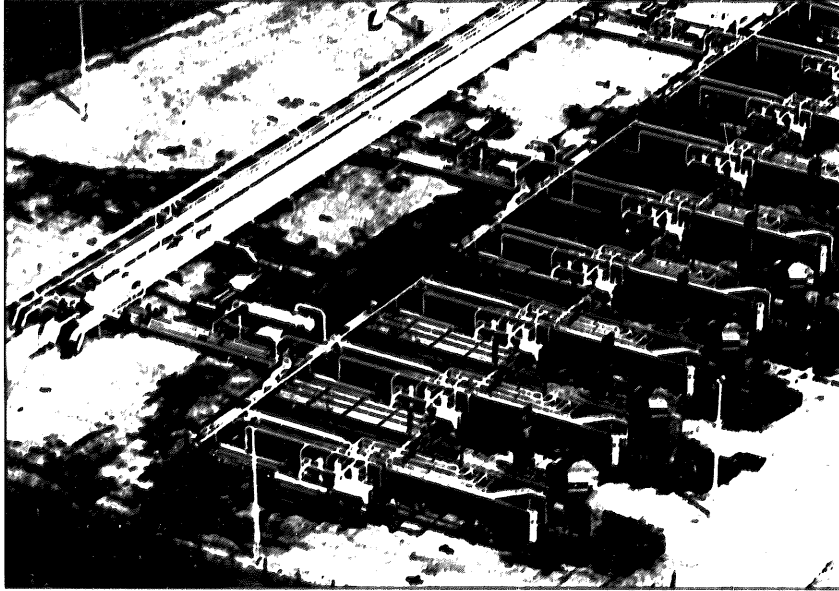


Figure 14: A large gas terminal pumping station. In this case, the compressors are placed in the open rather than inside a pump house.

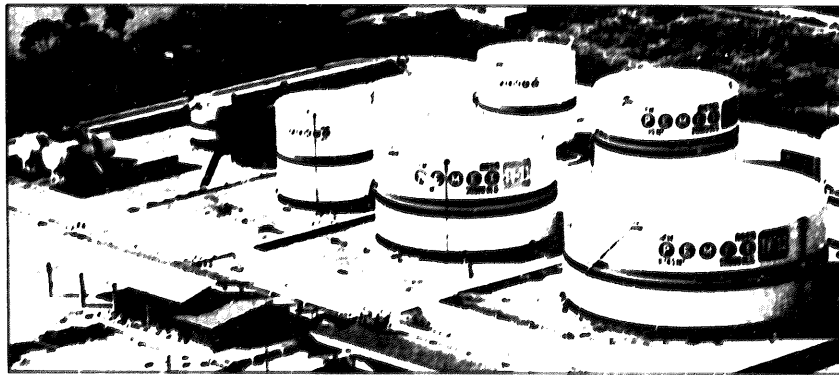


Figure 15: Oil and gas tanks at a POI transshipment point

Figure 58: A secondary light at the end of a breakwater.

Figure 59: A minor light powered by a battery, recharged through the use of a small solar panel.

at other points where it is necessary that mariners be warned or guided. Their principle purpose is to support a light

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used in water purification will be present. The water source (reservoir, river, wells, etc.) may be nearby, or the water may be brought in from a distant source via pipeline or aqueduct.

Sewage treatment plants are characterized by the presence of a number of round and rectangular aeration, sedimentation and treatment ponds. Sewage treatment plants are larger than water purification plants, and have more ponds. There will not be a water tower present.

For more information about sewage treatment plants, see Disposal Industries in Chapter 4. Oil and gas processing plants, and water treatment plants are discussed in Chapter 4, Processing Industries in the same chapter.

Aqueducts

An aqueduct is an artificial channel designed to transport water, for domestic purposes, from a remote source. The aqueduct is constructed with a steady downhill gradient, and the water flows to its destination without the aid of pumps. They are different from pipelines, in that the water is not confined to a closed conduit, and that water flow is maintained by gravity rather than pumping. Aqueducts are used worldwide, and extend from the water source to a city or town, or to industrial plants, sometimes emptying into another reservoir or a water filtration plant.

Aqueducts are normally built by excavating a trench in the ground's surface. Where soil conditions permit, the earthen slopes form the sides of the aqueduct. In many cases, the aqueduct is lined with masonry, concrete or asphalt to prevent erosion and loss of water.

In order to maintain the steady downhill gradient, aqueducts must be carried across valleys and other depressions on man-made, bridge-like structures. Various construction types are possible, but most common is the Roman masonry arch. Taller structures commonly use a multi-level arch. The aqueduct can be carried over smaller streams on flumes, or under the stream via pressure pipes known as inverted siphons. In some areas, it may be necessary to carry the aqueduct through tunnels cut into the hills.

Note: the term aqueduct is sometimes applied to the bridge-like structure, rather than the channel. This is especially common when referring to the Roman aqueduct bridges mentioned above.

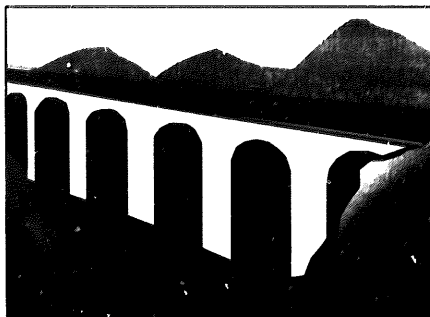


Figure 16: An aqueduct on a Roman arch type bridge

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Figure 61: This is a graphic representation of the placement of range lights for this harbor.

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Figure 17: An aqueduct crossing over a river

Aqueducts are usually open, but may be covered to reduce water loss through evaporation. Where an aqueduct crosses a valley on a bridge, it may also be covered, allowing a road to use the same structure.

The majority of aqueducts have sharp, straight or gently curved, man-made banks. They appear similar to canals, but are generally much smaller. Most aqueducts are between five and twenty meters wide and extend from less than a half kilometer to many kilometers in length. The water in the aqueduct will be dark, contrasting with the lighter tones of the aqueduct itself (white to light gray in tone for concrete, medium gray for metal or masonry, and dark gray to black for asphalt). Depending on the viewing angle, reflections from the water may be visible. Covered or dry aqueducts will have a lighter color, depending on the construction material. The shadow from a dry aqueduct would fall inside the channel, while the shadow of a covered aqueduct, if any, will fall outside.

Larger aqueducts may be confused with canals. There will be no boats present on an aqueduct, and thus the clearance under bridges crossing the aqueduct, and the vertical clearance in tunnels can be very low. In addition, there will be no locks, or other facilities common to canals. Inverted siphons are only used on aqueducts, and will not be found on canals.

The dark color of the water, and the regular sides and even width of the aqueduct, may make the feature resemble an asphalt road. Ripples or reflections would indicate the presence of water, and the absence of a centerline, or vehicular traffic suggest that it is not a road. Intersections with other aqueducts are rare, and aqueducts will pass over or under other features. Roads would have frequent intersections. Dry or covered aqueducts may look like concrete or masonry surfaced roads. Again, the lack of vehicles or centerlines, and the nature of the intersections, can be used to show it is not a road.

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Qanat (Karez)

A Qanat (or Karez) is an artificial underground conduit, that collects ground water and carries it to a location where it can be used for drinking or irrigation. It is characterized by a linear array of holes, which are surrounded by a mound of soil excavated from the holes. The holes are dug at regular intervals and connected underground to form a continuous conduit. The gradient in the conduit is steadily downhill and water flows by force of gravity. These features are found in arid areas, where surface water is rare, and the level of technology is low. The term qanat is used in the Middle East and northern Africa, but in western China it is called a karez.

Qanats are also found in Spain, Syria, Iraq and Pakistan, but are most extensive in Iran. Invented by the Persians in 3000 BC, there are currently over 22,000 qanats, comprising 270,000 km (167,770 mi) of underground conduits, that supply about 75% of Iran's irrigation water.

The qanat will begin in an alluvial fan, an ephemeral lake, or another area where the water table is near the surface. Several qanats can be used to bring water to a central location. The evenly spaced series of holes with the adjacent debris mounds make this an easily recognizable feature. The shadows within the holes stand out against the generally light tones of the arid landscape.

A qanat may be abandoned if the water table drops, the water becomes saline, or if a more dependable supply of water is found. Then the lack of maintenance will result in erosion and collapse of the holes and possibly vegetative growth in and around the holes.

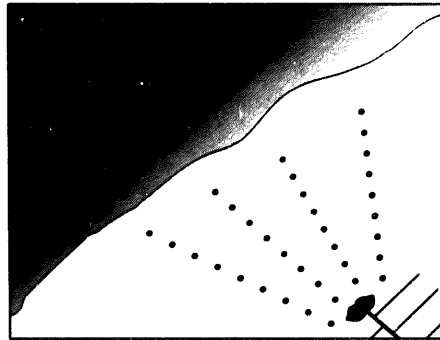


Figure 18: A set of four qanats bringing water to a small reservoir from which it is distributed via a series of irrigation ditches.

CHAPTER 4 – INDUSTRIES

Introduction

Chapter four deals with all aspects of industries. This includes components and industrial equipment, the extraction and transportation of raw materials, waste disposal, power generation, processing, and fabrication from materials provided by processing industries.

The text will cover the basic processes used in each industry, photo-identification of the industry, and a special emphasis on specialized equipment associated with that industry.

Industrial Components

There are pieces of equipment common to most industries. This common specialized equipment includes components used in handling, conveying, storing, and processing the materials for industry. The materials can be in solid loose or piece good forms, as volatile or non-volatile gases, and liquids. Every industry has the common problem of delivering raw materials and shipping finished products; transferring materials from storage, between processing sections, and onto transportation; and holding materials during processing.

This equipment is identified through its shape and size. The presence of some equipment is an indication of the process occurring in the plant. No one particular piece of equipment is definitive of a process but it does indicate industrial processing. Industrial components fall into one of five categories. These are storage, material handling, transportation elements, processing equipment, and support equipment.

Storage

Material storage is probably the easiest component to identify and one of the most prominent features of an industry. Depending on the material to be stored, storage can be required for solids, liquids, or gases. The type of solid, i.e., granular, piece goods, or bulk items mandate a certain kind of storage. The volatility of the liquid or gas also mandates a certain treatment.

Open Storage

Some materials are not sensitive to changes in temperature and humidity. These materials can be stored wholly in the open or in the open with minimal cover. Raw materials such as ores are typically stored in large open piles near transshipment and processing areas.



Figure 1: Stockpile

Extremely large stockpiles of ore are common at extraction and processing plants. Essentially this storage is a pile of material of varying tint (depending upon the material). Other materials that may be stored temporarily in the open, especially in semi-arid climates, include grains and vegetative products.

Often end products from an industry will be stored in the open. Examples of some of these materials include building materials, steel products, and wood.

The configuration of the stockpile sometimes defines the stored product. These stockpiles mostly represent finished products and are found near the outbound shipping area.

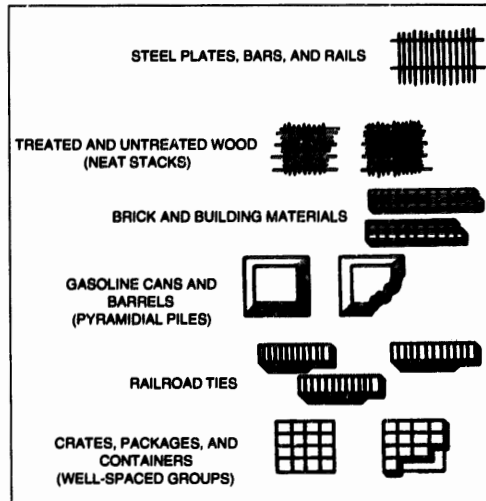


Figure 2: Open Storage Materials Key

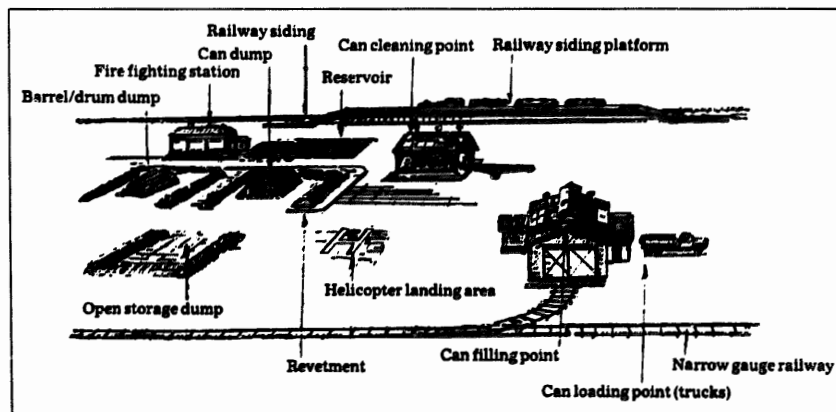


Figure 3: Open Storage Depot

Enclosed Storage

Most material used in industrial applications is sensitive to changes in humidity and temperature. Some material is photo-sensitive. These materials must be stored in enclosed areas for protection. Additionally, the very nature of some materials makes open storage impractical. Liquids and gases are obviously materials requiring closed storage. Of course some liquids can be stored in open reservoirs if volatility and contamination are not a concern. Other granular materials can be dispersed by winds and water and require closed storage. The dangerous nature of explosives and highly volatile fuels requires additional protection by either burying the storage area or through the addition of earthen walls and berms.

Warehouses

A common storage medium is the warehouse. Warehouses are commonly used to store bulk items, crates, and boxes. Sometimes granular material such as fertilizer (at fertilizer plants), sand and salt mixtures (at highway maintenance garages), and grains (at industrial sugar plants and grain elevators) will be stored in warehouses. The loose bulk material is stored in large domed storage structures or in large A-frame warehouse buildings. The typical construction material is sheet metal for the A-frame and concrete or steel framing for the dome storage.

However, most warehouses are single story flat or gable roofed structures that are very long in relation to their width. The warehouse is notable because of the lack of windows and lack of the numerous roof vents or cooling facilities normally associated with manufacturing and processing areas. The warehouses are usually aligned in an orderly arrangement. When associated with manufacturing and processing plants, the warehouse area is located adjacent to the outgoing freight or incoming raw material transshipment points. In all cases, the warehouse will have access to a transportation

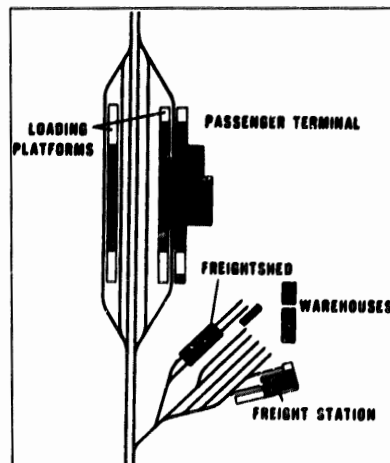


Figure 4: Warehouses at Freight Terminal

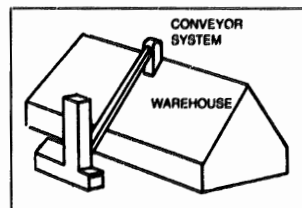


Figure 5: A-Frame Warehouse

network. Sometimes the warehouses will be connected by a road network. Steam pipelines may convey heat for temperature control. Generally, the warehouse area is distinct from an open storage area.

Another type of warehouse is the bunker (referring to a low solidly constructed structure), either above ground, buried, or partially buried. These structures store

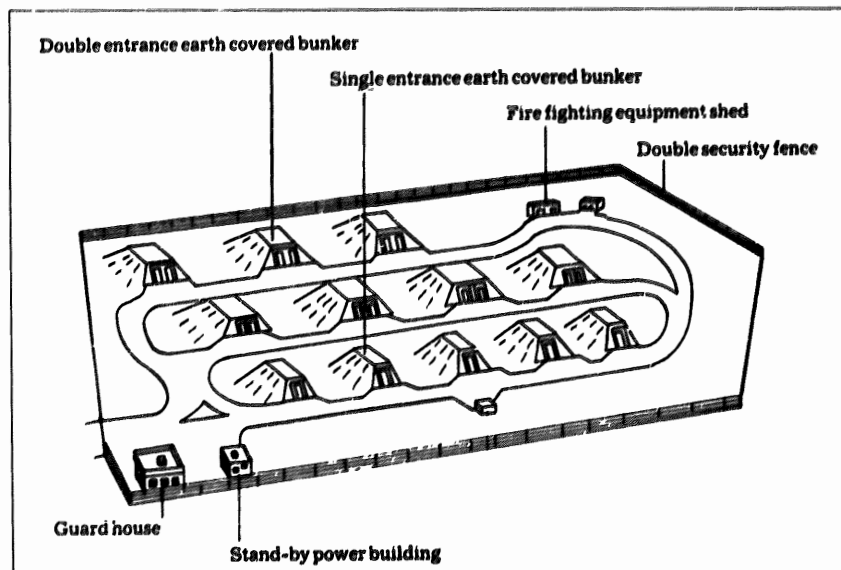


Figure 6: Earth Covered Explosive Storage Bunkers

hazardous and explosive materials. As with normal warehouses, the bunkers are aligned in neat orderly rectangular rows. These storage areas are most likely to be fenced with guard houses as access control points. Bunkers are readily identified by the orderly arrangement of earth covered mounds, casting distinctive shadows. Additionally the bunkers will be linked by road or rail lines.

Mobile material handling equipment may be visible in the area. The material handling equipment usually consists of forklifts or other specialized lifting and transporting equipment. Often the sides or ends of the warehouse will have freight docks to accommodate trucks or rail cars. Warehouse areas associated with rail, road, and shipping points are usually fairly clean, utilitarian, and neat facilities without the general clutter found around processing and manufacturing plants. Warehouse areas found in conjunction with large metropolitan areas will be found around the outskirts of the city or near manufacturing and processing zones.

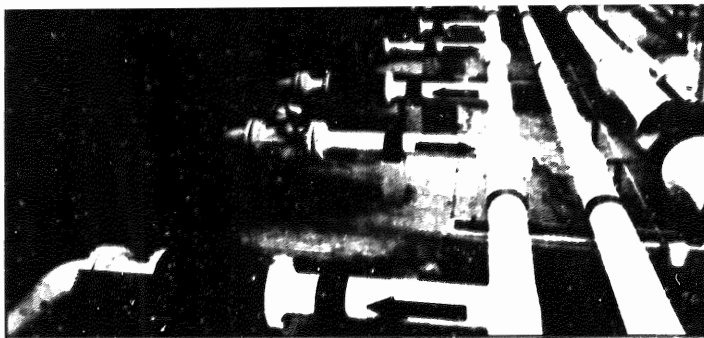


Figure 5: Large pipeline manifold at an oil pumping station

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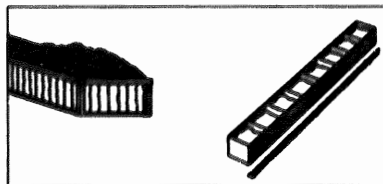


Figure 7: Open Storage Bins (Bunkers)

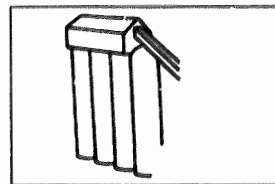


Figure 8: Silos

Silos, Bins, Bunkers, and Hoppers

Most solid chemicals and other granular materials require a method to both hold in storage and dispense for use. These storage mediums have in common their design to retain a solid granular material and dispense that material from the bottom. The material dispenses with the aid of a conical or pyramidal funnel. In the case of most silos, bins, and bunkers that funnel is internal and not visible. In the case of hoppers, the funnel is visible from outside the structure. These storage containers are filled from the top by way of conveyors (belt, screw, or bucket). Another method of fill involves driving the transporting vehicle over the container and releasing the contents directly into the container. Silos, bins, bunkers, and hoppers can occur singly, in groups, or inter-connected series.

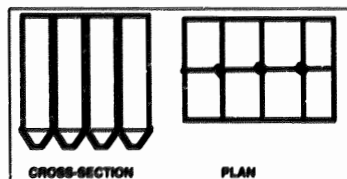


Figure 9: Inter-connected Silos



Figure 10: Silo and Grain Bin (Bunker)

A word about terminology is necessary. Silos, hoppers, and bunkers are types of bins. A silo is a deep bin while a bunker is a shallow bin. In the U.S., if $H > 1.5(A)^{1/2}$ [or in Soviet Code if $H > 1.5D$ (circular bins) $H > 1.5a$ (rectangular bins)], the structure is

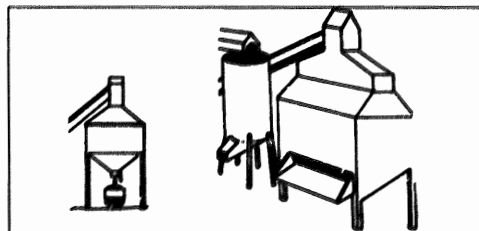


Figure 11: Bins and Silos with Visible Hoppers

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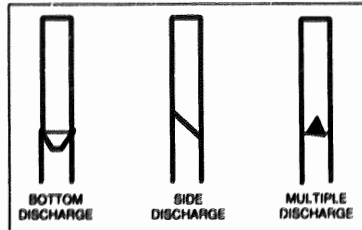


Figure 12: Hopper Discharge Type

a silo (H = height of container excluding hopper, D = diameter, A = area of the bottom of the container, and a = length of the longer side). Otherwise the structure is a bunker. The characteristics of the stored material (density, coefficient of friction, and angle of repose) determine whether a shallow or a deep bin is used. Most bins are equipped with hoppers to remove the stored materials.

In general use, what is often referred to as a hopper is a bin with a visible hopper. Bins can be rectangular,

hexagonal, or circular in cross-section although the circular bin is by far the most common. Most large industrial bins are made of concrete, a few are made of metal. Smaller bins tend to be made of concrete, metal, wood, and more and more, of composite materials. In agricultural use, grain bins are usually bunkers made of metal over a wood frame with conical sheet metal roofs. Some newer grain bins are of composite materials. Silos in agricultural areas are commonly used for storage of both silage and grain products. Silos in agricultural areas used for silage are made of masonry or concrete to withstand the high

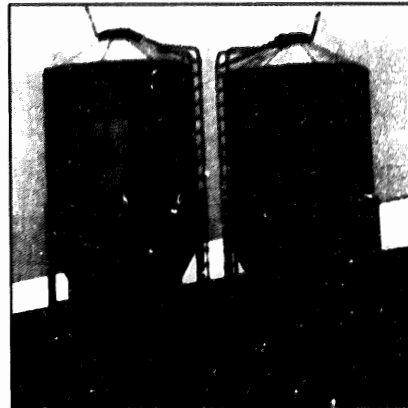


Figure 13: Agricultural Feed Storage Bins With Hoppers
Photo Courtesy G. J. Busbur



Figure 14a: Agricultural Grain Storage Bins
Photo Courtesy G. J. Busbur



Figure 14b: Agricultural Silos
Right to left: Masonry, Metal, Composite
Photo Courtesy G. J. Busbur

temperatures generated during the fermentation of the silage. Silos used for grain storage can be of concrete, metal, or composite materials. Most grain elevators are made of inter-connected concrete silos.

An additional note on objects that look like bins but aren't. In some geographic areas, particularly China, grain and grass products are stored in an upright position within an enclosure of scrap wood or fencing materials. The vegetative matter is further protected by the addition of a roof or cap of grasses. This looks like a grain bin but actually is not a permanent structure. Of course, this construct will not exhibit a radar reflectivity. Certain huts or dwellings commonly found in Africa, Asia, and South America also resemble grain bins but are in reality houses. Some configurations of water towers can also resemble silos. An important item to remember when identifying bins is the associations of features. Agricultural bins will be in farming areas, industrial silos will be found in manufacturing and processing plants, and water towers will be found in conjunction with water treatment plants, industries, and associated with inhabited urban or rural areas.

Tanks

Tanks are used to store fluid materials (gases or liquids). A storage tank is designed to store the fluid at a particular pressure. This could be atmospheric pressure or several hundred psi. The design accommodates a particular type of material, i.e., caustic or flammable. When the material is dangerous due to an explosive or inflammable nature, the tanks are bermed. This protects personnel and property in case of leaks or ruptures. In some cases, to provide additional security, the tank may be buried.

Almost every manufacturing and processing plant uses tanks. The tank is ubiquitous to industry. Often the tanks are found arranged in orderly rows, contained within a berm.

Tanks are classified by size and shape. In fact, the tank's configuration (size, shape, and number) in most cases can be used to enable the identification of what is stored in the tank and its use. This is especially true if even a partial identification of the utilizing industry can be made.

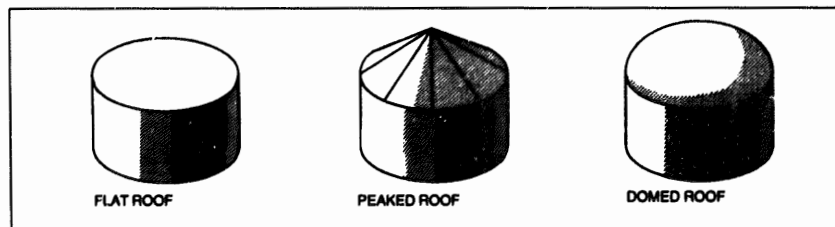


Figure 15: Upright Cylindrical (CAN) Tanks

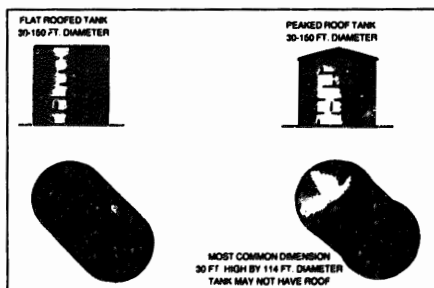


Figure 16: Shadows for Cylindrical Tanks

kerosene, alcohols, and crude oils. Domed tanks are used mainly in the storage of volatile fuels and chemicals. The dome flexes with pressure increases in the liquid due to evaporation. However, this type of tank is not designed to withstand pressure build-ups. Tanks designed for atmospheric pressure storage typically have a system of roof-top vents or pressure relief valves.

Cylindrical tanks are commonly placed on top of metal frameworks to serve as water supply towers. Water towers are easily identified due to their association with water treatment plants and domestic water users.

Tanks containing non-flammable chemicals usually are not bermed. Also, chemical storage tanks are normally connected across the top by walkways and a system of small (<4") piping.

Vapor Dome

The vapor dome tank is a cylindrical structure with a flat or domed roof. Additionally, the tank has a large dome on top of the tank roof. The dome allows for the collected vapor to accumulate and condense to fall back into the tank. This large tank is used in the storage of volatile fuels such as gasoline. These tanks are rare and will usually be found at distribution centers for fuels. The tank will normally be bermed.

Upright Cylindrical Tanks

Upright cylindrical (or can) tanks are used in storage of a variety of liquid materials. This type of tank can have a flat, peaked, or domed roof. The roof is fixed to the top of the tank.

The flat roof tank is used in the storage of crude petroleum, fuel oil, vegetable oil, tars and asphalt, molasses and sugars, chemicals, and water. Peaked roof tanks are used in the storage of volatile fuels such as gasoline and



Figure 17: Peaked Roof Gasoline Storage

Photo Courtesy G. J. Busbur

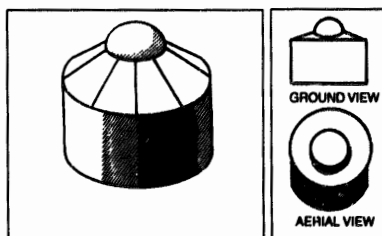


Figure 18: Vapor Dome Tank

Figure 19: Shadow

Figure 11: POL bunkering pier. Note the relatively narrow pier, the presence of pipelines and tanks, and the absence of cranes and other cargo handling equipment.

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Floating Top Tank

The floating top or pontoon top tank is used for the storage of volatile liquids and gasolines. The roof is not fixed but floats on top of the liquid. These large tanks are commonly found in bermed groups in fuel distribution centers and tank farms. The floating top minimizes the accumulation of vapors.

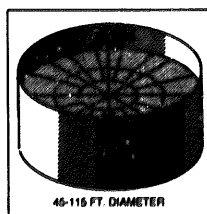


Figure 20: Pontoon Tank

Gasometers

Gasholders or gasometers are used solely for the storage of gases. There are two types of gasometers, the dry gasometer and the wet gasometer. The dry gasometer is a tall upright cylindrical tank with a dome on the top. The dry gasometer stores natural gas, industrial gas, and a variety of other gases. The wet gasometer is a telescoping tank contained within a steel framework. This steel lattice framework makes identification easy (especially when the shadow is fully visible). The lower section of the tank contains water to form a seal. As gas enters the gasholder, the pressure pushes the sections up, maintaining a constant pressure. The wet gasometer is used in the storage of natural gas, industrial gas, hydrogen, nitrogen, and oxygen.

Both types of gasometers are usually very large tanks. These are the largest of the tanks. Tank height can exceed 76 m (250 ft). Gasometers are found associated with coke, iron, and steel plants. They will also be found associated with natural gas distribution in urban areas.

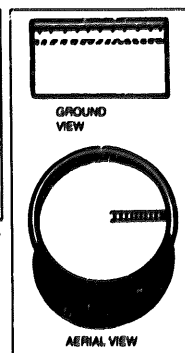


Figure 21: Shadow

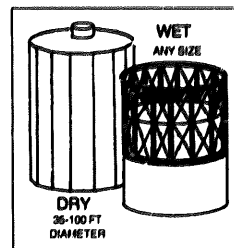


Figure 22: Gasholders

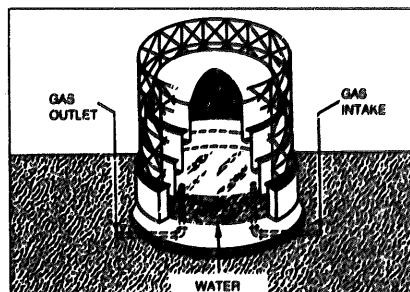


Figure 24: Wet Gasometer Operation

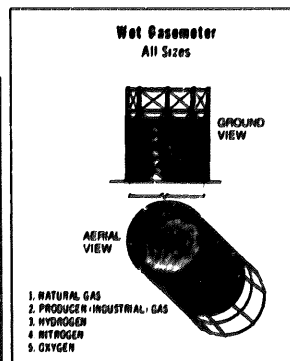


Figure 23: Wet Gasometer Shadow

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Bullet

Bullet tanks are elongated cylinders with rounded ends set upright. These tanks are used for the storage of high pressure gases or liquefied gases (such as LPG). These tanks are rarely found alone, but will be grouped in closely spaced rows. These are small tanks.

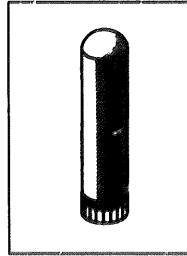


Figure 25: Bullet Tank

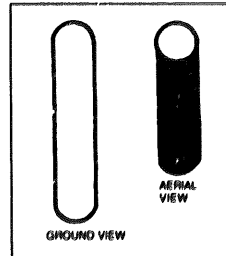


Figure 26: Bullet Tank Shadow

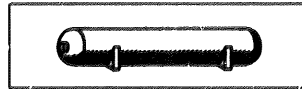
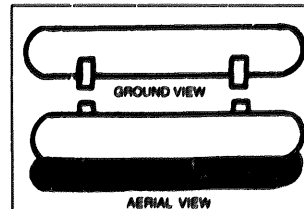
Blimp

Figure 27: Blimp Tank



Blimp tanks are elongated cylinders with rounded ends set horizontally. Blimp tanks are usually placed on a framework of concrete or steel. The legs may protrude from under the tank and be visible. These tanks are used for the storage of high pressure gases or liquefied gases (such as LPG). These tanks may be found grouped in closely spaced rows. They may also be found singly. These may be small tanks or size may range to medium. These are the type of tank used in "LPG" distribution (propane, and butane).

Figure 28: Blimp Shadow



Figure 29: Propane Storage in Blimp Tank
Photo Courtesy G. J. Busbur

Horizontal Cylinder

The horizontal cylindrical tank with flat ends is commonly used for the storage of fuels. These tanks are found in use by retail establishments and the user to store small and moderate amounts of fuel. This is the typical tank buried at gas stations and found throughout the country on farms, mounted on small metal frameworks.

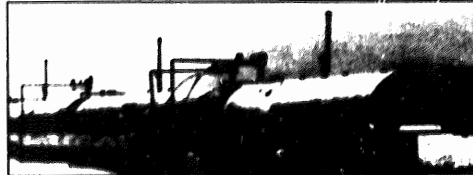


Figure 30: Horizontal Gasoline Storage Tank
Photo Courtesy G. J. Busbur

Spherical

These storage tanks can be a pure sphere, a flattened spheroidal shape, or a noded spheroidal shape. The spherical (Horton sphere) tank is used in the low pressure (15-55 psi) storage of LPG, natural gas, and industrial gases; or helium, nitrogen, and oxygen gases. Spheroidal tanks store highly volatile liquids such as LPG. The noded tank is found associated with gasoline storage and the storage of other highly volatile fuels.

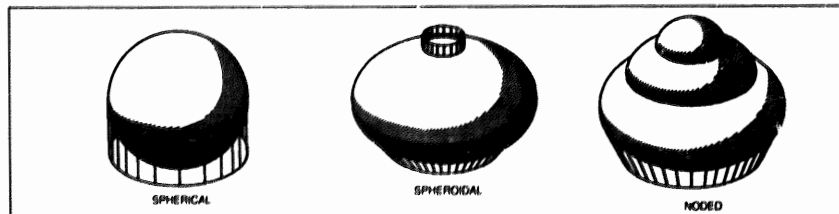


Figure 31: Spherical Tanks



Figure 32: Spherical Nitrogen Storage Tank
Photo Courtesy G. J. Busbur

A special note on the tonal appearance of tanks. Sometimes a mixed tonal pattern of light and dark tanks is found. The dark tones may be the result of stains or rust on the tank. Dark toned tanks result from a dark toned paint. Dark toned paint helps to heat the tank (solar radiation). The heated tank aids in reducing the viscosity of the heavy fuel or heavy oils contained within the structure.

Light toned tanks, in these cases, hold light fuel oils or volatile fuels which do not require the increased temperature in order to flow. The mixed tonal pattern is often found in at POL storage and an oil refinery.

Assemblages of solid black tanks are often used to store viscous materials such as molasses. Extremely light, bordering almost brilliant white, tanks could be insulated tanks for storage of LPG and LNG.

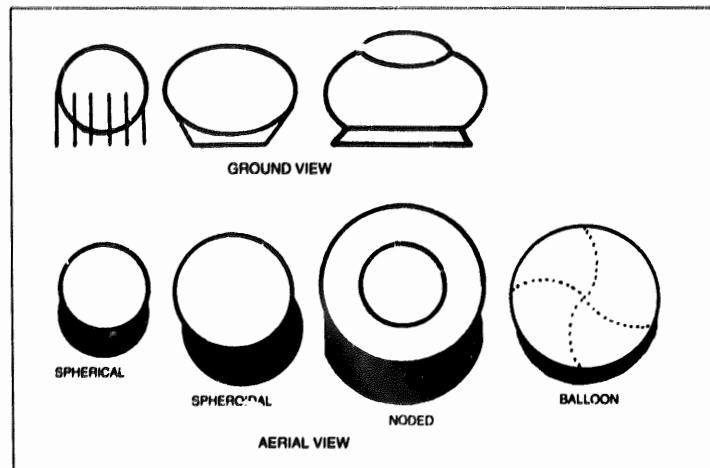


Figure 33: Spherical Tank Shadows

Materials Handling

This section on material handling addresses the methods of moving solids around the industry. The raw materials, semi-finished, and finished products must be moved numerous times during processing and fabrication. Numerous specialized devices have been created to accomplish this goal. Most of the specialized handling gear falls into one of three categories. These are cranes, mobile handling equipment, and conveyors. Pipelines, used to carry liquids and gases will be handled in a separate section.

Cranes

Cranes are used extensively in fabrication industries. To some extent some types of cranes are used in processing plants. A modern plant has a considerable array of lifting and materials handling equipment to move the heavy materials. The lifting equipment is composed of derricks and cranes. Identification of the type and capacity of the lifting equipment aids in assessing the capabilities of the plant. Cranes are grouped by their identification elements into cantilever, jib, gantry, bridge, derrick and shearlegs, cable, and pontoon (floating) cranes. The lifting apparatus on the crane can consist of a hook, a grab bucket, or specialized container attachments. The purpose of a crane is to lift and move the load from one spot to another.

Cantilever Cranes

Cantilever cranes are composed of a horizontal counter-balanced beam mounted on top of a tower. The load can be lifted and positioned laterally along the length of the beam. The crane arms rotate on the pedestal. Three types of cantilever cranes are tower hammerhead, elevated, and giant hammerhead. The tower hammerhead and elevated cantilever cranes move along on tracks while the giant hammerhead operates from a fixed base.

The tower cantilever crane is a beam crane with rails at the base. The elevated cantilever travels on a set of elevated rails or runways. Tower hammerhead and elevated cantilever cranes are used for construction and repair. Their capacity runs from 5—20 tons or more. A specialized tower crane is the tower transporter. This crane is used to load and unload bulk material such as grains and ores. The bucket picks up the load, runs it under the tower, and unloads on the opposite side. Most cranes of this type are found in port facilities and ore processing plants.

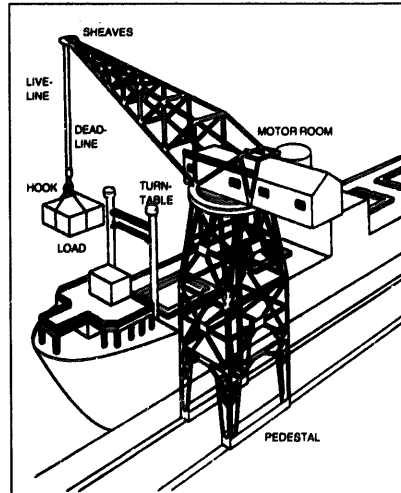


Figure 34: Crane Components

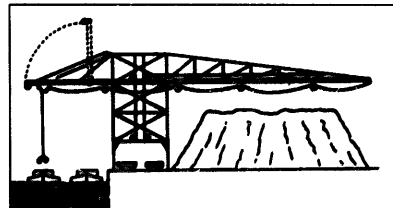


Figure 35: Tower Transporter

Giant hammerhead cantilever cranes are towering massive cranes with a fixed base. These cranes are used in lifting massive objects such as boilers and large sub-assemblies. General capacity is 100 – 300 tons or better.

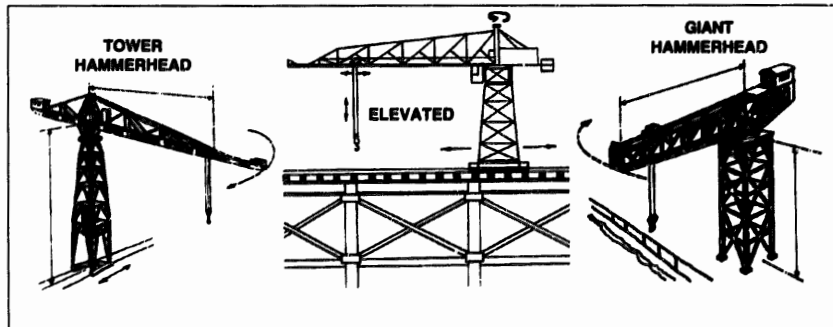


Figure 36: Cantilever Crane Types

Jib Cranes

Jib cranes are characterized by inclined booms (called jibs). The load is positioned laterally by raising or lowering the jib. The maximum reach for the jib crane depends on jib length, load weight, and jib angle. Types of jib cranes include tower jib, elevated jib, portal jib, semi-portal, locomotive jib, automotive jib, and the fixed-base jib.

The tower jib is mounted on a tower with rails at the base for travel. The crane is used for construction along the building ways. The capacity runs from 5 – 30 tons or more.

The elevated jib is mounted on elevated rails for movement. This crane is also used for construction in the building ways and has a capacity of 2 – 30 tons or more.

The portal jib is a crane is a boom crane mounted on a portal type base (large movable base with four legs and high clearance). The crane is used for heavy construction and repair with a capacity of 5 – 25 tons or better. The semi-portal crane has one side of the portal attached to a structure such as a building.

A locomotive jib is a jib crane mounted on rails with a low cab. The crane is used for repair and movement of materials within the industrial plant. The capacity runs from 1 – 20 tons and upward. Automotive jib cranes are boom cranes mounted on wheeled or tracked bases. This is the common crane found in almost any construction project. This crane is used for general utility purposes and has a capacity of 1 – 5 tons or so.

The fixed-base jib is a boom crane mounted on a fixed-base. The crane is usually used in shipyards and has a capacity of 5 – 10 tons or more.

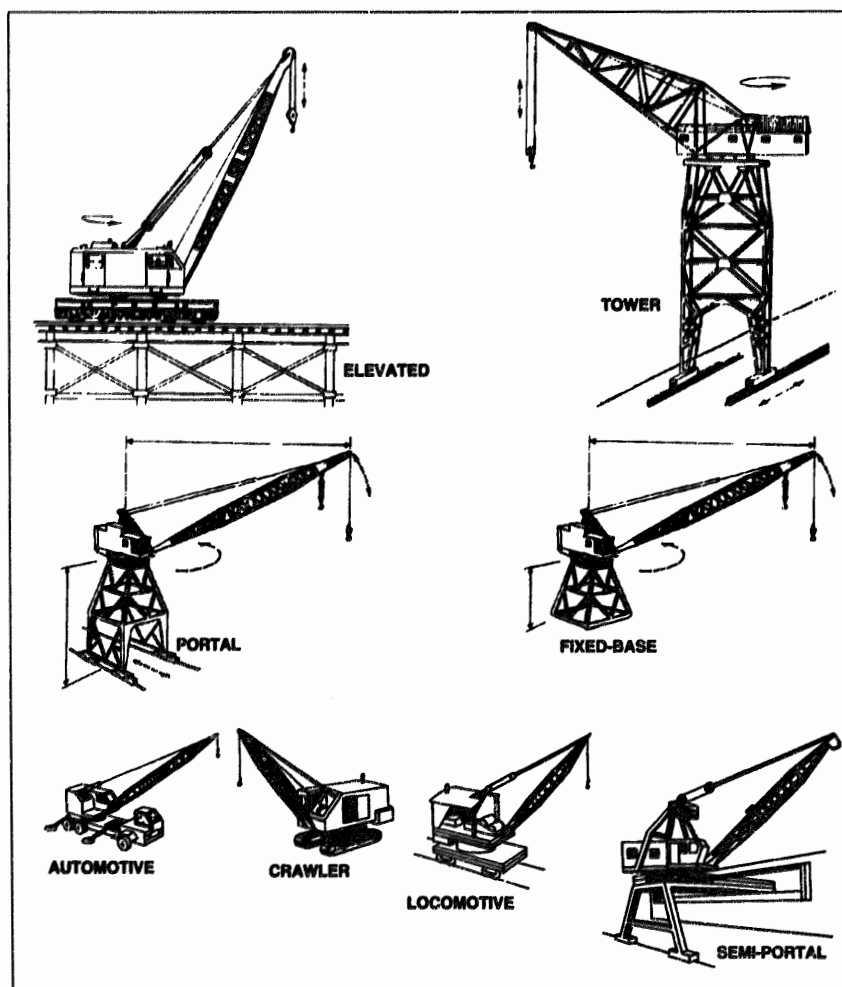


Figure 37: Jib Crane Types

Gantry Cranes

The gantry type crane is an elevated horizontal bridge mounted on one or two uprights that travel on rails. Or the gantry can be a bridge traveling on elevated runways. Types of gantry cranes are gantry, semi-gantry, bridge, and multiple-bridge. The load is hoisted by hook or buckets to the required height and moved laterally along the bridge. The entire bridge section can be positioned along the length of the supporting track.

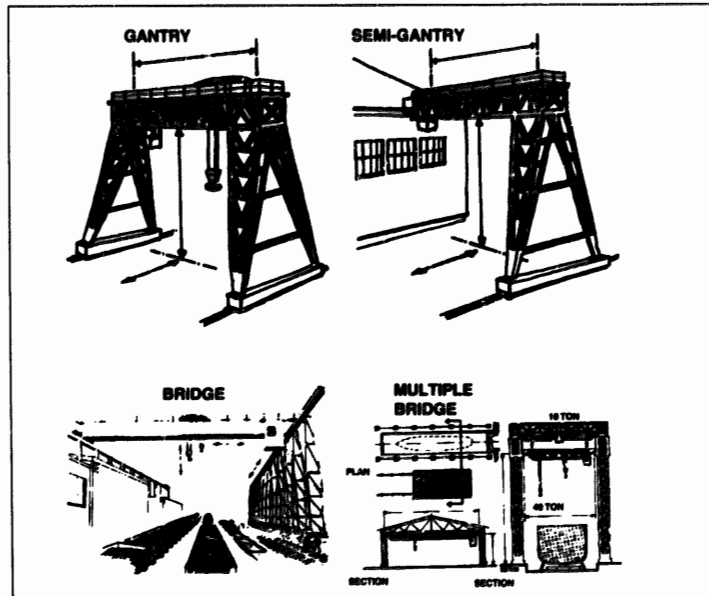


Figure 38: Gantry Crane Types

A gantry crane is an elevated bridge supported at either end by uprights that run on rails at the base. This crane is usually found over assembly and storage areas. The crane moves material for construction and storage. Capacity is 20 – 50 tons or more.

The semi-gantry crane is a horizontal bridge supported by one upright. The other end is supported on rails attached to the wall of a building. The capacity is a minimum of 5 – 50 tons. The crane provides for movement of material anywhere within the industry and is attached to the building.

Bridge gantry cranes are elevated gantry cranes traveling on trestle or otherwise elevated rails. The cranes are found over buildings, assembly, and storage areas. This crane has a minimum capacity of 5 – 150 tons.



Figure 39: Transporter Crane

Multiple bridge gantry cranes consist of two or more elevated bridges traveling on the same rail and same set of bridges. These cranes are used in construction and storage areas within the plant. The capacity ranges from 5 – 25 tons or more. These cranes are found in areas where the size range of the materials is great.

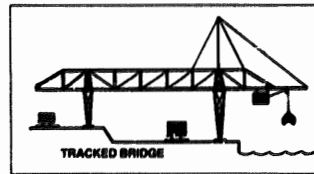


Figure 40: Bridge (Transporter) Cranes

Another type of gantry is the bridge crane, also called the bridge transporter. This crane operates in a manner similar to the tower transporter. It is also used in loading and unloading bulk grain and ores.

Derrick and Shearlegs Cranes

The construction of derrick and shearlegs is different as is their range of movement. However both play minor roles in shipbuilding and construction projects. A derrick is an arrangement of masts, guys, and braces usually consisting of a

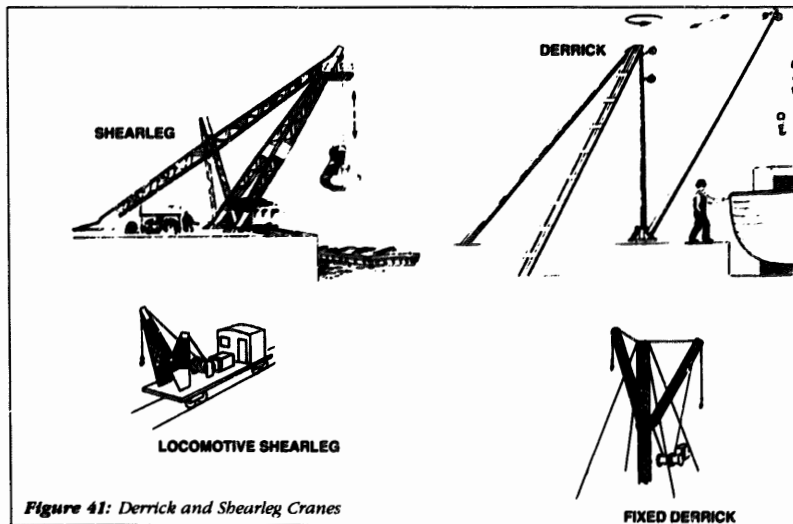


Figure 41: Derrick and Shearleg Cranes

vertical mast with an inclined boom. Derricks are fairly small with a capacity of 1 – 10 tons. These cranes are used in fitting-out and repair work where the load is small and great mobility of the load is not required. They will be found in dry-docks, along wharves, and positioned on vehicles to provide integral loading and off-loading capabilities.

Shearlegs are A-frame structures secured by beams and braces directly to the ground. They are commonly found at graving docks or wharf structures (quay, wharf, or pier). They are used in fitting-out and repair work where only hoisting is required since these cranes cannot swing a load. The capacity runs around 1 – 30 tons.

Specialized Cranes

There are several highly specialized devices that can be classified as cranes. Most of these are found in ports and are used in loading and loading vessels. Container cranes are a type of tower crane designed to load export containers (conex). A coaling tower or coaling hoist consists of either a car hoist or a bucket system designed to handle loose solids. Another type uses a continuous bucket system (conflow) to unload loose solids from ships. Typically this system is also suspended from a tower.

Cable cranes (sometimes called aerial cableways, refer to the subject of conveyors) are rare and consist of a set of cables supported by two or more large trestles. Usually they are found spanning assembly areas with a hoisting trolley moving along the cable. Their capacity is fairly small, from 2 – 5 tons.

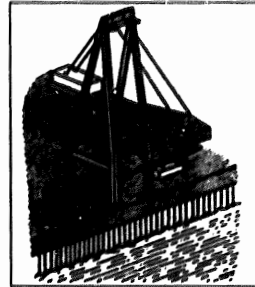


Figure 42: Container Crane

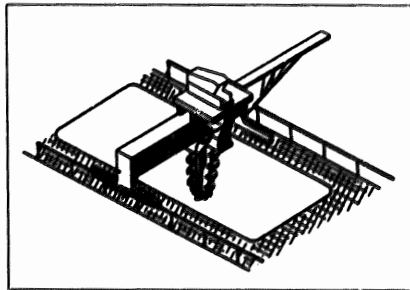


Figure 43: Conflow (Continuous Flow)

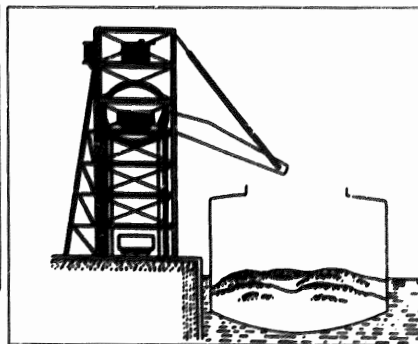


Figure 44: Coaling Tower

Floating Cranes (Pontoon Cranes)

Floating cranes are used intensively in shipyards and repair facilities to augment other cranes. These cranes are constructed on barges to allow free movement within the port area. Most floating cranes are floating jib cranes or floating shear-leg cranes. They are used for fitting-out and repair work. The capacity can run from 5 – 150 tons. Some floating cranes are specifically designed to handle extremely large loads. These are commonly found in shipyards and construction facilities building oil-field rigs for offshore. The capacity runs into hundreds of tons of lift.

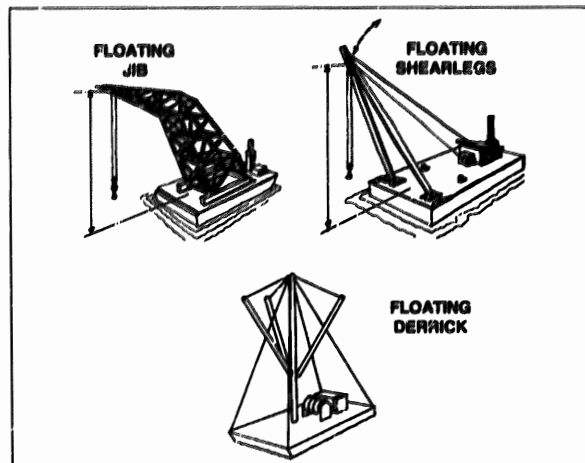


Figure 45: Floating (Pontoon) Cranes

Mobile Equipment

Since most cranes are limited to a specific range of operations, other pieces of equipment are used to manipulate materials out of range of the cranes.

Forklifts provide a medium to transfer large crates and other solid objects around the fabrication industry. Other vehicles may include front end loaders, bulldozers, wheeled dozers, power shovels, and tractor-trailers. Draglines and dredges are found associated with extraction industries (mining) and are covered within that section.

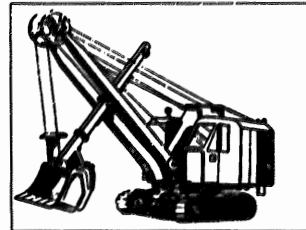


Figure 46: Powershovel

Conveyors

A central necessity in fabrication plants is the ability to move materials through raw storage yards, through the production process, and out to the shipping department. The most efficient method of handling materials within most plants is the conveyor. The term conveyor refers to a driverless and wheelless vertical or horizontal transportation system. Conventional elevators, hoists, and cranes are excluded from this classification.

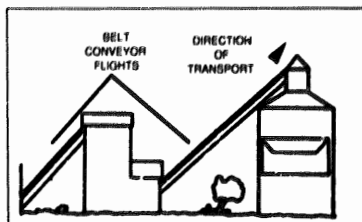
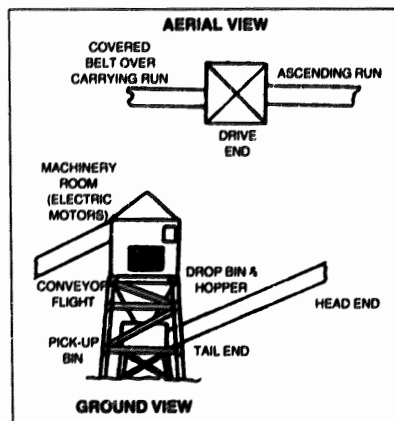


Figure 47: Belt Conveyor System

There are many types of conveyors. Each is designed to handle a certain class of material, i.e., loose solids, bulk solids, crates and piece goods, or granular solids. Some of the general classes or conveyor types include screw (augers), flight and apron (metal pans mounted on endless chains or transverse scrapers in troughs), bucket (vertical bucket elevators and chains), rollers, pneumatic and hydraulic (dust catchers and flumes), overhead (tram and overhead rail), and belt. Conveyors can be powered by gravity, electricity, or pneumatics.

Many of the conveyor systems operate within the plant buildings. Others operate transferring materials from outside storage. Some systems transport material for miles. Most of the visible conveyor systems consist of the bucket, screw, and apron or flight conveyors used to load silos and bunkers. The most common visible system is the belt conveyor. These also tend to be the longer systems along with overhead trams used in aerial cableway systems.



No matter which system is used, the material must initially be placed on the conveyor. In the case of granular solids stored in bins, the material is usually dispensed directly onto the conveyor using the bottom hopper. Augers can pick up materials by inserting the bottom of the screw into the top of the materials. Rail cars and trucks can dump into hoppers or rail or car tips can upend the vehicle and drop the material into temporary hoppers or directly into the hoppers feeding the conveyor. A conveyor designed to handle bulk loose solids usually consists of the conveyor and bins with hoppers at either end.

Figure 48: Conveyor Components

Figure 15: Upright Cylindrical (CAN) Tanks

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The belt system consists of an endless belt (rubber, composite, or metal) running on rollers. Each segment, or flight, normally runs at a slight uphill incline and dumps its load onto the next flight.

Screw systems consist of a helical inner sleeve rotating within a metal tube. The material enters at one end and is transferred through the pipe to the outflow end.

Apron or flight systems consist of metal trays carrying the material on a chain or a metal plate with transverse plates to restrain the material. The solids are deposited at the outflow as the tray tips over at the end of travel.

Pneumatic systems use a series of tubes or pipes powered by blower motors. A cyclone (conical hopper) recovers the transported material from the entrained air. These conveyors work with finely divided solids or in the recovery of dust.

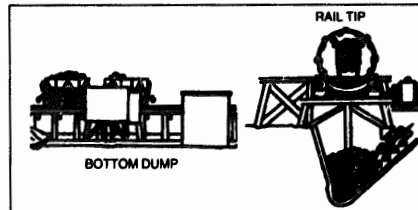
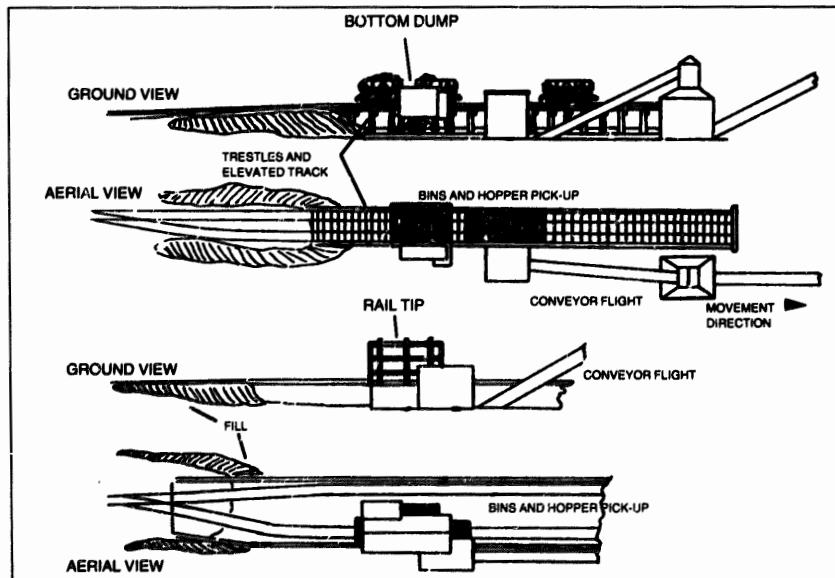
**Figure 49:** Car Unloading**Figure 50:** Conveyor Unloading Systems

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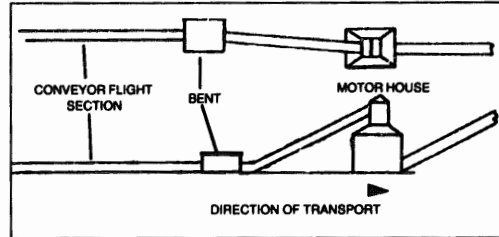


Figure 51: Conveyor Operation

Pneumatic conveyors are typically seen as part of the dust collection system on the roofs of plants, or, as short nearly vertical conveyors feeding silos.

Hydraulic conveyors (flumes, penstocks, and some types of pipelines) use water to transport materials. The material is divided small enough that the water can move the substance.

Conveyors can also be used for the long distance transportation of materials.

In most applications of this kind, the belt conveyor is the mode of transport. These systems can run for miles. The conveyor is normally covered and placed on or slightly elevated above the ground surface. At points along the route requiring the change of direction, a small mechanical structure is placed to accommodate the direction change (bent). Additionally, numerous motor houses are placed at intervals to provide additional motive power. The long, thin covered conveyor and small structures indicate the conveyor route.

Aerial cableways are rare and consist of a set of cables supported by two or more large trestles or pylons. The typical application is the transportation of ore from the mine to ore concentration or ore loading areas. The conveyor operates by a chain of buckets riding along the supporting wire. Their capacity is fairly small, from 2–5 tons. The aerial cableway is differentiated from a series of power pylons by several factors. The aerial conveyor begins and ends at industrial areas instead of transformer yards and substations. Substations may be positioned near the termini of the conveyor to provide motive power. Additionally, the buckets tend to lose a portion of their load as they pass over the rollers at the pylons. This results in a pile of ore on either side of the pylon.

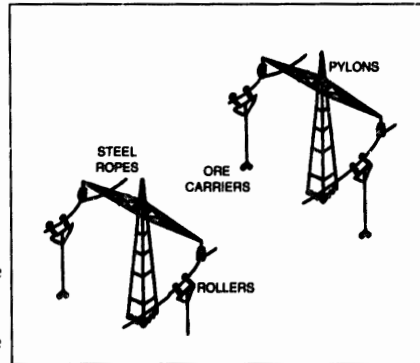


Figure 52: Aerial Tramway (Cableway)



Figure 24: Wet Gasometer Operation

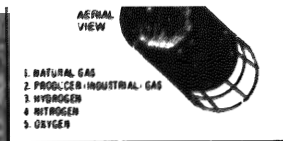


Figure 23: Wet Gasometer Shadow

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Transportation

Pipelines

Pipelines are unique in that the material is carried directly through the pipeline, rather than in a vehicle. This means that very little human supervision is needed. Transportation is not affected by the weather, as are other systems. Liquids and gases are not the only materials that can be moved through pipelines, some solids (such as coal) are pulverized and mixed with water to form a slurry in some conveyor systems. The volume of material that can be moved depends only on the diameter of the pipe and the strength of the pumps. Pipelines are very economical for long distance transportation. Additionally, pipelines are used extensively within industrial plants for moving fluids from one area to another. Every industry dealing with fluids has an absolute requirement for pipelines. While long distance pipelines tend to be large, at times exceeding 1.22 m (48"), pipelines in industry tend to run in the range of 6 cm - 11 cm (2 3/8" - 4 1/2"). Steam pipes will appear thicker due to the insulation around the pipe.

Location

Surface pipelines will appear narrower than roads or railroads, and will have regularly spaced angular jogs that compensate for expansion and contraction of the pipeline due to temperature changes. They are distinct from and darker than the surrounding ground. Buried pipelines may be revealed by the scar in the earth, and their trace may be discontinuous. Pipelines are straight, with angular bends, but may be very gently curved. Although the alignment is straight, there will be little evidence of cuts and fills, as pipelines follow the surface of the ground. A cleared way will be present whenever the pipeline passes through a forested area. Pipelines are more likely to cross the drainage pattern than to follow it.

Pipelines on the ground surface are readily recognizable. They are straight and narrow, and make angular bends. Frequent 90° bends at expansion joints are visible.

Junctions and branching are common within industrial facilities. This makes a maze of pipes, manifolds, and valves, rendering the tracing of pipes a virtual impossibility. Underground pipelines can be very difficult to locate. Terminal facilities are composed of pump stations, storage tanks and processing facilities that are readily identified.

Pipelines within an industry are commonly elevated off the ground surface. They may be supported at intervals by concrete abutments or telephone poles. The pipelines within the complex tend to be fairly short, running from one tank to another between processing areas.

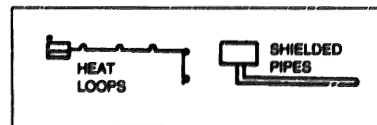


Figure 53: Pipelines

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Crossing points must be constructed where surface pipelines cross roads or railroads. At one type of crossing point, the pipeline is simply buried underground for a short distance, allowing the road or railroad to pass over it. These are easily recognized, as the pipeline disappears at the crossing point, and there is no discernible change in the road. An other alternative is to elevate the pipe a sufficient distance to allow traffic to pass under it. This is accomplished by placing a vertical jog or loop in the pipeline. The shadow of the elevated section of pipeline is very distinctive. A third method is to build a ramp over the pipeline. The ramp is usually easy to spot, as the pipeline is covered for only the width of the ramp. The shadow of the ramp may be visible.

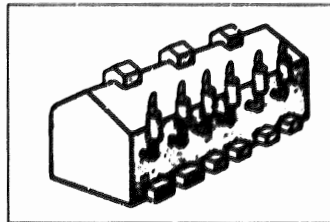


Figure 54: Pumphouse

Pumping Stations

Gases and liquids are fluids, that is they have no definite shape and conform to the shape of their container. They move or flow in response to gravity or other forces. Gases expand to fill the space they are contained in, and can be compressed into a smaller volume. Liquids are essentially incompressible, and will maintain a level free surface if their volume is less than that of their containers. It is these similarities and differences that dictate how gases and liquids must be handled. Liquids, because of their greater density and fixed volume, flow downhill readily, while gases need to be introduced into the

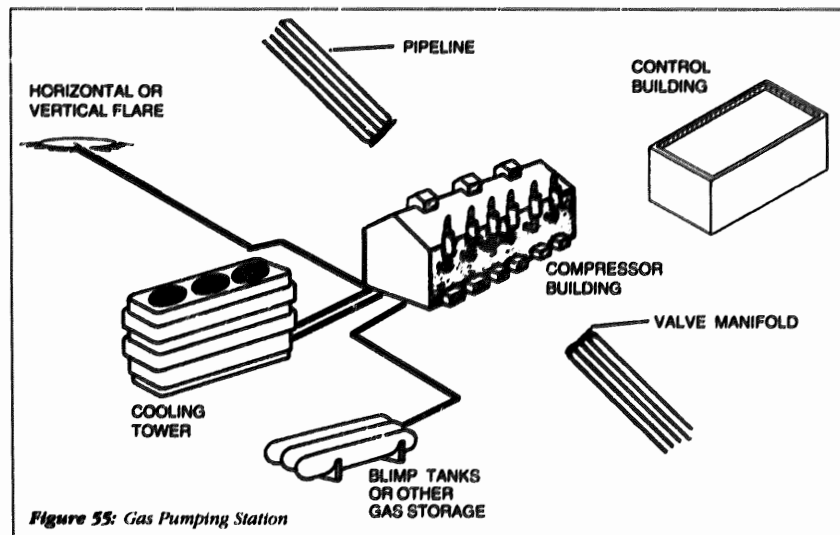


Figure 55: Gas Pumping Station

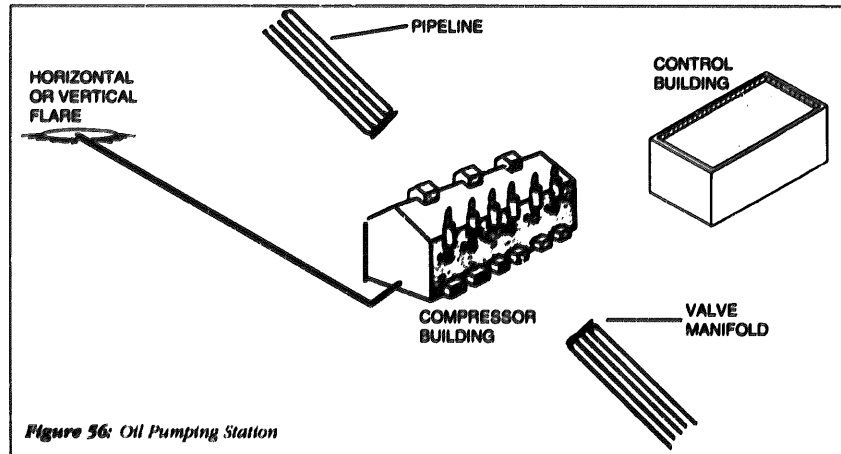


Figure 56: Oil Pumping Station

pipeline under pressure to induce flow. For uphill grades, both fluids require pressurization. For short pipelines, such as those internal to a facility, the initial pressurization is sufficient to carry the material to its destination. For longer pipelines, a series of relay stations (compressor stations for gases and pumping stations for liquids) are required to overcome frictional losses and to move the material through uphill grades.

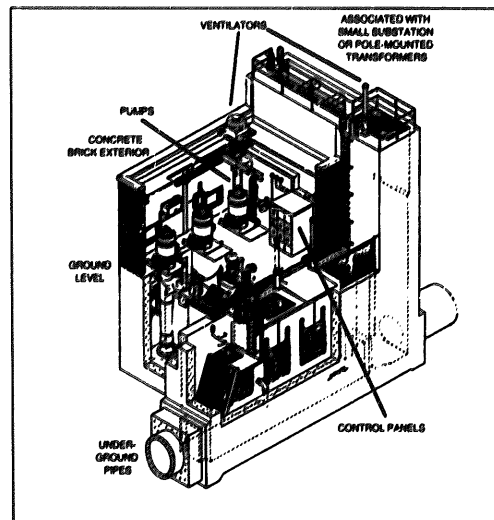


Figure 57: Water Pump Station (Domestic, Sewer, or Storm)

Both pumping and compressor stations have a small, narrow, rectangular building that houses the pumps or compressors. It may have a gabled or flat roof, but will always have ventilators spaced along the length of the roof. The building is typically of light steel frame construction. The building may be open along one side. If the pumps are powered by internal combustion engines, the exhaust pipes, with mufflers, will be visible along one side of the building. The number of pumps or compressors, and thus the lengths of the building, are proportional to the size and capacity of the pipeline.

An oil pumping station will usually have two or three small regulatory tanks with cylindrical, flat or peaked roofs nearby, as well as a pipe manifold. A gas compressor station will usually have a pipe manifold, and a gasometer may or may not be present. Water pumping stations consist of a small building housing the pumps and an elevated or tower-mounted regulatory tank. Sewage pumping stations are small plain buildings with no associated tanks. The sewer line will not be visible.

Pipeline Contents

The appearance of the pipeline does not provide much of a clue as to the material being transported. The best clues to this information are the terminal and storage facilities and relay stations associated with the pipeline. These facilities may be the only clues to the presence of a buried pipeline.

Chemical pipes run between components and the functional areas in a processing plant. They are usually small pipes that are raised off the ground surface. Look for pipes terminating at chemical storage tanks.

Gas pipelines are usually raised off the ground surface within the industrial complex. Long distance natural gas pipelines usually are buried but when not, more expansion loops may be visible. Gas pipelines are associated with gas wells (natural gas, helium, carbon dioxide), natural gas plants, and compressor stations. Also they will be present in vast numbers within most chemical processing plants.

Gasoline pipelines will be found within a refinery from those components producing gasoline. Long distance gasoline pipelines will be buried and of medium size.

Most of the pipes within a refinery will be transporting oil, specifically the crude and rundown storage areas. Long distance crude pipelines are large (several feet in diameter), require numerous pumping stations, and may have visible pipeline heaters.

Terminals

The large size and distinctive appearance of terminal facilities make them easy to identify. The storage facilities associated with the terminal are the best indicators of the contents of a pipeline, as each product has distinctive storage requirements. Since a pipeline is normally used for one-way transportation, there will be a source terminal and a destination terminal. Occasionally, a pipeline will end at a point of consumption, such as a manufacturing plant, where the obvious clues are absent. In these cases, a detailed examination of the components of the facility is required.

Source terminals can be oil or gas fields, reservoirs, rivers, storage areas, processing plants, or transshipment facilities. In any case, there will be a terminal pumping or compression station to propel the fluid through the pipeline. Terminal pumping stations are large buildings, substantially larger than relay stations. Destination terminals can be storage areas, processing plants, transshipment facilities or points of consumption. Storage facilities will also be present.

An oil terminal pumping station will have a large pipe manifold and a complex of pipes around the building. Storage facilities consist of cylindrical tanks, and occasionally spherical or spheroidal tanks.

A gas terminal pumping station will also have a large pipe manifold, but not as much pipe around the building. The building is high-roofed, and smokestacks are present. Storage facilities consist of wet or dry gasometers, but cylindrical, flat-roofed tanks may also be present.

Railroads, Ships, and Barges

An essential requirement for any industry is transportation to and from the plant. All industries require transportation of raw materials into the facility and finished products out. For this reason, industries are always located with good road, rail, or marine access. Many industries will have multiple transportation types available. The identification of road, rail, and shipping is covered in detail in other chapters. Please refer to these sections for additional information.

Many large industries have dedicated rail and truck yards or port facilities to handle the large amounts of material. Occasionally, an extremely valuable or isolated industry will also maintain its own airfield. In these cases, the airfield is normally used solely for personnel transportation or the delivery of small repair parts.

Freight terminals deal with the shipping, transshipment or receiving of materials. For packaged materials, a single-story warehouse is used. Loading platforms are present along one or two sides of the building. If material is to be stored at the location, the building can be quite large. A small building indicates that it is mainly concerned with transshipment. There must be enough room around the loading platforms for the trucks to maneuver, as well as an adjacent, normally paved, parking area for waiting trucks. Trucks and trailers will usually be present.

Bulk materials require special handling and storage. Solids are stored in silos or elevators or are piled in open storage areas. Specialized loading equipment, including conveyors and tipples will be present. Liquids and gases are stored in tanks, and special loading points, sometimes covered, are connected to the tanks by above or below ground pipelines. The presence of a parking area and trucks, which may be specialized vehicles such as tank trucks, indicates that the facility is a road terminal.

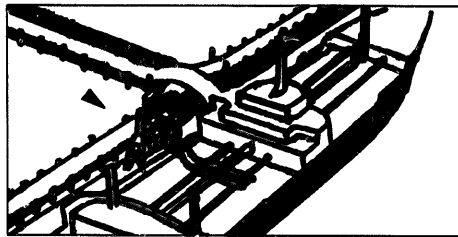


Figure 58: Liquid (Oil) Transloading Equipment

Processing Equipment

Essential to any industry is the processing equipment. This is the equipment used to hold the raw materials during whatever reaction or treatment is required to complete the process. The equipment includes vats, kettles, kilns or ovens, and an entire range of specialized tanks (thickeners, settling, and basins). Much of the equipment will not be visible since it is housed within the industrial structures or obscured within steel framework. Some industries have no visible processing equipment while others have equipment outside the buildings. In any case, a knowledge of the components can assist in the identification of the industry. Highly specialized processing equipment most often used in a particular industry will be covered in depth within the section dealing with that industry.

Kettles and Vats

Kettles and vats are tanks used to hold raw materials during chemical and heat reactions. Kettles and vats are used in the reactions involving liquid materials. Most treatment vats are enclosed to maintain even temperature and prevent the escape of the reacting chemicals. The vats and kettles are cylindrical tanks with rounded bottoms. Often the tanks are supported on a metal framework.

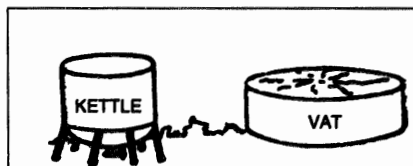


Figure 59: Vats

Kilns

Kilns are large ovens used to dry or calcine bulk materials. They are used also to fire or vitrify brick and other clay products. Most kilns are gas-fired but a few are electric powered. Rarely will a coal or coke fired kiln be identified. The most common type of kiln in modern industrialized nations is the horizontal rotary kiln. Vertical kilns can also be used. Some older installations (or in special applications) use a beehive kiln. The beehive (and oval) kiln is a conical shape oven used in manufacture of coke or brick (ceramics) products.

Kilns are used mainly in the earth and ore processing industries. Some of the industries include petroleum coke, cement and clay products, ore concentration, gypsum, phosphate rocks, alumina, magnesium, potassium, zinc, and titanium processing. These ovens can also be used in disposal industries for the reduction of hazardous waste materials.

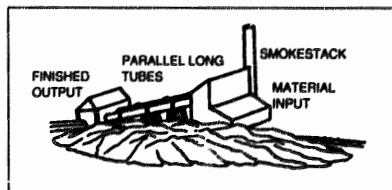


Figure 60: Rotary Kiln

The rotary kiln is a long cylindrical (tank-like) oven supported at the ends and often in the middle by gears. One end is higher than the other. The length of most rotary kilns ranges from 18 – 183 m (60 – 600 ft). The gears turn the kiln to assure even heating and to move the materials through the kiln. Typically the kiln is heated by gas flames fed from the lower end of the kiln. Rotary kilns consist of two or more parallel rotary ovens with small buildings at either end. One end introduces the raw material and the other extracts the material and houses the heating equipment and a small smokestack.

Vertical kilns are large tower-like (fixed) structures. They are fired from the middle of the lower level of the oven.

Rotary driers are smaller versions of the rotary kiln used for drying processed materials. They operate at a much lower temperature, not exceeding 427° C (800° F). Often the rotary drier will be associated with a de-watering tank or sedimentation tank that removes most of the liquid before drying operations.

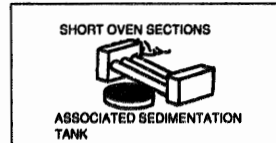


Figure 61: Rotary Drier

Tanks, Thickeners, and Other Treatment Vessels

Sedimentation tanks are used for the removal of suspended solids. Gravitational settling separates the denser and lighter components. Industries using sedimentation tanks include most processing industries, most notably the ore concentration, alumina, and magnesia plants.

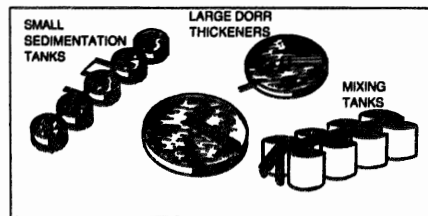


Figure 62: Sedimentation or Mixing Tanks

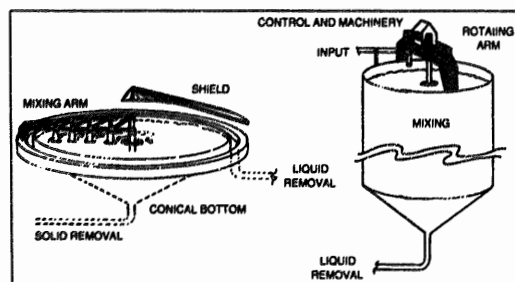


Figure 63: Industrial Vats and Tanks

There are several configurations of sedimentation tanks. Dorr thickeners (or de-waterers) are the low round tanks with a central pivot for bottom scrapers. The thickener can also have a large cross-arm across the tank to support the mechanical mixers. Often the tank has an access catwalk across the tank from the edge to the central pivot. These tanks are also used in the mixing of materials. Heavier materials settle to the bottom while the lighter material is removed from the top of the tank.

Sedimentation tanks can also be rectangular with or without bottom scrapers. Often this type of sedimentation tank is used in water treatment facilities.

Support Equipment

Smokestacks and Chimneys

Chimneys, smokestacks, or waste gas stacks dispose of unwanted and dangerous gases by diluting the concentration and releasing the material away from personnel and property. The type of emission and the particular danger associated with the gas determines the design criteria for the stack. The height of the stack partially determines the construction material (steel, brick, block, or concrete). The characteristics of the effluent, i.e., temperature, caustic, or acidic properties, determine which materials are used to line the stack flue (ceramics, metal, brick, or concrete). The design must provide for an exit velocity and a wide enough base to maintain structural integrity.

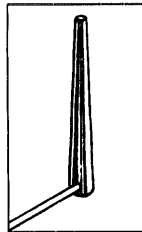


Figure 64:
Smokestack

The chimney is ubiquitous to industry. Almost every processing, power, disposal, or fabrication plant has one or more stacks. The size can range from a few feet to over 1250 feet tall. Extremely tall stacks are indicators of particular industries. Examples are nuclear power facilities, zinc, and copper processing plants.

Smokestacks up to 107 m (350 ft) can be made of brick, block, concrete, or steel. Brick or block chimneys are typically have a fairly wide base and diameter in relation to height. Tall brick smokestacks often use reinforcing steel bands at the top, bottom, and at intervals up the height. The bands provide additional structural support.

Stacks more than 107 m (350 ft) are made of steel or concrete. Steel smokestacks display the smallest height to base diameter ratio. The smooth sides often show the bands where the stack sections fit together. Steel stacks are sometimes guyed to provide resistance against wind loading. In some cases, the steel smokestack is supported by a steel lattice framework for structural support.

When the chimney height exceeds 380 m (1250 ft) concrete must be used as the construction material. Concrete smokestacks are constructed with walls 20 cm (8") thick for an internal diameter of 8.5 m (28 ft) or less. For every .6 m (2 ft) increase in diameter, the wall thickness increases by .6 cm (1/4"). The ratio of height to base diameter for concrete stacks is 12-13 to one.

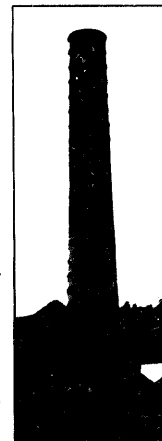


Figure 65: Brick
Smokestack

The primary function of the chimney liner is to protect the structural elements of the stack from the corrosive effects of the hot gases. A secondary function is to insure an adequate exit velocity of the gases, which ensures an adequate draw. Many stacks are brick lined with fiberglass or fused silica insulation between the brick and the stack. The brick lining will be supported at intervals by shelves built into the side of the stack. The shelves are made of Corbel block with asbestos seals. To protect against highly corrosive gases, steel liners will be used. These steel liners often are independent of the chimney, that is, the liner is supported at the bottom or hung from the top of the chimney.

Other liner types include independent concrete liners, independent brick liners, and the fiber re-enforced plastic liners. The fiber re-enforced plastic and brick liners are used when scrubbers are used. The scrubbers low temperature gas output results in higher levels of corrosive condensation within the stack.

Equipment found associated with smokestacks include dust catchers, scrubbers, precipitators, and horizontal flue collection systems.

Precipitators

Electrostatic precipitators are used to remove solid particles from combustion gases. This air cleaner operates by applying an electric charge, using suspended plates, to the gases passing through the flues. The solid particles then fall to the bottom of the device for later removal. Air cleaners are used to remove solids from the gases from burning coal, ore roasters, ore smelters, and steel production plants.

Gas scrubbers are also used in the removal of corrosive and dangerous gaseous materials from the waste gases by passing the hot gases through a scrubbing medium and exhausting the cooled and clean gas into the chimney.

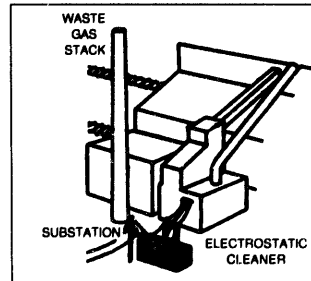


Figure 67: Air Cleaner

Dust Catchers

Dust catchers are mechanical devices used to remove solids from air. The dust catcher operates by blowing air entraining dust particles into a cyclone. The cyclone is a cylindrical tank with a conical bottom. As the air enters the cyclone, air speed drops. This allows any entrained solids to settle by gravity to the bottom of the cyclone for later recovery or disposal.

Cyclones may be found on the roof tops of most fabrication plants. Large cyclones are found anywhere dust could pose a health or safety hazard. Dust catchers are found in lumber operations and many ore processing plants.

Flare

Flares are used for the venting and disposal of combustible gases from processing units. Flares are common in petroleum refineries, petrochemical plants, and coke plants. The flare in the simplest form is a vertical or horizontal steel pipe with an igniter. A vertical flare is situated within a cleared area, often bermed, to provide a safety zone. Horizontal flares are virtually always bermed. The ground around horizontal flares will display burn marks on the surface.

Taller flares are often supported by steel lattice frameworks around the pipe. Flares within refineries often exceed 50 m (164 ft) in height. Often the flame and smoke from large flares are readily visible.

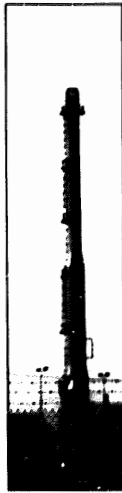


Figure 69: Refinery Flare.
Photo Courtesy G. Szigeti

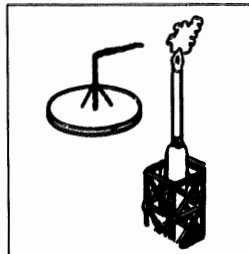


Figure 68: Vertical Flare Pipes

Cooling Facilities

Disposal of waste heat is a major concern in industry. Almost every industry, whether it be processing, extraction, power, or fabrication, generates an enormous amount of excess heat. In order for the industry to operate at peak efficiency, some method must be used to maintain the proper temperature. A case in point is chemical reactions. For every 10° C rise in temperature, the reaction rate doubles.

Industries with direct access to large rivers, lakes, or the sea are able to use the water as a heat sink. The plant will pump water from the body into the plant. When the water is heated, it will be exhausted directly back into the water body. The system is cheap, easy, and simple. The water, in most cases, requires only the removal of debris before use. Facilities include a pumphouse and intake pipe, on the upstream from the plant in the case of rivers, and an outlet pipe, on the downstream side. In the case of lakes and the ocean, the intake and exhaust is sometimes separated by small levees to prevent mixing of the water. Sometimes the outlet is visible as the returning heated water discolors the body of water.

Sometimes an industry will build an artificial reservoir equipped with a pump-house and an array of sprayers. The heated water is sprayed into the air, is cooled, and falls back into the spray pond for recovery. This method has the disadvantage of requiring a continual source of clean and treated water to replace

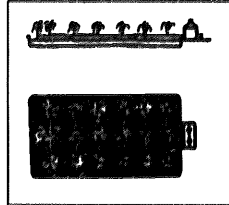


Figure 70: Spray Pond

water lost to evaporation. This system works best in areas of low humidity and moderate temperature.

More sophisticated cooling systems have been developed to cool the large amounts of waste heat generated by modern industry. Most of these systems require the use of treated water, i.e., clean and free of debris, and rely upon pumps, heat exchangers, and condensers in normal operations.

Perhaps the most common system is a radiator cooling system. This is the basis for the common home air conditioner along with larger industrial versions. The system uses ammonia or freon based coolants. The coolant expands, cooling an interior exchange system. The heated coolant is pumped to the outside, passing through a series of radiator equipped coils. The waste heat is passed to the atmosphere through radiation and conduction.

The cooled coolant material is then re-used without loss of material. The system is fairly simple but only supplies moderate amount of cooling. Units range in size from very small, sized for domestic use, to extremely large. Often the radiators will be placed on rooftops to take advantage of increased air flow.

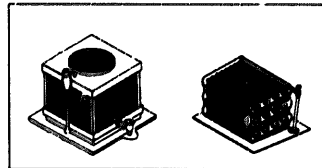


Figure 71: Radiators

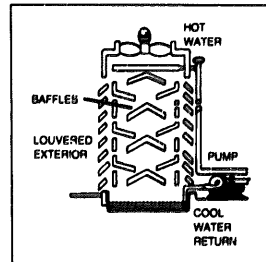


Figure 72: Operation of Cooling Tower

Larger capacity industrial systems use water as the coolant. The water operates the same manner as the freon in cooling systems. Heated water is cooled outside, returns inside to provide cooling, and is pumped outside again. Various types of systems are used depending on the amount of cooling required, the availability of replacement fluids, and local environmental conditions. The exterior portion of the cooling system consists of the cooling tower and connecting piping. The heated water is pumped to the top of the tower.

The water falls down over a series of baffles that break the water stream up. This provides a greater surface area for cooling. The cooled water is collected from the bottom of the tower and returned to the interior cooling exchange systems. During operation, these systems generate steam under the proper atmospheric conditions. In fact, sometimes the cooling towers will be totally obscured.

These systems can operate using the natural draft formed as the water cascades downward and loses its heat. Alternatively, the system can operate using forced draft provided by fans. These fans are situated at the top of the cooling tower

and are often visible. Some systems use a combination of natural draft assisted by fans. These units range in size from a small American Deck forced draft cooling tower to the extremely tall and large venturi towers commonly associated with nuclear power plants. As with radiator cooling systems, these units may be located on the top of buildings. Forced and natural draft cooling towers are commonly constructed of steel framework with wood louvers and interior baffles. Increasingly, more cooling towers are made of composite plastics and plastic over steel. The large venturi towers are usually constructed of concrete. Some older towers were constructed entirely of wood.

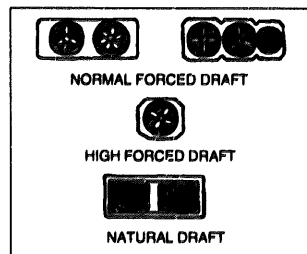


Figure 73: Draft Type

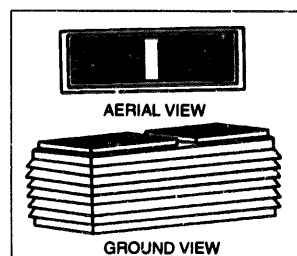


Figure 74: Natural Draft Cooling Tower

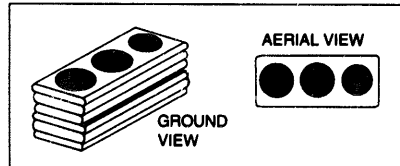


Figure 75: Forced Draft Cooling Tower

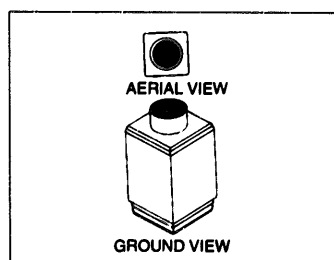


Figure 76: High Draft Cooling Tower

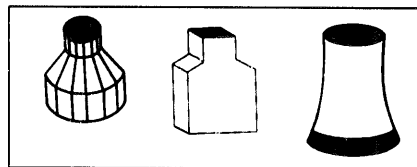


Figure 77: Venturi Cooling Towers

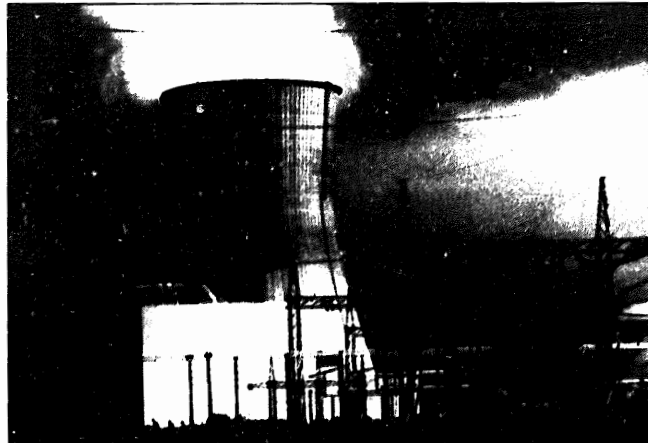


Figure 78: Large Venturi Cooling Tower at Nuclear Power Plant
Photo Courtesy F.J. Bushur

Heat Exchangers

Heat exchangers and condensers cool or heat a fluid through conduction. Almost every processing and fabrication industry uses heat exchangers in conjunction within cooling towers or other facilities.

Heat exchangers and condensers are used in cooling of fluids by contact with water, air, or coolant materials, condensing a vapor through coolant contact, and pre-heating and reheating through transfer of heat from hotter materials.

Most heat exchangers and condensers are extremely difficult to discern on imagery.

Extraction

The removal of mineral resources from the ground is the concern of extraction industries. This includes both the mining of mineral deposits and the production of fluid resources from wells.

Exploration

Prior to any attempt at mining or drilling, exploratory work must be performed to locate and confirm the presence of a sufficient amount of material to justify the expense of the operation. These exploration activities will leave their own special marks upon the landscape. Many activities, such as seismic surveys, are applied to the search for both solid and fluid deposits.

Geophysical Prospecting

Geophysical prospecting is the measurement of various physical properties (radioactivity, magnetism, seismic, and gravitational) of the rocks below the surface of the ground. These methods are used over areas ranging from a few kilometers to hundreds of kilometers in extent. A common denominator between all methods of geophysical prospecting is the requirement for precisely locating the sites at which the sensors are emplaced and measurements are taken. This involves the surveying and establishment of lines or grids across the area of interest. Where they are visible, geophysical prospecting lines are distinctive and can be used as landmarks for navigation purposes.

Although the lines themselves are not visible, the activity along the lines will often result in noticeable scars or marks. Trees and brush may be cleared to provide a line of sight for the surveyors. Subsequent movement of personnel and vehicles along these lines can damage vegetation and leave ruts in the ground.

Seismic exploration lines for example, may extend for over one hundred kilometers along a perfectly straight line. To provide access and space to lay out the sensors (geophones), a track will be cleared along the survey line. Survey points will be marked through metal poles or pipes (and attached plaques) along the line. The survey crews will use these tracks during survey operations after which the track will be abandoned. Occasionally, these tracks may be incorporated into the local road network.

In many areas, vegetation will quickly grow back and the prospecting grids will be completely hidden within a few years. In arid areas, however, there is little vegetation, and once disturbed, the ground surface will be distinctly marked. Because the soil forming processes work so slowly in the desert, these marks may remain for many tens of years. In addition, blowing sand (and soil) will build up around the survey markers and the abandoned geophone spikes forming small hummocks.

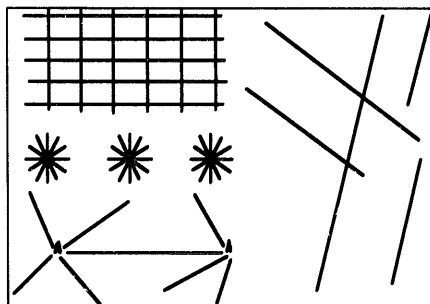


Figure 1: Common Geophysical Prospecting Grid Patterns

In forested areas, the trees are often cleared away from the survey lines to provide line of sight for the surveyors, and to provide access for vehicles. These cleared lines will also remain visible for many years after the surveying activity has been completed.

The patterns formed by geophysical prospecting lines vary from isolated linear features to grids or networks of linear features. Rectangular and radial patterns are common. The lines are perfectly straight, no matter what the terrain is like, and do not have logical starting and ending points. This helps to distinguish them from tracks and trails. Figure 1 illustrates some common geophysical prospecting patterns.

Prospects

Before large scale mining operations start a prospect is excavated. This is a small exploration mine intended to determine the extent of mineralization. If the prospect finds an economic ore body, the operation will be expanded to full scale, long term mining. Otherwise the area will be abandoned.

The typical prospect is a horizontal or vertical shaft mine. Small tailings (spoil) piles will be next to the mine entrance, usually on the downhill side of the operation. A prospect will not require more than minimal road access to the mine since ore will not need to be transported or processed at the site. If the site is abandoned, it will quickly become overgrown with vegetation.

Exploration Drilling

Before development wells are drilled, exploration (wildcat) wells are drilled to determine if the area has sufficient resources to justify further operations. If the resources are present, additional wells are drilled and the area becomes a producing field, otherwise the well will be plugged and abandoned. The same drilling equipment is used whether the well is for exploration or for development. While exploration wells are extensively used for oil and gas, mineral exploration also utilizes drilling (using smaller drill rigs) in the search for ore deposits.

Mining

Mining operations are classified by the method in which the materials are exposed and removed. Where the deposits are near the surface, the overlying material (overburden) is removed prior to the mining of the deposit, creating an open excavation. Where the depth to the deposit makes this method impractical, a tunnel (adit) or a shaft is dug to gain access to the deposit, and the mining is done underground.

Unless the mine can be linked to a nearby processing industry, it is nearly impossible to identify the ore being extracted.

BLACK	DARK GREY	MID GREY	LIGHT GREY	WHITE
				SALT
			BAUXITE	
			LIMESTONE	
				SULFUR
			GYPSUM	
			PHOSPHATE ROCK	
		IRON ORE		
			CLAYS	
			SAND	
		GRAVEL		
	COAL			
	LIGNITE			
			ORE CONCENTRATION WASTE	

Figure 2: Tonal Characteristics of Ores

	OPEN MINING	SHAFT MINING	PLACER
IRON	X		
COPPER	X	X	
LEAD		X	
ZINC		X	
TIN	X		X
NICKEL	X	X	
URANIUM	X	X	
ALUMINUM	X	X	
MAGNESIUM*	X	X	
TITANIUM	X		X
COAL	X	X	
PEAT	X		
SAND	X		
GRAVEL	X		
BUILDING STONE	X		

Figure 3: Common Mining Methods
 *Magnesium is also concentrated from brine.

Open

Open Pit

Open pit mining is used when the ore body is close to the surface and in a massive body or in thick layers. In the typical open pit mine, the rock is removed in stepped excavations (benches) resulting in steep cut sides (shear walls) arranged in a distinctive spiral pattern. These mines are large, sometimes several kilometers wide and more than a hundred meters deep.

Tailings (overburden) will be stored in large open piles. Ore may be stored in open piles, bins, or silos. There will be minimal (or no) buildings at the mine. Most open pit mines use explosives, so powder houses will be located at or very near the mine works. Drill rigs for drilling explosive shot holes will also be present.

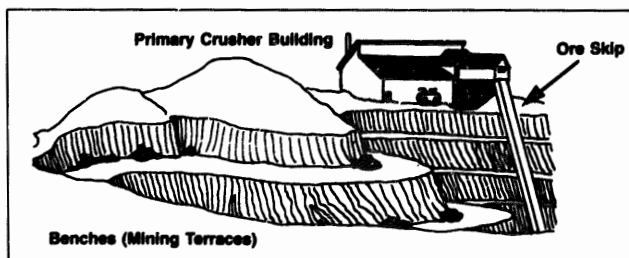


Figure 4: Open Pit Mine

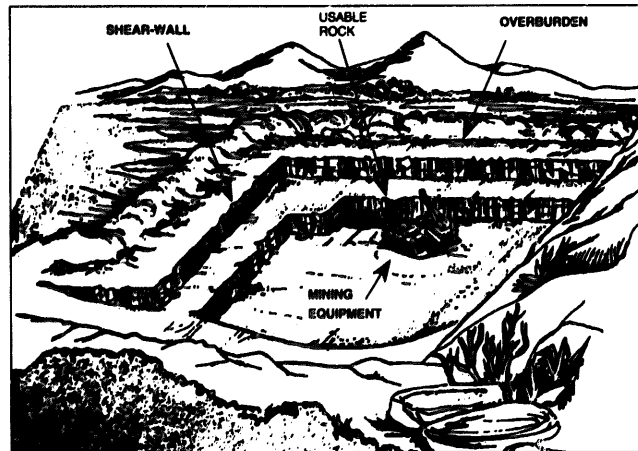


Figure 5: Quarry

Most of the equipment will be for handling the rock and ore and will consist of power shovels, draglines, mining trucks, front loaders, mine cars, and various conveyor systems.

Quarries are specialized open mines for the extraction of building materials such as sand, gravel, and stone. Processing for the extracted material consists of crushing, grinding, and sorting. Clay pits could be considered a form of quarry.

Barrow (borrow) pits are for excavation of fill materials. Such operations are found close to highways and railroads and usually parallel the route. Barrow pits will occur close to overpasses, fills, and causeways. Often the barrow pit will become a small lake after the required material is removed.

Quarries and barrow pits do not have tailing piles (except for dirt removed from the surface of the excavation) associated with them.

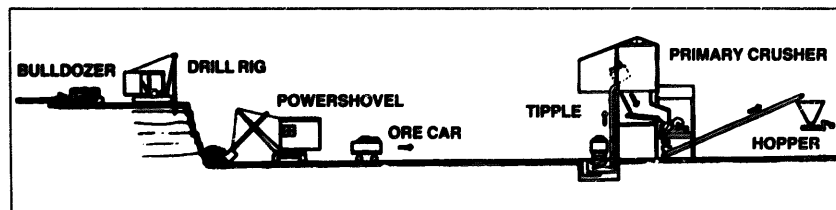


Figure 6: Strip Mining Operation

Strip Mines

Excavations of ores at shallow depth frequently take the form of strip mines. The overburden is fairly thin and the ore body occurs in thin beds. Area strip mining takes place in level and gently rolling terrain. Contour strip mining occurs where the terrain is steep.

In area mining operations the overburden is removed and transferred to previously mined areas. This results in a series of long narrow strips of parallel furrows. The operation continues until the ore thins or the overburden thickens. When the overburden becomes too thick, the mining is often continued via horizontal shaft (bank) operations.

In conventional contour mining operations the spoil is simply pushed over the downhill side of the bench, resulting in a series of wide fairly level ledges. In valley fill operations the mining proceeds laterally along the bench. A suitable low spot or valley is selected along the bench and the spoil is pushed over the side at bench height resulting in long narrow nearly flat ledges. In mountain top leveling mining the overburden is removed to the adjacent valley. This results in flattened hilltops, shallower valleys and a reduction in the local relief.

In haul back operations the spoils and overburden are moved laterally along the bench to the adjacent previously mined area. Once the operation has moved on, the land will be reclaimed and replanted. When reclamation is complete the area will very nearly regain its natural appearance.

Most equipment found at strip mines will be for material handling. Power shovels and draglines are used in mining operations. The draglines can be very large, sometimes over one hundred meters tall. Bulldozers and front loaders, along with mining dump trucks are also common equipment found at these mines

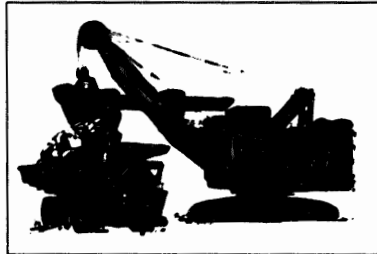


Figure 7: Mining Equipment Consisting of Ore Transporter and Dragline

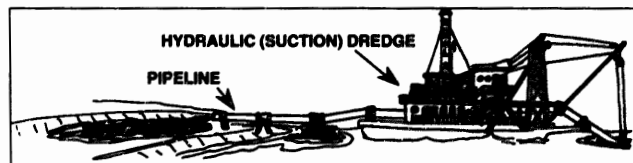


Figure 8: Placer Mining Operation

Placer

Placer mining is the extraction of disseminated ores from alluvial and glacial deposits. Placer mines are found along river courses. The deposit is excavated by digging,

dredging (using bucket, screw, or suction dredges), or water cannons. The ore is separated from the deposit by washing and manual inspection, and the spoils are returned to the excavation.

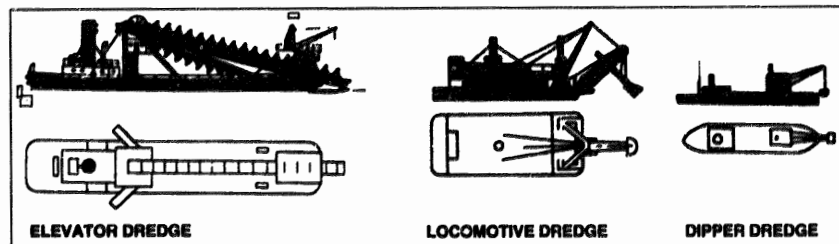


Figure 9: Dredge Types

Except in areas where large scale dredging is being performed, there is little scarring of the mined area. Large scale operations often leave scars similar to area strip mines. Sometimes the natural drainage will be disrupted to the point where it is realigned.

The presence of washing equipment such as sluice boxes, pumps, pipelines, and conveyors are indications that placer mining is occurring.

Peat Cuttings

Peat is an unconsolidated deposit of semicarbonized plant material occurring as false bottoms in bogs or fens. This organic material is high in moisture content but burns freely when dried. Peat is mostly found at high latitudes.

Peat is mined by cutting blocks of the material out of a ditched and drained bog, resulting in a distinctive rectangular pattern of shallow pits. The peat is very dark (due to high moisture and organic content) and is easily recognized when piled near the excavation.

Underground

When the ore deposit is situated too deep, or it is disseminated in narrow veins and seams, open mining techniques are not economical. In these cases the mining operations are carried out totally under the ground surface. Because the operation and equipment are underground and out of sight, and the mine is often located in mountainous terrain, it is difficult to identify the location of the mine. However the presence of an ore concentration plant and low capacity rail lines leading to the plant from the mine are useful indicators of underground mines.

Mine head equipment and signatures vary depending on whether the entrance is through a vertical shaft or a horizontal shaft. Both types have in common the

requirement for adequate ventilation. Block-like or cylindrical air shafts may be visible in the immediate area. Additionally tailings piles will be situated near the mine entrance. A store of timbers, used for shoring up mine walls and ceilings, will also be located near the mine.

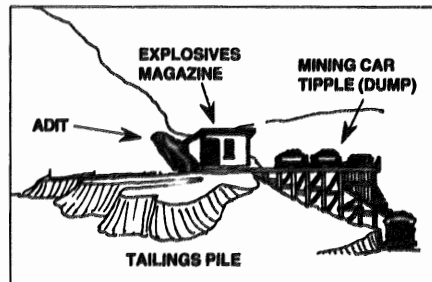


Figure 10: Horizontal Shaft Mine

Horizontal Shaft

Horizontal (bank) mines occur in mountainous areas where the entrance can be placed at the same elevation as the deposit being mined.

The actual entrance (adit) is a tunnel into the side of the hill with a low capacity road or rail line leading to it. Usually mine cars (small rail cars operating on narrow gauge) bring the ore from the mine to a tipple or skip where the material is dumped into hoppers or bins. From here the ore is transported by way of trucks or rail to a processing plant.

Vertical Shaft

Vertical shaft mines can occur in any type of terrain, and are constructed when the deposit to be mined cannot be reached by a horizontal shaft. The typical vertical mine has an 'A' frame latticework headframe over the shaft. The headframe can be substantial in construction, very tall, with lattice supports bracing the main structure. The large pulley may be visible at the top of the structure, or the entire structure may be enclosed.

Collocated with the headframe will be the winch house (for the lifting mechanism), the compressor house (and bullet tanks), various small buildings, and the ore

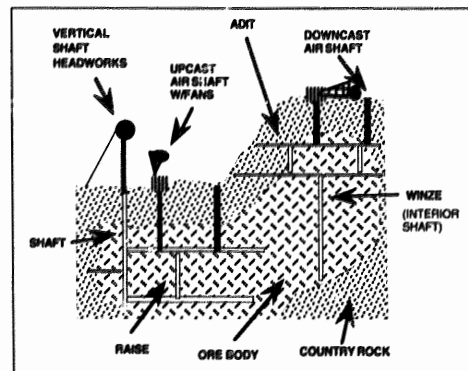


Figure 11: Shaft Mining

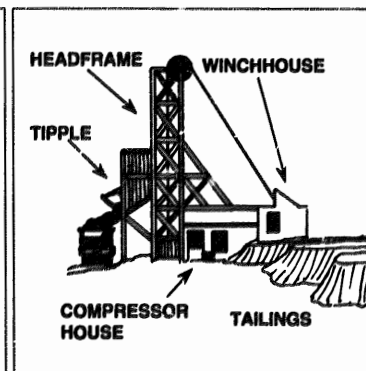


Figure 12: Vertical Shaft Mine

skip or tippie. The ore will be dumped to hoppers or bins and then transported to the processing facility.

Ore Concentration

In order to reduce transportation costs, the ore is often concentrated at or near the mine. First the mined material is reduced in size. Then differences in the physical properties (natural and induced magnetism, specific gravity, solubility, and wettability) are exploited to separate the mineral and the gangue (worthless rock). Afterwards the mineral is stockpiled and shipped on for further processing.

All or most of the associated equipment may be housed within a concentrator building. This building will have a characteristic stepped appearance with numerous roof vents.

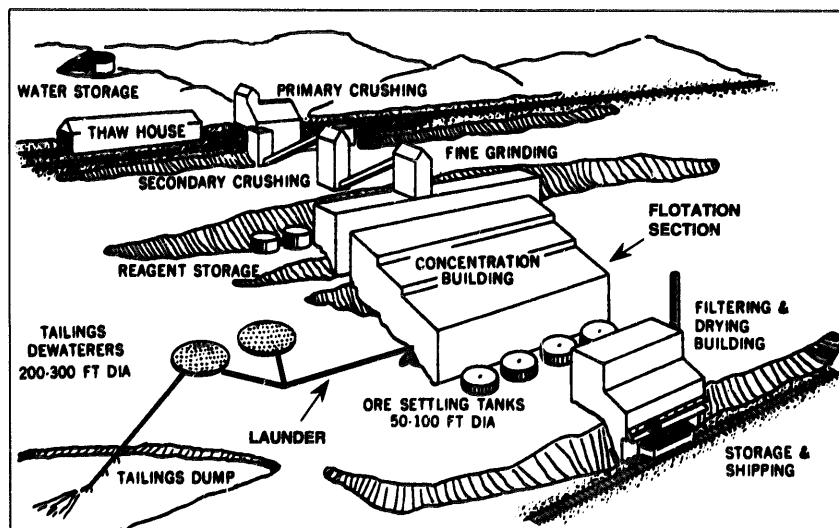


Figure 13: Ore Concentration Processing Plant

Initially the ore is greatly reduced in size in the primary and secondary crushers (gyratory, disc, and roll crushers). The material is then sent by conveyor to the tertiary (fine) grinding where the ball and tube mills reduce the mineral to flour like consistency.

The ore is mixed with water before being concentrated. The ores may be concentrated through a flotation separation method. This method uses rows of flotation tanks to separate the ore. The mineral rises to the top of the tank and

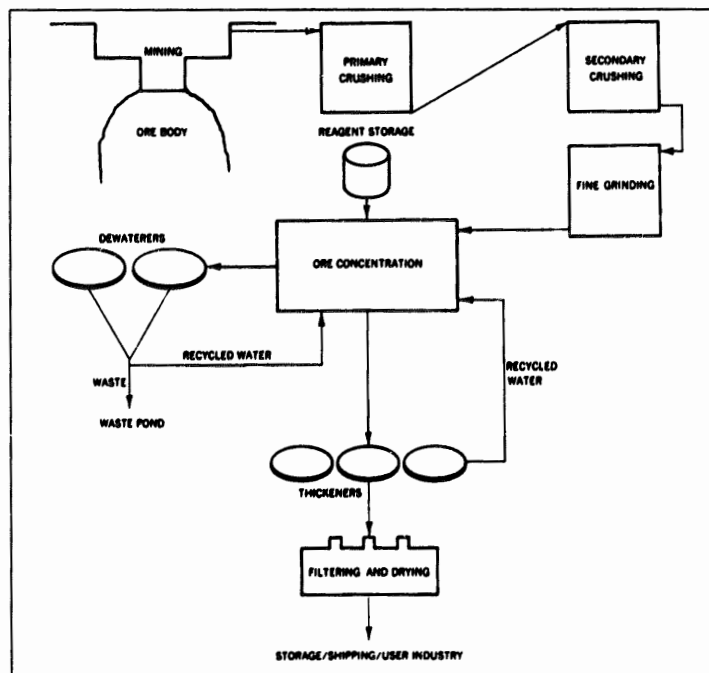
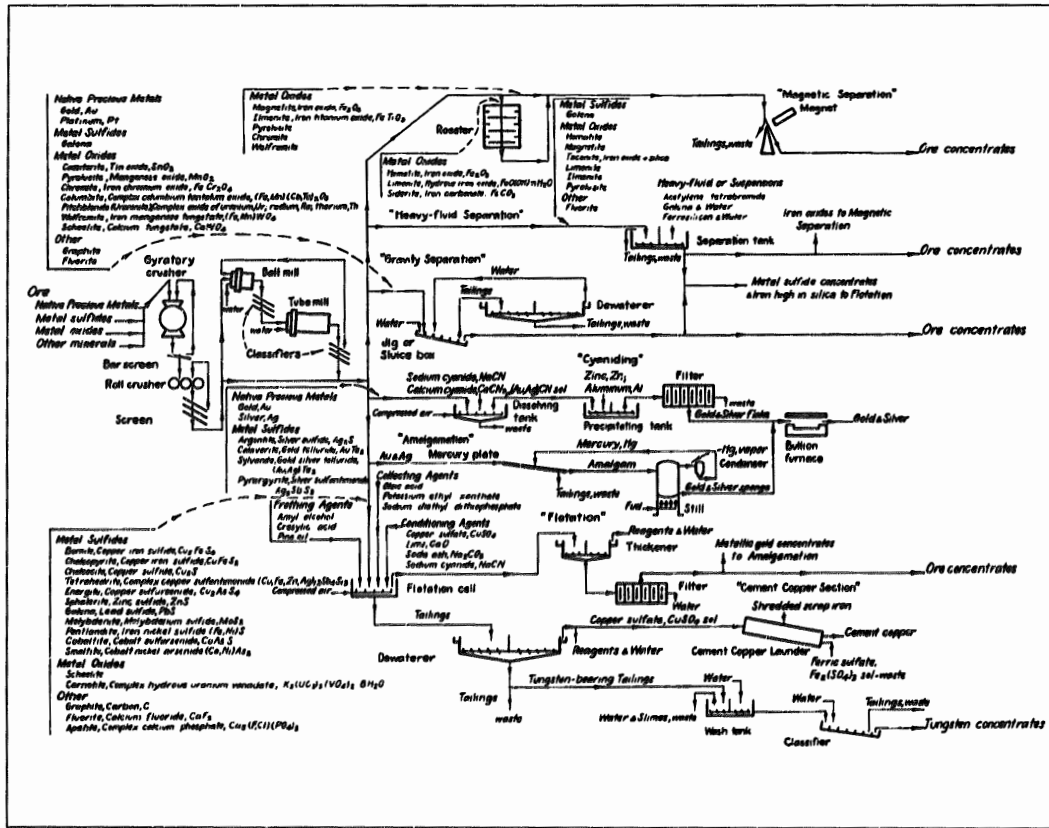


Figure 14: Flow of Concentration Process

is skimmed off while the tailings settle to the bottom. In a similar method, heavy fluid separation, the ore sinks and the tailings float. The tailings are sent down the launder to the tailings dewatering tanks where the water is recycled and the tailings sent to the tailings pile.

The skimmed ore concentrate is sent to the thickening (settling) tanks where the ore concentrate settles out and is recovered for further processing. After concentration has occurred, the mineral is sent to the filtering and drying building (stacks and vents are visible) where excess water is removed and the material is readied for shipping.

Gravity concentration may be used where the ore is passed through a series of sluices (inclined open-end troughs) submerged in water and vibrated. The heavy ore minerals settle to the bottom and the gangue is washed away. Other concentration methods include magnetic separation, cyaniding (precious metals dissolved and then precipitated), and amalgamation (mercury coated copper plates dissolve metals that are later distilled).



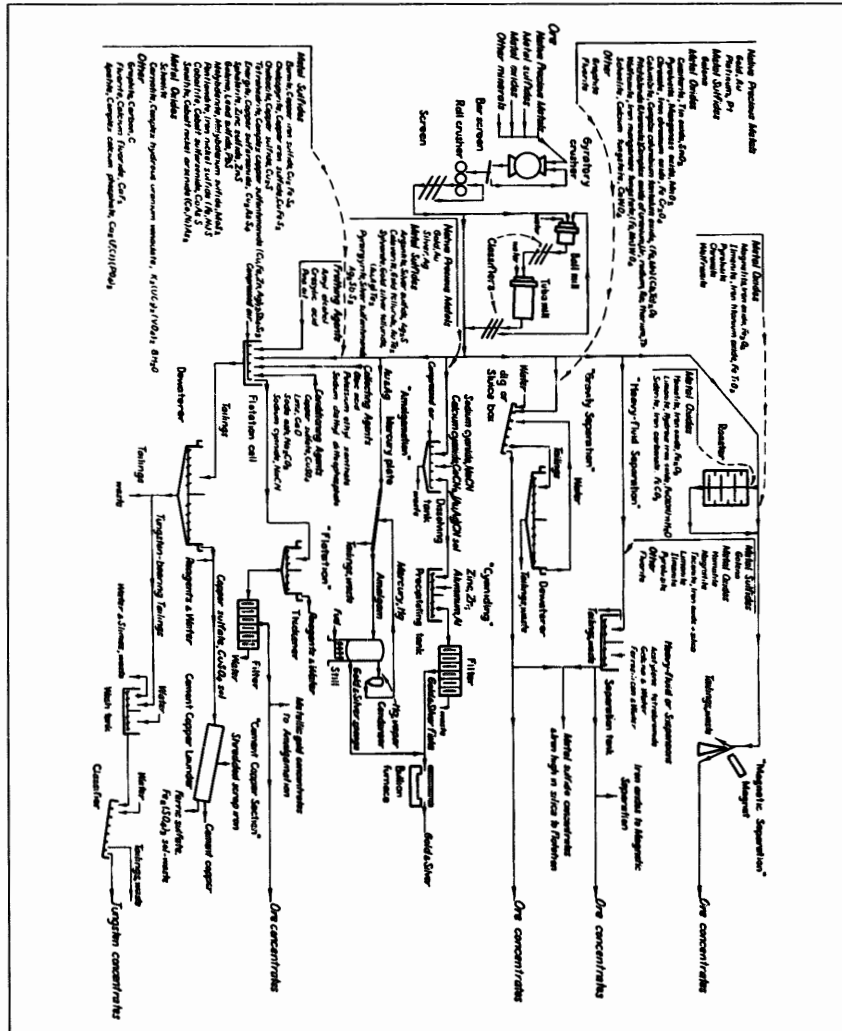


Figure 15: Ore Concentration Flow Chart

Coal is processed in a different manner. First a series of breakers separates the coal from the rock. Then crushers, screens, and classifiers reduce the coal to the necessary size and consistency. The coal is then washed and dried and shipped. In some cases, the coal is liquefied and pipelines are used to transport the coal.

Material from quarries is sent to a classifier, which sorts the material by size. Branching conveyors then deposit the material in various storage piles, hoppers, or silos.

Silos, bins, and warehouses will store the material at both intermediate stages and final product stage. Reagent storage will be in enclosed cylindrical tanks.

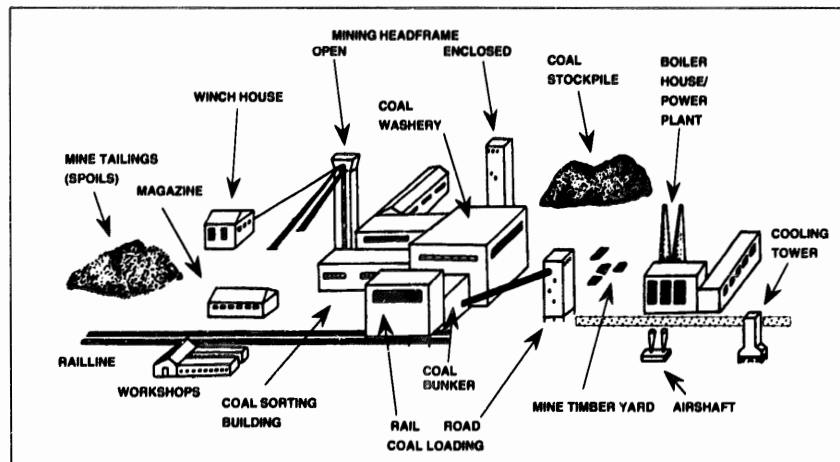


Figure 16: Coal Mine and Classification/Sorting Plant

Wells

Wells are used to extract resources from the earth which are not accessible through mining operations. Wells produce gases such as petroleum gas, helium, and carbon dioxide; liquids in the form of water, oil, iodine, and bromine; and products of solution mining such as sulfur and salt. Wells are also used for the disposal of semi-solid and liquid waste products.

Oil fields are the most complex type of well system to address. Water and mineral wells can be considered a subset of well drilling methods. The type of equipment can be identified by its association with one of the four interrelations of production. These are drilling operations (and associated completion operations), actual production through the well (including maintenance and eventual abandonment), field processing of the petroleum, and gathering and field storage of petroleum.

Shallow water wells may be dug rather than drilled. In agricultural areas, water wells are near housing or livestock holding areas. Often the availability of water determines where the farm or ranch is situated. Often livestock tracks and footpaths lead to a well. These wells may have walls, holding tanks, and some mechanism to bring water to the surface.

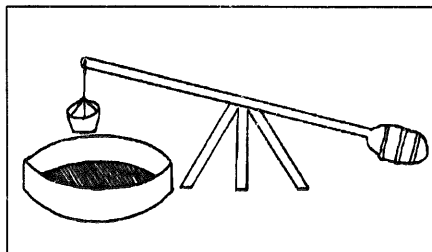


Figure 17: Dug Water Well

Drilling

Almost all drilling is done using rotary drill rigs. Rotary rigs use a bit attached to the end of a rotating string of drill pipe. In some cases the drill string remains stationary and downhole motors turn the bit. This method is used mostly for deep or highly deviated holes.

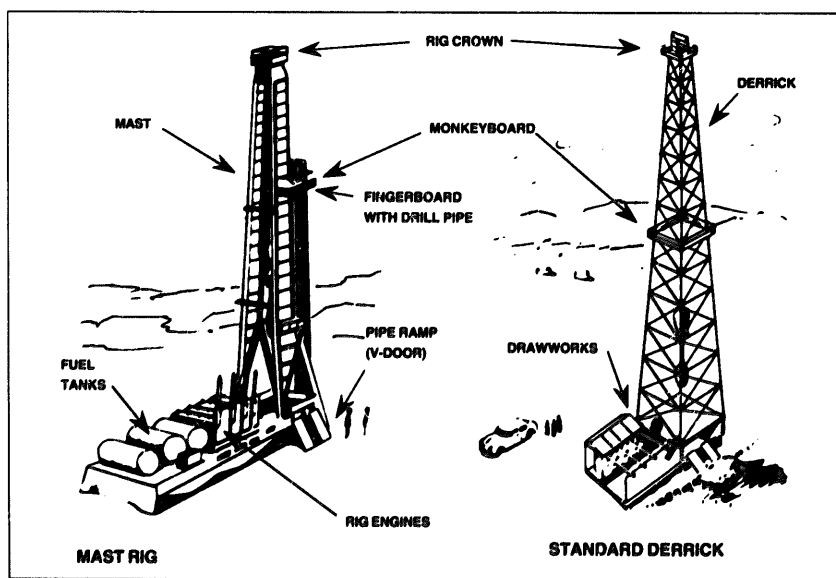


Figure 18: Rig Types

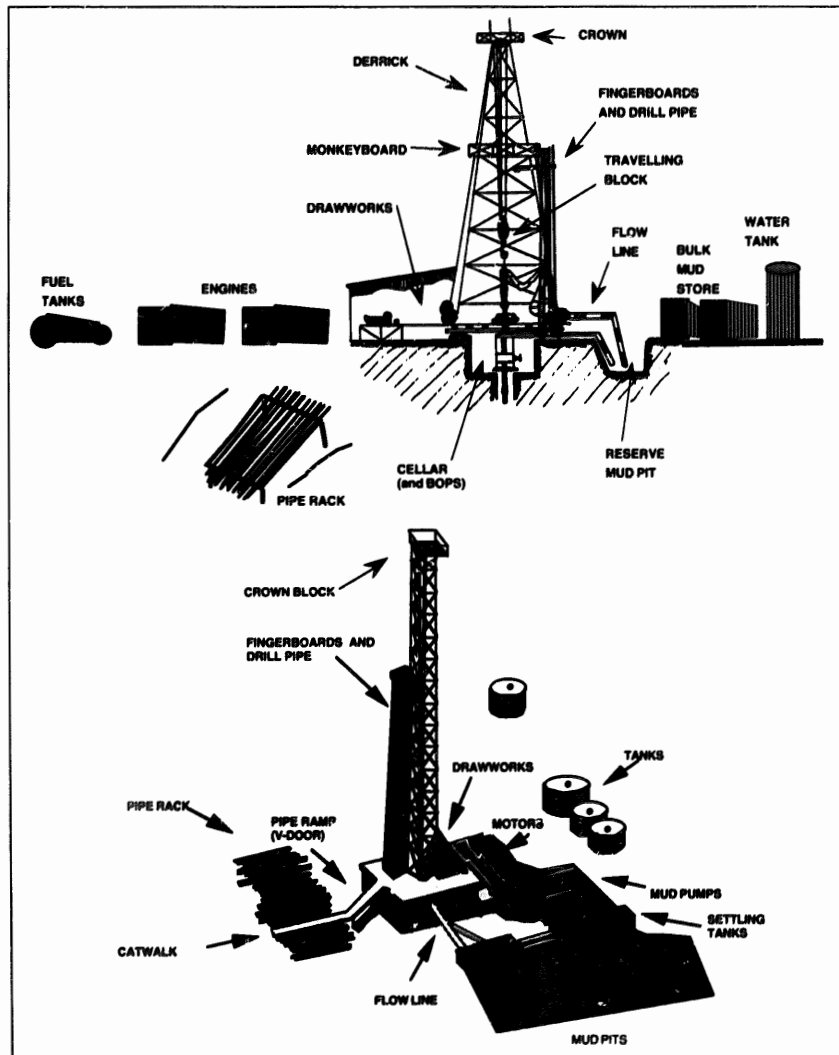


Figure 19: Standard Derrick (Rig) Components

The rig is a modified 'A' frame tower, called a standard derrick, which is assembled at the location, used to drill the well, and then disassembled. A second type is a mast rig that was assembled at a factory and then moved as one piece from location to location. Both are referred to as "derricks" or "rigs". Rigs can exceed 50 meters in height. The derrick is set on top of a rig substructure that provides a stable platform for drilling, clearance for work under the rig around the well-head, and room to accommodate pressure control equipment over the wellhead.

The rig provides the support for a set of pulleys and blocks that handle the drill pipe and casing pipe during drilling. There will be a work platform (monkey board) for the derrick man and storage racks (fingerboard) to hold pipe. Attached to the front of the rig are ramps ('V'-door) to pull material up onto the rig floor and working platforms (catwalks) to stage pipe. Pipe racks will be placed on one or both sides of the catwalk. At the back of the rig will be the drawworks with the winch to power the blocks.

Motive power is provided by a series of two to four prime movers, usually diesel engines, mounted on box like skids. Transmission is by mechanical linkage to the drawworks, or electrical generators may transfer power to electrical motors.

Most rigs drill using drilling mud, so there will be a set of steel mud pits, hoppers, mud house, a shale shaker, desilter, desander, and a degasser associated with the rig. Additionally, expect to find fuel and water storage, offices, and bulk storage. In a busy field numerous rigs may be conducting operations at the same time.

A water well rig is a much smaller version of an oil rig with the same type of equipment, but it is usually self-contained on a truck chassis.

Onshore

Prior to setting up the rig, the site is cleared and leveled. If required, improved roads are built and sometimes gravel, shells, or boards are applied to provide easy access. Very important wells, or those expecting to accommodate operations for several years, may have a hard surface pavement applied.

A water source is located or, if necessary, a water well is drilled. Reserve (mud) pits are

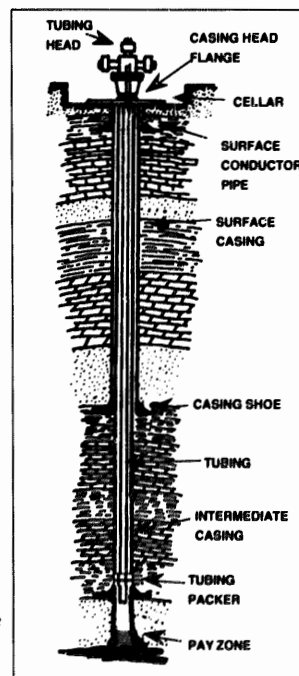


Figure 20: Well Configuration

dug for mud storage and waste fluids. The cellar (area immediately around the wellhead) is dug out and faced, usually with boards or poured concrete.

Then the rig will move in and drill the well. Several times during the drilling process a protective pipe string (casing) is installed in the well. This casing serves to keep the bore from collapsing and protects the ground water from contamination. Several strings of decreasing size casings are run as the well goes deeper.

If a pay zone is not found the well is plugged. If pay is found, the drilling rig may complete the well (conduct formation perforating, set tubing, and assemble the wellhead pressure control or pumping equipment) or the drilling rig is removed and a smaller completion derrick is moved in to perform well completion.

After the last string of casing is run and cemented in place, the producing formation is perforated. That is, a series of shaped charges are lowered into the well and detonated to punch holes through the casing, cement, and into the formation. Then a string of production pipe (tubing) of small diameter is placed into the well.

If sufficient gas exists in the formation, the well will flow on its own, and production will occur through a Christmas tree assembly for high pressures, or through a simpler orbit valve for low pressures. If the well will not flow on its own, a downhole pump is placed at the bottom of the tubing, sucker rod (solid steel rods to provide mechanical linkage between the pump and pump jack) is attached to the pump, and a pump jack (or other type of pump engine) is assembled over the well head.

The final wellhead consists of casing head flange, pressure control equipment such as valves (in the form of a low pressure orbit valve, a stuffing box [for pump jacks], or higher pressure Christmas tree), and a series of pipes through which to produce the well fluids.

Water wells can have a windmill placed over the wellhead, a hand operated pump is sometimes used, or a pump house will totally enclose the wellhead.

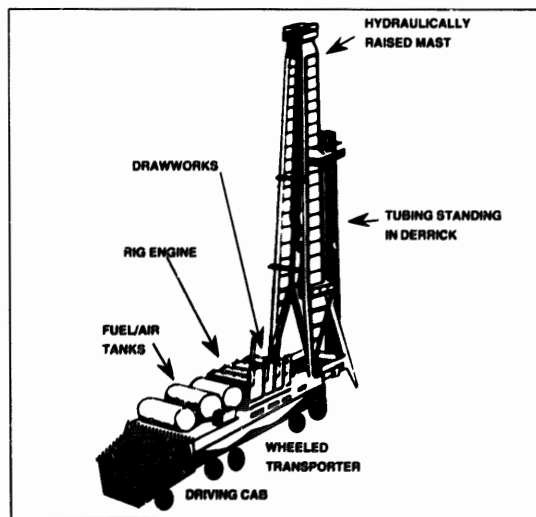


Figure 21: Completion (Workover) Rig

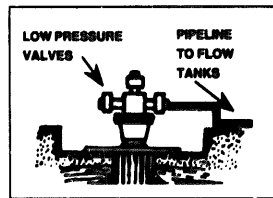


Figure 22: Orbit Valve Wellhead

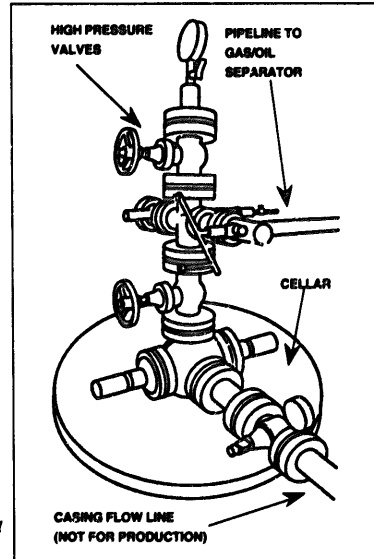


Figure 23: Christmas Tree Wellhead

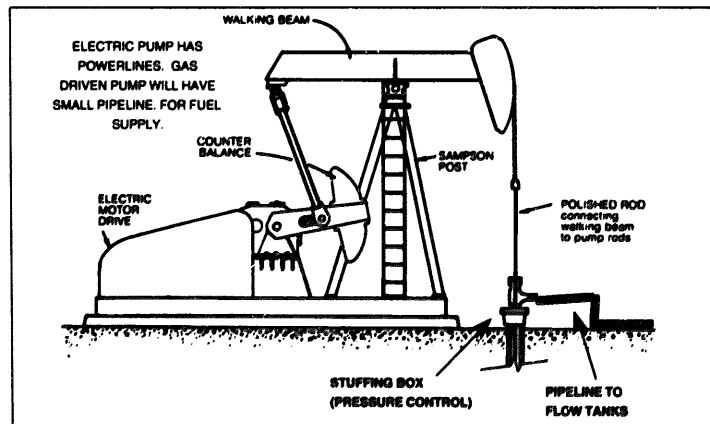
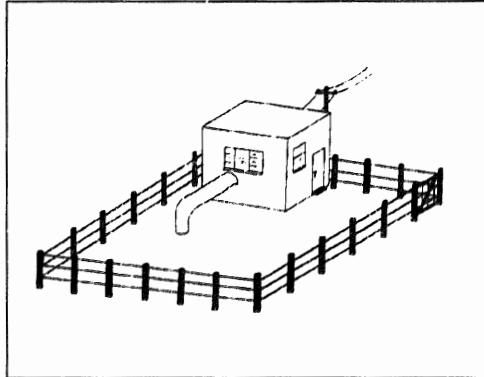
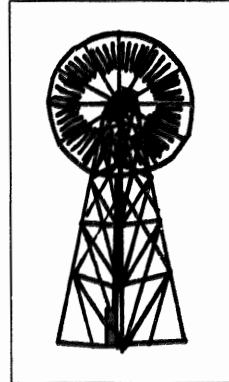


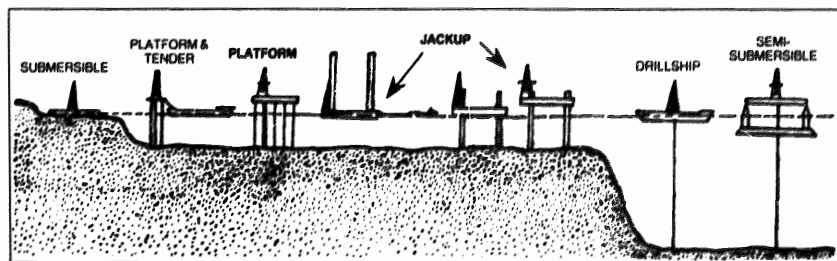
Figure 24: Pumpjack (Walking Beam Pump)

**Figure 25:** Water Well Pumphouse**Figure 26:** Windmill

Offshore

On land, the rig, the rig substructure, and all the ancillary equipment rests directly on the earth's surface. Offshore, a drilling platform is provided to support the rig and all the ancillary equipment. The water depth and the number of wells expected to be drilled determine the type of offshore platform to be used. With the exception of the permanent platform, once the wells are completed and producing, these rig drilling platforms are moved away to another location for more drilling activity. That is, they are not of a permanent nature.

For very shallow water, normally bays and lakes, a self-contained drilling barge is used to conduct drilling and completion activities. During production the well-head equipment will either rest directly on the bottom or will be placed on a small permanent platform.

**Figure 27:** Offshore Drilling Platform (Rig) Types

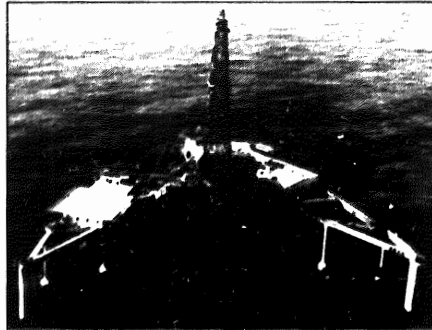


Figure 28: Submersible Drill Platform

A submersible drilling platform is used in shallow water. This rig is floated on buoyancy tanks to its location where water is pumped into the tanks, the drilling platform sinks, and drilling operations are conducted with the drilling platform resting directly on the seafloor. Most of the mobile rigs have a 'keyway' (slot) cut out in the area of the platform under the drilling rig that is large enough to accommodate a production platform. If a production platform is planned, it will normally be erected prior to the drilling operation commencing. Otherwise production wellhead equipment is placed on the seafloor.

In moderate depth water a small production platform is built (permanent platform) and a tender (small ship or other vessel) will provide support functions such as drilling mud and living quarters. A movable drill rig will be placed on the small platform to drill the required number of wells.

Permanent platforms are used in shallow to deep water. The drilling rig and its ancillary equipment are contained on the platform. After drilling operations are completed, the rig is removed but the platform remains and provides all the production equipment needed for normal operations. Numerous wells, sometimes as many as thirty-six, are drilled from one platform.

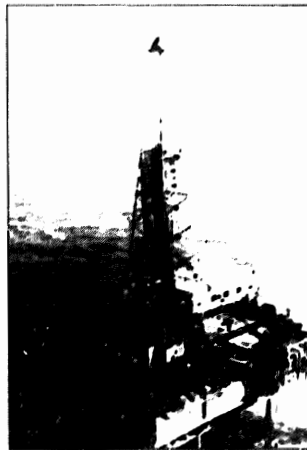


Figure 30: Permanent Platform

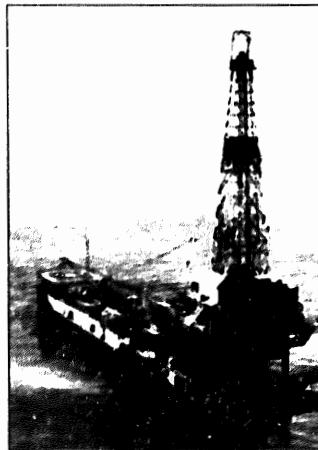


Figure 29: Drilling Platform and Tender

The jackup drilling platform rig is used for water depths less than 250 feet (depth determined by maximum extension of legs). The platform is floated to its location, then large legs are cranked down to lift the platform clear of the sea. This type of platform uses three (or four) hollow or lattice work legs to support the platform.

A drill ship can operate in any water depth that is at least deep enough for the vessel's draft. This type of vessel is normally used only for exploration wells, because of its high operating costs, and another type of drilling platform is used for developmental wells.



Figure 32: Drillship

The semi-submersible drilling platform (floater) has large buoyancy tanks. The platform is moved to its location, the tanks are flooded, and the rig is either anchored or conducts station keeping while the well is drilled. This rig is usually used for fairly deep water. The semi-submersible rig is characterized by numerous anchor lines and winches on the vessel's decks. The presence of the anchors differentiates the semi-submersible from the submersible platform.

Production from wells in deep water is usually accomplished from subsea production platforms, these platforms are placed on the sea bottom and are not visible.

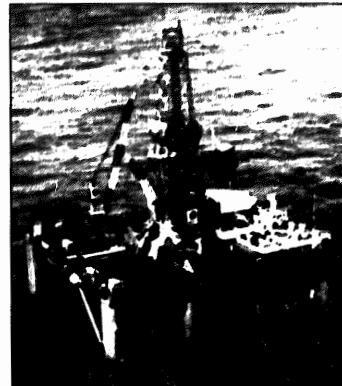


Figure 33: Semi-Submersible Drilling Platform

Offshore wells are drilled and completed the same as land wells. One notable exception is that pump jacks are not used in offshore operations. If a well does not flow on its own, a gas lift (gas injected from the surface to the production zone and allowed to expand to move the oil uphole) is utilized.

Production

Production from a well is not a simple matter of pumping the well fluid to the surface. Most types of wells require some in field processing to remove impurities. This occurs at the wellhead or at a central location connected to several wells. Common impurities removed at oil and gas wells include sand, silt, salt water, sulfur, and gas (either unwanted petroleum gas or hydrogen sulfide gas).

Gathering and field storage are also part of the production process. Here fluid from several wells is moved to a central location for in field processing and storage prior to transshipment to users or a refinery.

Oil & Gas

Most petroleum wells have a maintained road leading to the well. The road may make a loop around the location. Typically some treatment equipment is located at the well or nearby. Wells with pump jacks are the easiest to identify because of the large pump assembly over the well. Wells with only pressure control equipment over the well are harder to detect.

After the fluid reaches the surface, the gas is separated from the oil using a gas/oil separator. The gas/oil separator is a horizontal or vertical tank with chambers to reduce flow turbulence, allowing the gas to separate and rise to the tank top where it is drawn off. Unwanted gas is burned at a flare. If there is enough gas for gas production, it is compressed and sent through a pipeline for further processing.

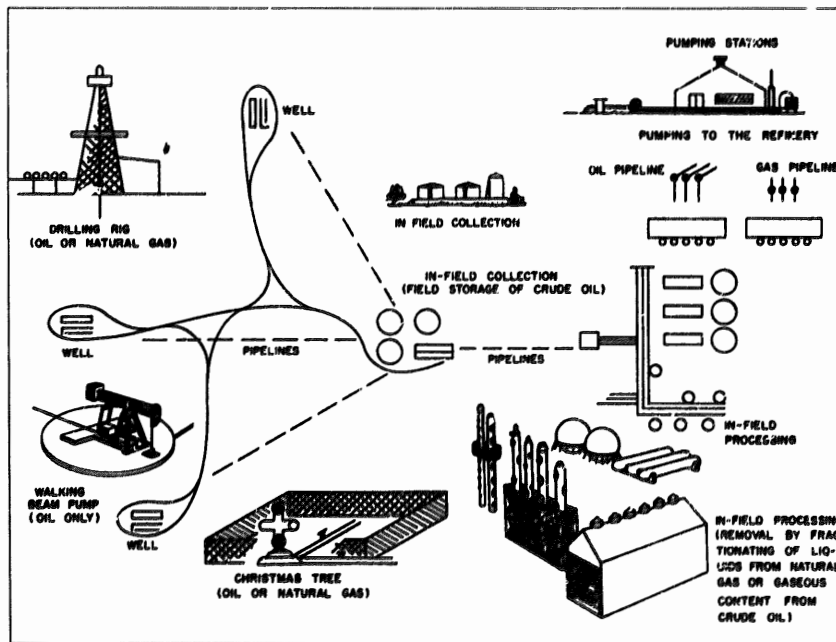


Figure 34: Oil and Gas Production Field

When the well fluid reaches the surface, it also contains unwanted material, most of which is in the form of salt water. After passing through the gas/oil separator, the well fluids are sent to the flow tanks (50 to 250 Bbl) near the wellhead. Here water and some solids are removed. The separated water is moved, usually by gravity, to water tanks (modern water tanks are plastic) for eventual disposal.

The oil is moved to lease tanks (large steel tanks) for removal by trucks or injected into pipelines for transshipment. The gas and oil are handled through separate pipelines in the gathering system.

Additional lease equipment includes heater treaters (to handle paraffin) and accumulators (to handle gas).

Numerous pipelines are associated with petroleum wells. A 2" to 4" pipeline connects the well to the flow tanks and the ancillary lease equipment. A series of 4" to 6" pipelines connect the flow tanks to batteries of lease tanks. Gas compressor stations or oil pump houses inject the petroleum into larger pipelines for transshipment to refineries. These pipelines vary greatly in size.

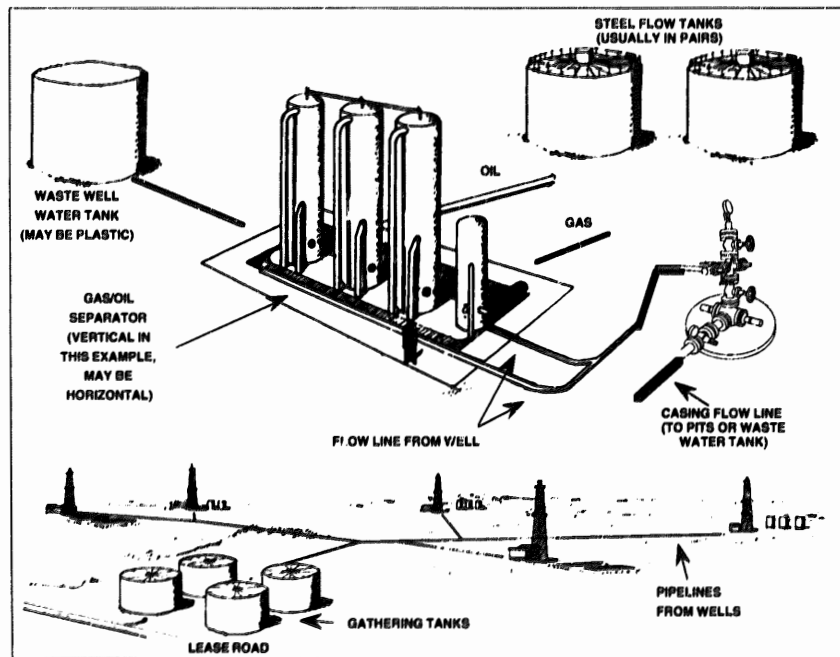


Figure 35: Gas/Oil Separator (GOSP) and Gathering System

Water

Limited volumes of water are produced from a dug or drilled well by means of buckets or small hand operated mechanical pumps. These wells have a minimum of wellhead equipment. Sometimes the well is covered by a small building (or covered by a shed roof) and is fenced. A small holding tank, usually open, is often associated with small low volume wells. For agricultural usage a larger volume is required and often windmills are used to drive pumps at the well.

Larger volumes and pressure requirements require mechanical pumps to move the water. Most of the time the pumps are contained in a pump house. The pump house may have power lines leading to it or exhaust stacks may be visible. In large scale operations the water is transferred through a pipeline to a water treatment facility.

Most water wells are dispersed throughout an area. A small well field of 15-20 water wells sometimes provides water for cities.

Other

Helium and carbon dioxide are also produced from wells. These wells are characterized by a small field of wells, compressor houses, and high pressure storage tanks. Because of the low volume of gas produced, the field will not have a pipeline system to transport the gas.

Solution mining is used for production of salt, sulfur, bromine, iodine, and other minerals. Solution mining wells require large amounts of fluid to transport the dissolved solids. Often an injection well near the production well is used to force fluids through the formation to dissolve the minerals. A complex of large pipelines (8" or larger), a series of large surface pumps, a lack of wellhead ancillary equipment, and an association with a processing plant is an indication of solution mining.

Another type of well is a disposal well. This is a well used to dispose of waste or unwanted material. In an oil field, for example, a disposal well is used to dump the large amounts of salt water generated by the wells. Industries also use disposal wells to rid themselves of waste chemicals. The typical disposal well has several storage tanks or open sumps (to temporarily hold the waste), a small pump house, a small office building, and a set of scales to weight tank trucks. The disposal well often is isolated from other wells.

Disposal

The disposal of waste products from everyday living and industrial plants is an ever-growing problem for any industrial nation. An enormous amount of waste is produced daily and this material must be handled in some manner. Figure 1 displays the amount of combustible waste generated in the U.S. in 1974. This totals 624 million tons of waste annually. This does not include inert materials such as slag, tailings, and recoverable metals and glass.

WASTE SOURCE	% TOTAL WEIGHT	10 ⁹ KILO-GRAMS
URBAN REFUSE AND SEWAGE	16.3	92
MANUFACTURING AND PROCESSING	5.8	33
AGRICULTURAL	77.9	441

Figure 1: Combustible Waste U.S. (1974)

Solids

Tailings

Tailings are waste earth or rock excavated during mining operations or the spoil (refuse) material separated during processing operations. The tailings generated during mining and processing represent an enormous amount of solid waste.

The overburden from surface mining operations is sometimes used in reclamation activities, however it is not economical to replace all the excavated material.

Mining operations usually dispose of tailings by dumping the rock clear of the excavation. A belt or bucket conveyor, or dump trucks are used to transport the material to the disposal area (often a hillside). Over time, the tailings pile grows very large, at times exceeding 50 meters in height. The tailings have a different tone and texture from the surrounding area. Another key to aid in differentiating tailings piles from ore piles is the obvious lack of facilities for retrieval of the material from tailings piles.

BLACK	DARK GREY	MID GREY	LIGHT GREY	WHITE
	SCRAP STEEL			
		IRON SLAG		
	SLAG FROM MINING OPERATIONS			
SMELTING SLAG			ORE CONCENTRATION WASTE	
		BAYER ALUMINA WASTE		
		COAL ASH WASTE		
CITY TRASH				

Figure 2: Tonal Characteristics of Solid Waste Material

Because the actual mineral content can be so low, more than 99% of the ore-bearing rock extracted may be gangue (rock of worthless mineral content). The tenor (grade or percentage) of economically recoverable minerals can be less than 0.02%, that is 200 grams of mineral per 1000 kilograms of ore. Most of the spoil from ore processing is in fluid form.

Processed spoils are often dumped in sludge ponds. The launders from the dewatering tanks carry the excess material to the tailings pond, where the water evaporates, leaving the waste. When the ponds fill, another pond is built to handle waste material.

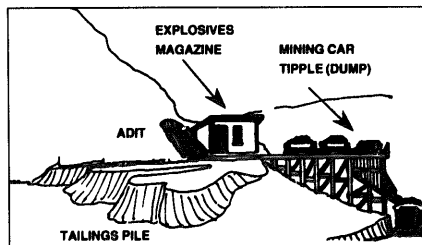


Figure 3: Mine Tailings Pile

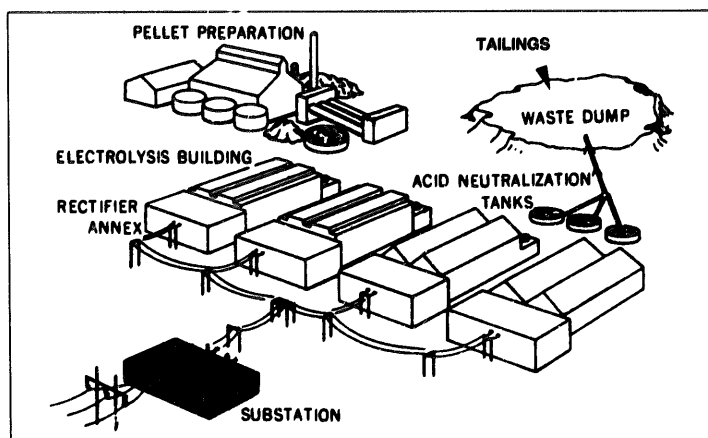


Figure 4: Tailings at Magnesium Reduction Plant

Slag

Slag is the solid clinker by-product (dross) of ore and metal processing. In order to produce one ton of metal, more than 5,000 tons of ore may have to be processed. Other than dumping, there is no economical method available to dispose of this material.

Normally a belt or bucket conveyor transports the material to the disposal area (often a hillside), where it forms a large pile. Earth moving equipment, rail cars, or trucks may also transport the material. Slag is dumped in long parallel rows to

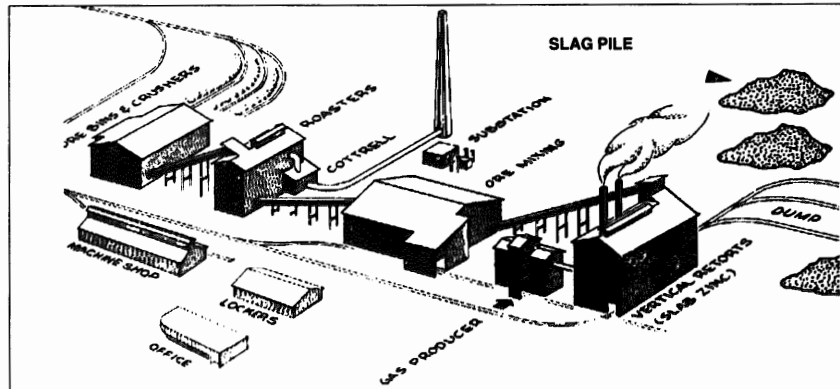


Figure 5: Slag Pile at Zinc Plant

one side of the industrial area. The lack of a mechanism for retrieval differentiates slag piles from ore stockpiles. Pure clinker material (without toxic elements) is used to manufacture building blocks (cinder blocks). In these cases, facilities to move the slag to the manufacturing plant are present.

Scrap Yards and Wrecking Yards

Scrap and wrecking yards are used to reclaim useful material, usually metals (in the form of discarded automobiles), but reclamation of ceramics and glass is possible. The scrap material is brought to the yard, the material is sorted, and then stored (in large open storage) until the material is resold and removed. Often, metallic scrap yards are near metal processing industries. Using scrap metal is cheaper than processing raw ores.

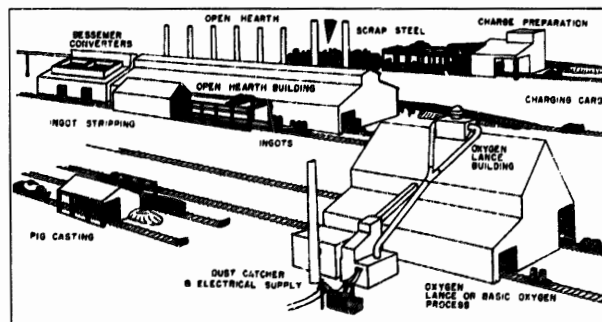


Figure 6: Steel Scrapyard at Steel Plant

The open scrap storage area has a distinctive appearance due to the non-uniform size and shape of the scrap materials. Tonal differences are apparent from both shadows and non-uniform color. Wrecked and scrapped vehicles are easily identified, since the vehicles are piled on top of each other. Also, there are no provisions for easy removal of the vehicles (i.e., minimal driving lanes in the yard). Within the yard, overhead gantry and rotating cranes (sometimes equipped with electromagnets rather than buckets), and various specialized vehicles are used to move material.

One or more open sided sorting buildings can be present. Sorted material is stored within the buildings prior to transport, or the material may be stored in bins.

Landfills

The most popular and economic method of disposal for solid waste is the landfill. Usually the landfill is located near the waste producers (i.e., city), but in recent years trash has been transported by road, rail, and barge enormous distances due to the scarcity of suitable dumps. The typical operation involves trucking the trash to the site (in waste disposal and dump trucks), dumping the trash into a prepared area, and backfilling (covering) the trash with dirt (for sanitary and esthetic reasons). Leaching of effluent from the landfill into the water table is a major concern. Most modern landfills have clay or plastic lining to prevent leakage and monitoring wells to detect leaks.

The landfill covers extensive acreage, and unless care is taken, the trash will blow for some distance from the dump. The trash will display a range of colors, tones, sizes, and textures. Material handling is in the form of bulldozers, both to move and level the trash and backfill dirt (usually piles of dirt are found in the area). A well-maintained transportation access is a vital necessity for the landfill.

Incinerators

An alternative to landfills is the incinerator. The waste heat from municipal incinerators can be used for power generation and steam heating. Solid waste material is stockpiled, sorted to remove large non combustible items, and shredded. Processing of the shredded material includes air sorting (a vertical or horizontal sorter uses gravity and air flow for separation) and reclamation of materials. Waste heat is used to dry the trash. Liquid waste can be injected into fluid bed combustors along with solid materials.

The incinerator is a tall building with prominent truck ramps. The ramps

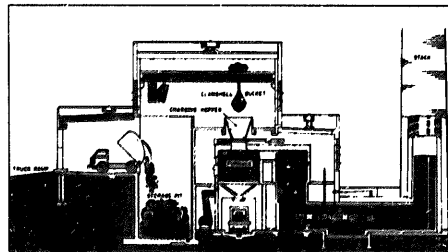


Figure 7: Incinerator Operation

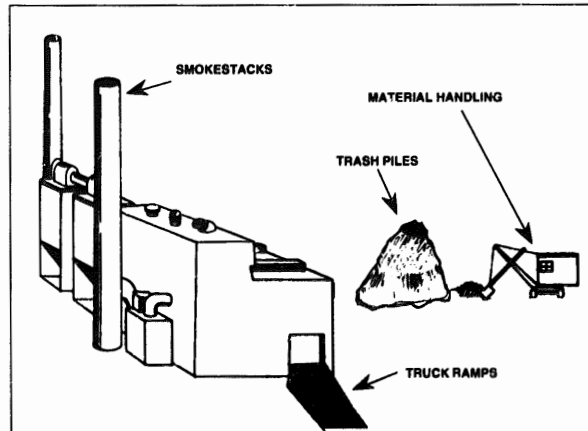


Figure 8: Trash Incinerator

usually enter opposing sides of the building. Fuel sources (other than trash) are not apparent. Overhead cranes and material handling equipment are found at the plant. Large operations can burn enough material to run generators or steam plants for local use. In this case, transformers or steam pipes are visible.

Composting

To alleviate the load on landfills, composting the organic portion of solid waste is becoming a common disposal method. The organic material (in large scale operations) is mixed with dirt and piled in parallel rows. The material is turned occasionally, and after bacterial action, the material becomes soil. The soil is transported and used in agricultural and residential applications. The presence of earth moving equipment and dark toned, parallel compost piles (situated clear of residential and industrial areas) is an identification key.

Liquids

Isolated dwellings and small industries can use septic systems for disposal of liquid wastes. Some waste liquids are dumped directly into streams (essentially treatment is by dilution). Larger urban areas and large industrial complexes cannot rely upon such crude systems. A city will have domestic sewage from dwellings (bath, kitchen, and laundry waste), industrial sewage (waste from food, cooling, and manufacturing processes), and street waste (refuse, storm water runoff, grease, and oil). Typically, 100 gallons per capita per day is the expected amount of liquid waste produced in a city.

Sewage Treatment

Some areas of the world rely upon waste collection from individual houses for transport to a disposal site. This is not an efficient system in large urban areas. A waterborne system of pipes, pumping stations, and disposal plant is the best method for large cities.

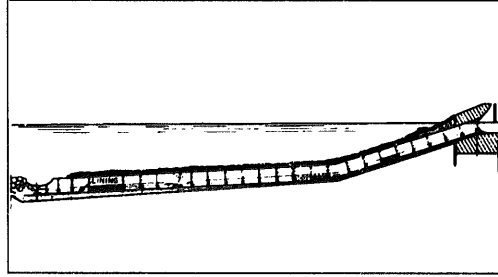


Figure 9: Sewage Outfall Pipe

Sewerage is the process of waste removal using water as the medium. The sewerage system includes all the facilities for collection and transportation (sewer pipes), treatment (sewage disposal plant), and disposal (landfill, incinerator, or irrigation methods) of sewage. Modern cities use a system of sewer pipes and pumping stations to transport waste. Sometimes separate (dual) systems of sanitary and storm sewers keep storm runoff from overburdening the treatment facilities.

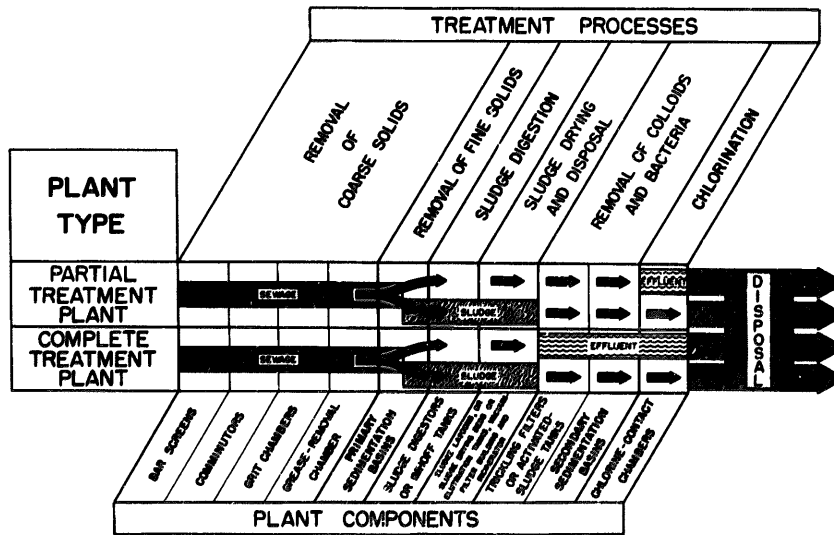


Figure 10: Sewage Treatment Processes and Components

Purification of sewage is the oxidation of sewage by bacteria to its basic mineral components. In low flow systems, sewage can be dumped directly to the stream (disposal by dilution) without adverse effects. Higher flow requires more treatment if upset of the stream system is unacceptable.

The simplest form of treatment is natural purification where the solid and liquid components are separated by sedimentation, the liquid (effluent) is pumped to the stream and the solids are treated. Another method is irrigation, where the effluent is sprayed over porous ground and allowed to evaporate and percolate into the soil. In order to prevent stream pollution from large quantities of sewage, a more complex treatment is necessary. Mechanical, chemical, and biological means are used to reduce organic content, remove solids, and neutralize chemical contaminants. A sewage treatment plant consists of numerous water-filled basins and very few buildings (relative to site size).

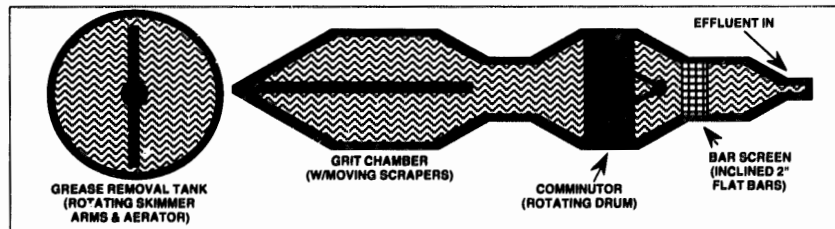


Figure 11: Coarse Solids Removal

Primary Treatment

Primary (partial) treatment consists of separating and treating the solid portion of sewage leaving a partially treated effluent. The initial process in treatment is the removal of coarse (and indigestible) solids. The indigestible solids are removed by bar screens (coarsest objects), comminutors (grinding of remaining large, decomposable materials), grit chambers (removal by settling of heavy solids), and grease-removal tanks (skimming off oil, fat, and grease). The process is carried out in a single structure, usually a long, narrow, open concrete tank nearly flush with ground level.

The next stage is the removal of fine solids. Commonly this is accomplished using either primary sedimentation basins or Imhoff tanks. Primary sedimentation basins are rectangular or round, open, concrete tanks nearly flush with ground level. They are

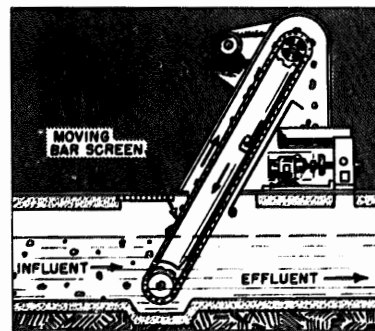


Figure 12: Mechanical Bar Screen

equipped with sludge scrapers to direct the settled sludge into a bottom discharge well. The basins may have surface skimmers for grease removal.

Chlorine-contact chambers are used to treat the effluent. Turbulent water and chlorine are mixed in these long, narrow, baffled chambers, killing any remaining bacteria.

It is necessary to treat the raw sludge from the primary sedimentation basins because it rapidly decomposes. Stabilization is accomplished by digestion. Here bacteria are allowed to act on the organic content. The end product is a stable material that is incinerated, used as soil conditioner, or dumped. Rectangular or circular open top digestors are used in warmer climates. In cooler climates (warmth is needed for the bacteria to operate) covered circular digestors are used. These tanks may be earth-bermed to conserve heat. In both types, raw sludge is introduced into the tank and allowed to stabilize. The treated sludge sinks and is removed from the tank.

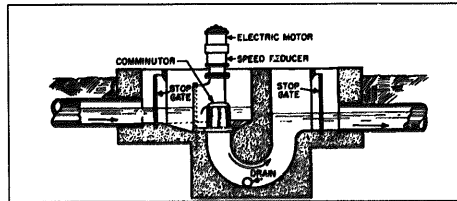


Figure 13: Comminutor

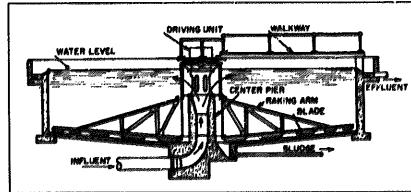


Figure 14: Primary Sedimentation Tank

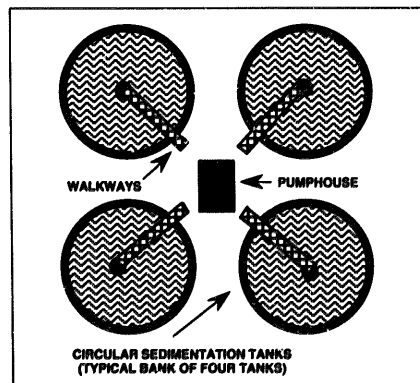


Figure 15: Circular Sedimentation Tank Arrangement

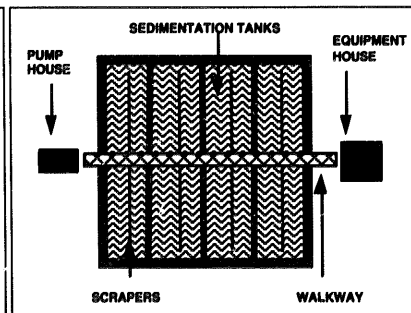
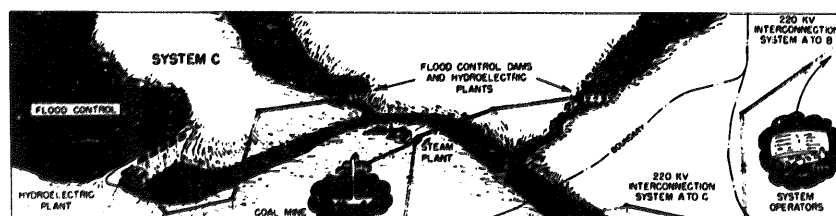


Figure 16: Rectangular Sedimentation Tank Arrangement

Photo Interpretation Training Course



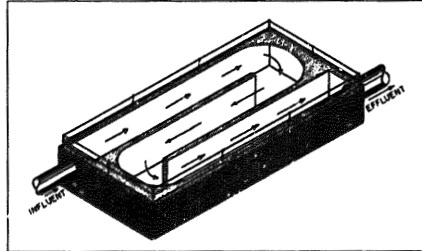


Figure 17: Chlorine Contact Chamber

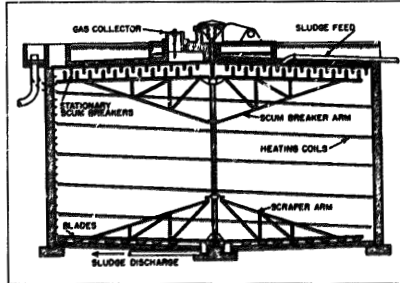


Figure 18: Fixed Roof Covered Digester

During the digestive process, methane gas is released. In covered digestors (roof may be fixed or floating top), the gas is collected, held in a gas-holder for use as fuel, or sent to a flare for disposal.

Imhoff tanks act as a primary sedimentation basin built over a digester. An Imhoff tank is a bi-level septic tank that requires 6 to 9 months to process the sludge. Because of the long time required for processing, several Imhoff tanks must be used. They are found clustered in a rectangular arrangement.

Water must be removed from the digested sludge before disposal. Several methods are possible. The sludge is sent to a sludge lagoon where the water evaporates or drains into the soil. When the sludge is dry, it is removed by scrapers. Sludge drying beds are a system of low, rectangular basins (one meter deep) with drain tiles under 20 cm. of gravel and 10 cm. of sand. The sludge flows out over the bed, the water drains, and the dried sludge is removed. In colder climates these beds are enclosed by glass structures resembling greenhouses.

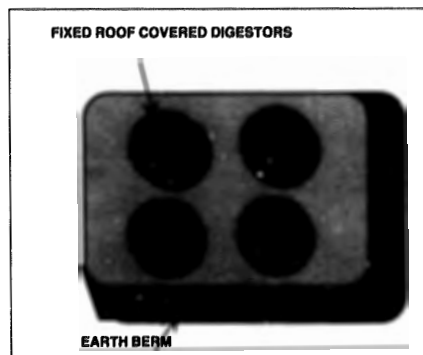


Figure 19: Typical Earth Covered Digester

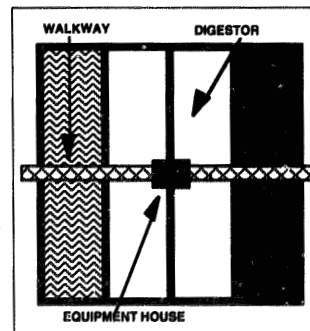


Figure 20: Rectangular Open Digester

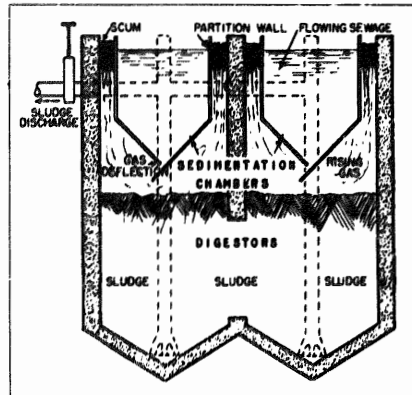


Figure 21: Imhoff Tank

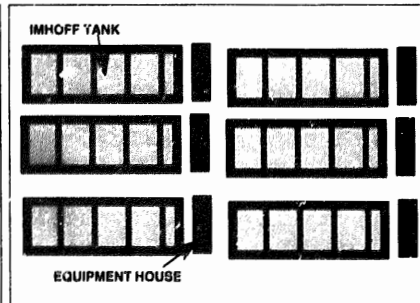


Figure 22: Imhoff Tank Arrangement

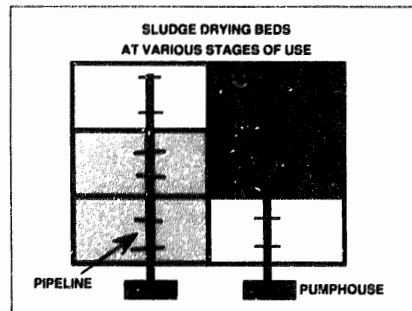


Figure 23: Sludge Drying Beds

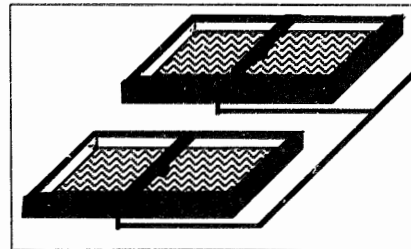


Figure 24: Elutriation Basins

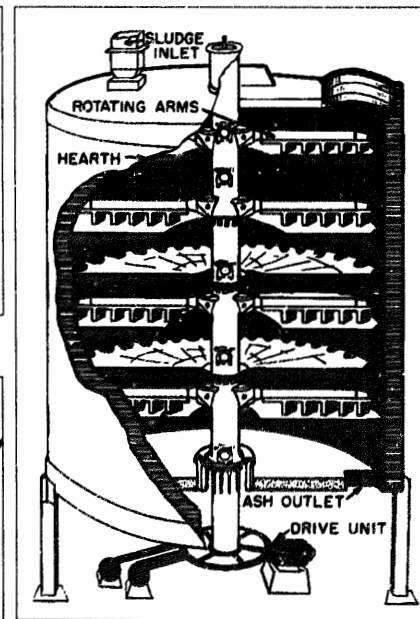


Figure 25: Multiple Hearth Furnace

Another method involves washing the sludge with fresh water in elutriation tanks (narrow, open, rectangular basins), conditioning with chemicals to coagulate the sludge particles, and then removing water with a vacuum filter. The vacuum filter is contained in a building between the elutriation tanks and the incinerator. Sludge dried in a vacuum filter can be incinerated for final disposal.

Secondary Treatment

Secondary (complete) treatment for the solid component of sewage is identical to the processing of the sewage by primary treatment systems. Additionally the effluent is treated by oxidation, filtration, and chlorinating processes similar to water purification. The result of secondary treatment is a completely treated effluent with practically all solids removed and treated.

For secondary treatment, the next step is the removal of colloids and bacteria (using trickling filters or activated sludge tanks) from the effluent. Filtration is done by trickling filters, which are composed of layers of crushed stone and sands (giving a dark tone to the tank) over which the effluent is sprayed.

The sewage percolates downward, leaving behind organic matter, which is stabilized by bacterial action. The resulting stabilized soil is carried out with the effluent and sent to secondary sedimentation tanks.

Rotary trickling filters are large, circular, concrete tanks with two or more rotating sprinkler arms that operate continuously. Fixed nozzle trickling filters are large,

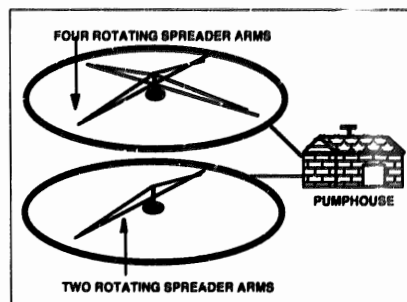


Figure 26: Rotary Trickling Filters

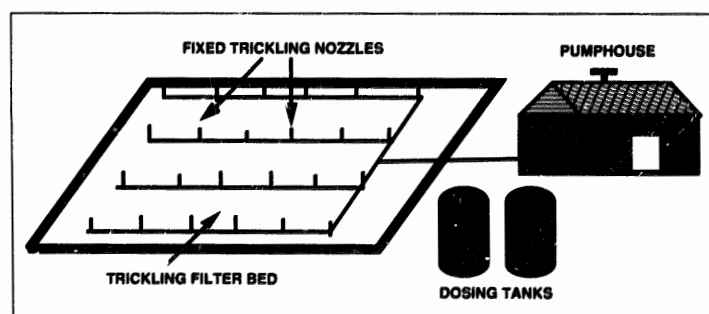


Figure 27: Fixed Nozzle Trickling Bed

open, rectangular concrete structures (with two dosing tanks nearby). The dosing tanks collect the effluent, and when full, discharge the effluent over the filter in discontinuous operation.

Alternately, activated sludge tanks may be used. Activated sludge tanks (oxidation beds) are long, open rectangular, concrete tanks arranged in parallel banks of two or more units. Here, the effluent is mixed and agitated by compressed air or rotary paddles (the foaming sludge aides identification). The resulting coagulated mixture is sent to the secondary sedimentation basin.

The secondary sedimentation basins operate in a manner identical to the primary sedimentation basins. Here, the final separation of coagulated solids occurs and the sludge is sent back to the digestors.

Modern plants treat the effluent with lime, metallic hydroxides, or ion exchange systems to remove phosphate and polyphosphate compounds. This treatment reduces unwanted vegetation blooms around the waste water discharge pipes. Chlorine-contact chambers kill any remaining bacteria.

Tertiary Treatment

In some areas, increased environmental concerns have mandated additional waste treatment. These tertiary treatment systems are used to reduce the BOD (biological oxygen demand). The result of treatment is lower concentrations of ammonia, nitrates, phosphates, heavy metals, and toxic organic compounds. Another concern is reducing pathogenic bacteria, enteric viruses, protozoan cysts, and helminth eggs that, if left untreated, would contaminate the water. The tertiary treatment facilities are similar to potable water treatment facilities.

Tertiary treatment plants are expensive to operate. Common treatment systems include reverse osmosis and dialysis, ammonia stripping (air forced through effluent), coagulation, filtration with sand and coal, activated charcoal treatment, and disinfecting with ozone or chlorine treatment. The final effluent is stored (for three weeks) in lagoons or used to irrigate grass beds.

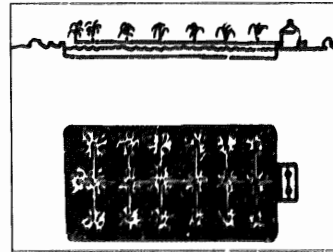


Figure 28: Fixed Nozzle Trickling Filter Bed

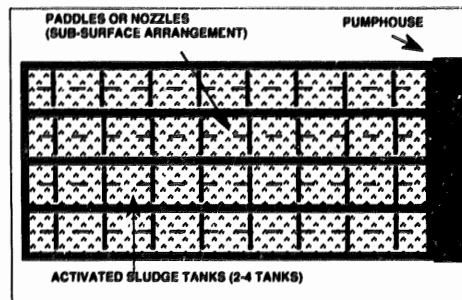
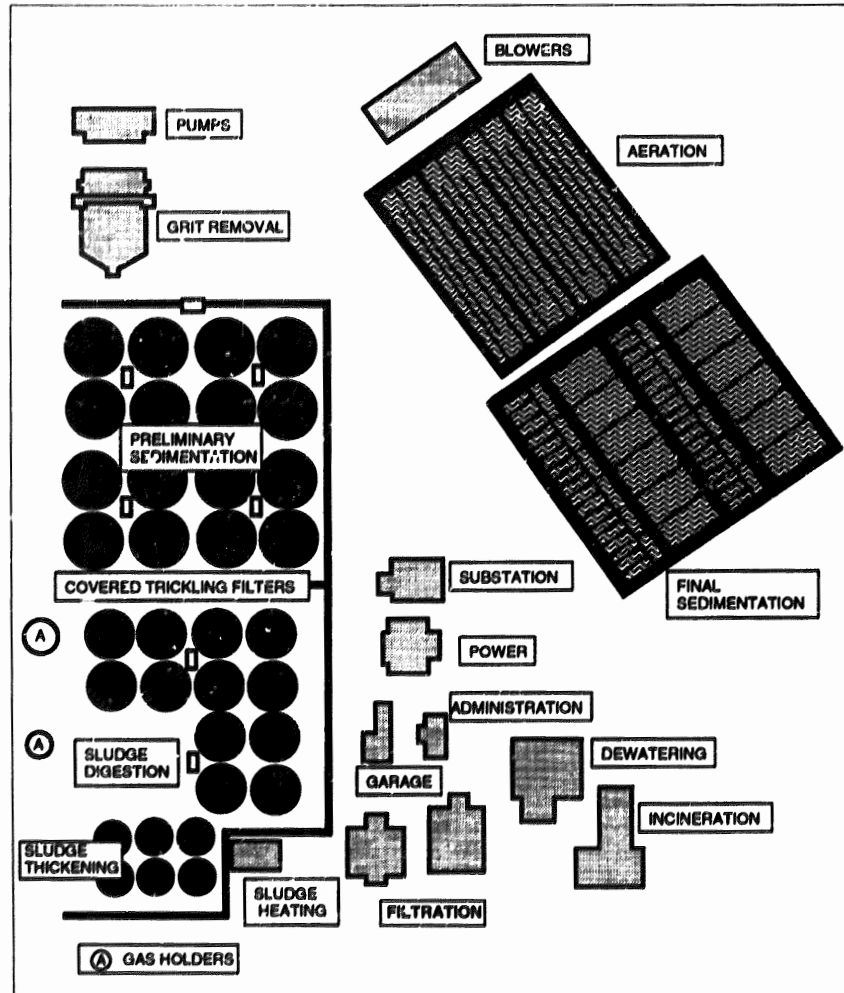


Figure 29: Activated Sludge Tanks



Industrial Liquid Waste Treatment

Most industrial plants pretreat waste water prior to releasing the fluid to the sanitary sewer system. This must be done since municipal systems cannot handle the toxic chemicals and dissolved metals from industrial processes. Some plants will treat waste water and recycle the treated fluid.

Treatment from most industrial process consists of precipitation, reduction, oxidation, coagulation, and flotation methods. After this initial treatment in various clarifiers, thickeners, and flocculation units, the waste is treated as sanitary waste material. Some industries dispose of waste through irrigation and evaporation methods.

Gases

Gases resulting from sewage treatment and industrial processes can be vented directly to the atmosphere when the concentration is low and no health hazard is feared. When the gases are combustible, they can be stored, usually in a gasometer, and used as fuel.

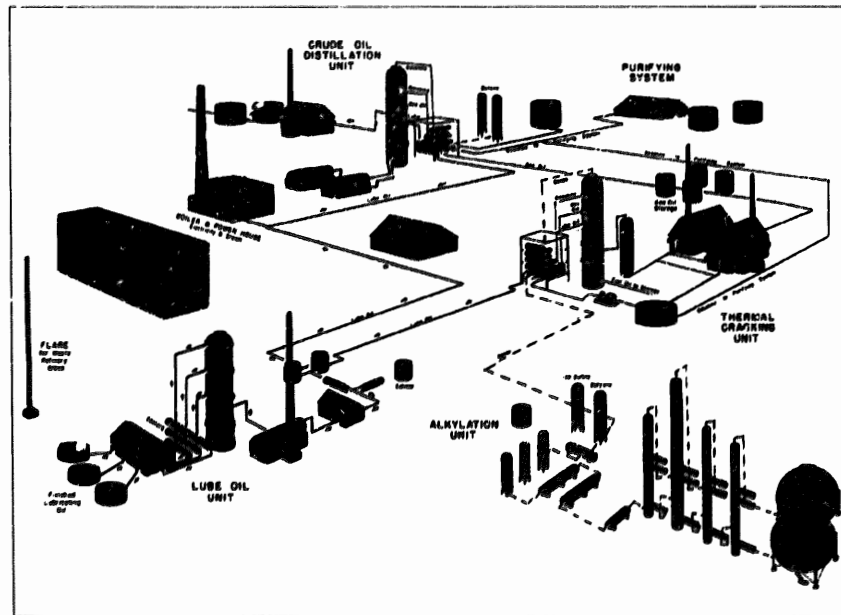


Figure 31: Vertical Flare at Oil Refinery

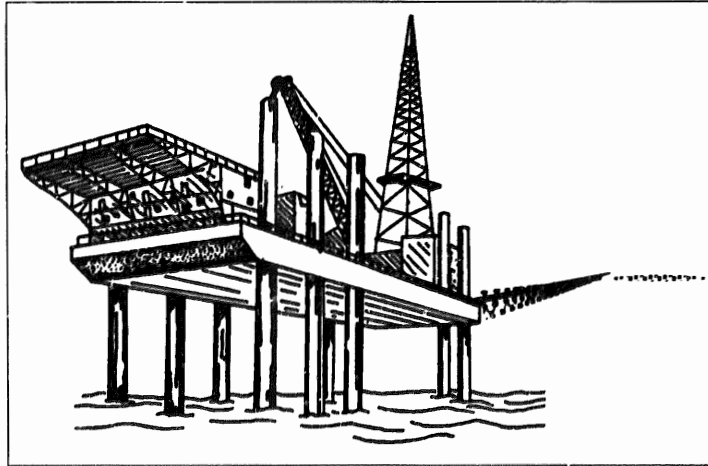


Figure 32: Horizontal Flare on Jackup Oil Platform

Unwanted combustible gases are flared. The flare can be horizontal when the flared material is low in volume and flare use is intermittent. Large scale burning on a constant basis requires a tall vertical flare. This keeps the dangerous gases and fumes of combustion far enough from the ground surface that no health hazard is posed. A flare is simply a pipe, usually equipped with an electrical lighter, which can be free standing or supported by latticework. The flare is situated clear of other structures and is often centered in a bermed area. Petroleum refineries, sewage plants, petroleum wells, and coke plants use flares.

The exceptions to large vertical flare systems are on offshore petroleum drilling and production platforms. Here, to provide clearance for rotary aircraft, the flare is boomed out horizontally from the platform.

Power

Introduction

Power generation consists of the production and distribution of electric power. The power plant provides the method to convert fuel to mechanical energy, which drives the generators and produces electricity. The main methods of generation are thermal energy (using steam driven turbines), hydroelectric (using water pressure to drive turbogenerators), and internal combustion (direct conversion of mechanical to electrical energy).

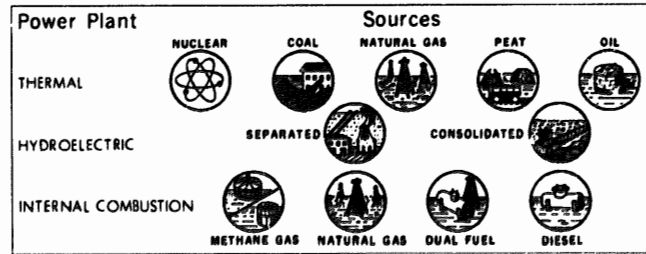


Figure 1: Electric Power Sources

A system of substations (transformer and switching yards) and power lines (suspended from transmission towers or pylons) distribute electricity to the user. The distribution system allows the connection of numerous power plants and subscribers. This allows the network to minimize variations in load demand on any one power plant.

The size of the plant varies by its intended use, i.e., whether the plant supplies the primary power (base load) to a region, or if the plant provides intermittent power during peak power demand. Fuel quality and type also influence plant size. Typical output for a large base load plant using coal is 1200 megawatts and for a hydroelectric plant 825 megawatts. For a peak load plant, designed to handle increased load demands, the power output ranges from 200-600 megawatts.

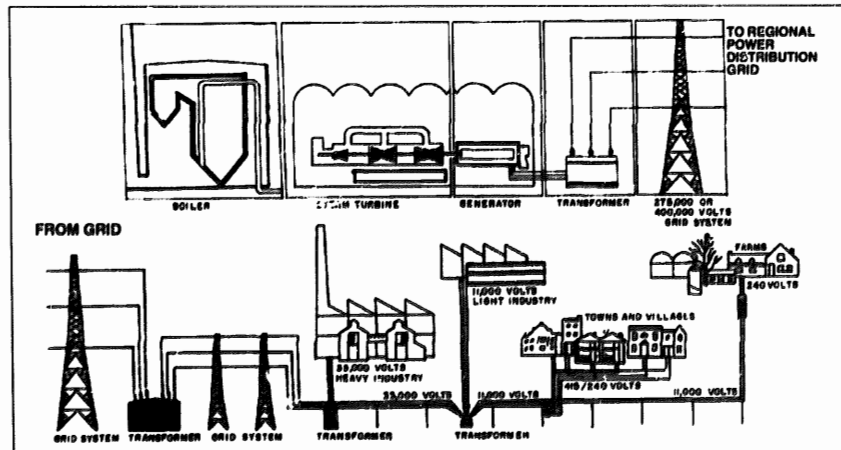


Figure 2: Electricity Flow from Power Plant to Consumer

Power Transmission

The power distribution grid starts at the power plant and ends with the subscriber. High voltage electric current (45 kilovolts or more) can be transmitted long distances with low power losses. However, the customer uses low voltage current. A system of stepping up transformers (increasing voltages for power transmission), stepping down transformers (decreasing voltages for subscriber use), and switching stations (directing current from transmission line to transmission line at the same voltage) manipulates electricity along the transmission network.

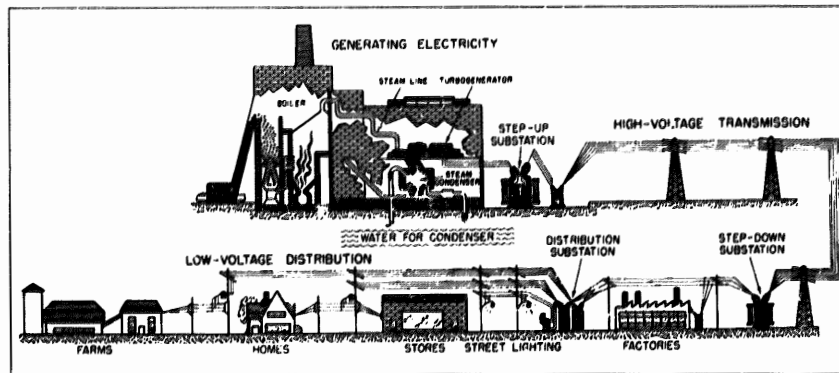


Figure 3: Power Transmission Network

Substations and Transformer Yards

Transformer yards are extremely large transformer complexes found at power plants. These yards are a complex of large transformers and switching networks. A substation is the complex associated with the rest of the distribution network. The basic classification of substations divides those associated with transmission of electricity (high voltage substations) from those associated with distribution of electricity to the user (low voltage substations). The type of equipment at the yard is the basis of an additional distinction. Transformer substations consist primarily of transformers and equipment related to transformers. Switching substations consist of current and voltage switches. Customer substations are substations on the user's premises and provide distribution only within a particular complex. Converter substations convert AC (alternating current) to DC (direct current). Inverter substations convert DC to AC.

A transformer substation consists of transformers (large primary transformers), circuit breakers (for over-voltage protection), disconnect switches (controlling current flow), bus bars (flexible conductors or hollow aluminum pipes to create

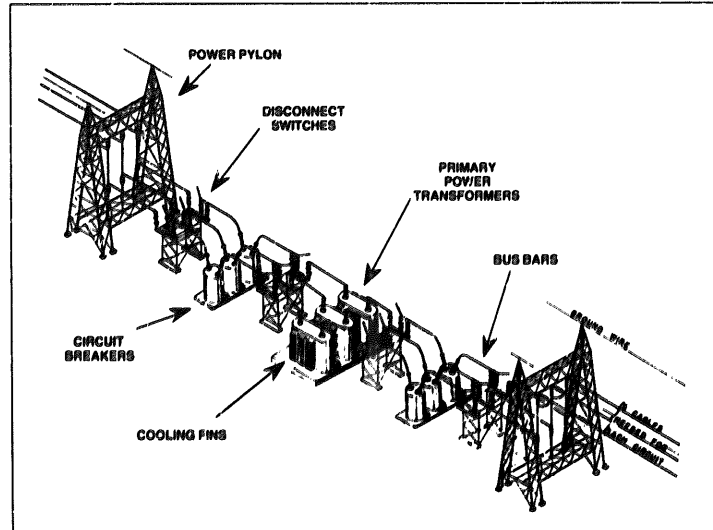


Figure 4: Transformer Substation

the electrical connections), shunt reactors and capacitors (to provide voltage and current to operate the equipment), current and potential transformers (used to measure voltage and current flows), and the control and protection relays.

The large, primary transformers are rectangular (enclosed) boxes. Air insulated transformers have their electrical connections open to the atmosphere. The air's non-conductive properties protect against grounding. This type of transformer requires a fence to limit access within the danger zone. Metal clad transformers have both the electrical connections and the transformer contained within a metal box. Large pipes containing a non-conducting gas, such as sulfur hexafluoride, protect gas insulated transformers from arcing. The gas pumped into the pipes provides insulation around electrical connection points and between components in the substation.

Transformer substations are usually light-toned because they are built on beds of crushed gravel or cement. They are rectangular features with a gridded or framework appearance. The primary transformer will be a solid rectangular unit (ovoid or cylindrical shapes are possible), centrally located between the high and low voltage switchyards and circuit breakers. The transformer is isolated from the general metal framework of the rest of the yard. The transformer has multiple electrical conductors attached at the top. Cooling fins provide heat transfer for the transformer. The transformer is often placed on top of a concrete pad.

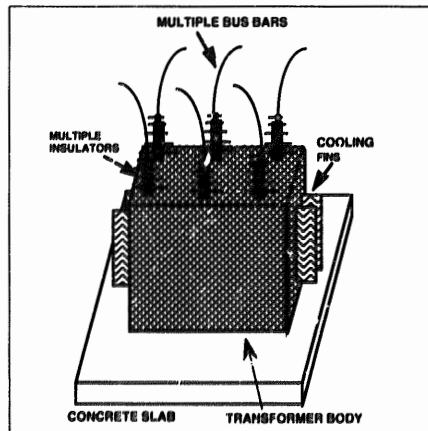


Figure 5: Transformer

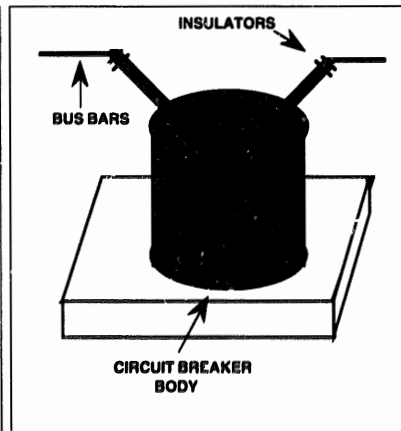


Figure 6: Circuit Breaker

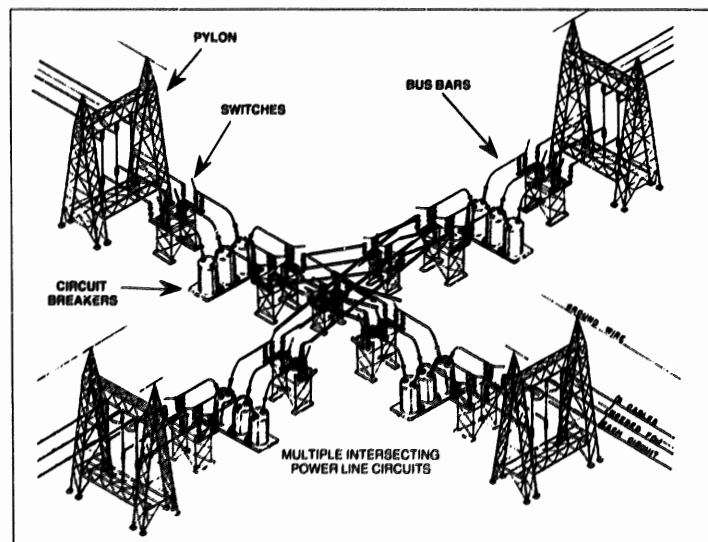


Figure 7: Switching Substation

Sometimes it is isolated from the rest of the installation by blast walls. A control building is also present.

The switching substation consists mainly of switches and circuit breakers. The overall appearance is similar to transformer substations, but without the primary transformers. The circuit breakers and switches are cylindrical or ovoid arrangements of solid black equipment. Circuit breakers and switches have two bus bars at the top, while transformers will have multiple conductors. Additionally, the circuit breakers and switches are incorporated within the metal framework of the substation. Substations for switching, converting, and inverting usually have their primary equipment housed within a building.

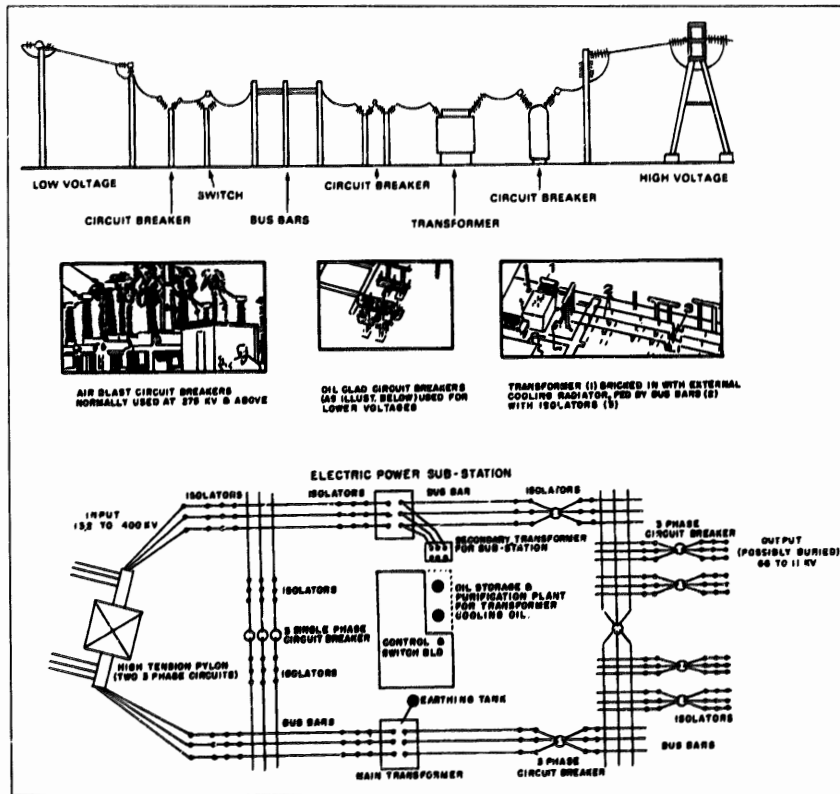


Figure 8: Distribution Substation

Customer substations are small transformer units (of the metal clad type). They are associated with plants and factories.

An industry requiring large amounts of direct current (DC) uses converter substations (converting the alternating current from the power grid to direct current). For submarine cables more than 50 kilometers in length, the use of direct current reduces excessive line loss. The converter substation consists of a series of enclosed converter valves (thyristors), filters, reactors, capacitors, and transformers. A building contains all the equipment, except the transformers.

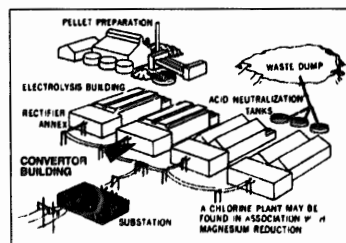


Figure 9: Converter Building

Transmission Lines and Pylons

Networks of power transmission lines, carried on transmission line pylons, transmit the electricity from the power plants through the various substations and transformer yards. These high tension lines carry the high voltage current. So called because of the stress the line conductors are placed under. For example, a 22.2 mm (.875 in) conductor is under 68600 N (15425 lbs) of stress, or around 18% of its ultimate breaking strength.

High voltage efficiently carries large currents over long distance. Low voltage loses too much current to resistance losses to be economically feasible. A network of lower voltage lines carries the electricity from the distribution substations, situated near the consumer, to even smaller pole mounted transformers. The small transformers provide the consumer with the 120 and 240 VAC needed for house current (at least in the U.S.). When possible, the route is planned to be as direct as possible. The large power lines typically cut across country while smaller lines follow roads and railroads for easier access for construction, maintenance, and to minimize right-of-way costs.

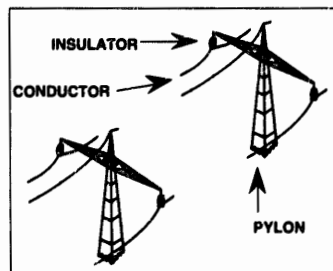


Figure 10: Powerline

A comprehensive study of the entire power system (power grid) provides the input for the actual power transmission line design. Some factors in the study include the size and location of the generators (power plants), the size and location of the loads (the consumers), and the possibility of modifying existing power lines. This information determines the required voltage (and current), the start, and end points of the line. Other influencing factors include soil conditions (soil

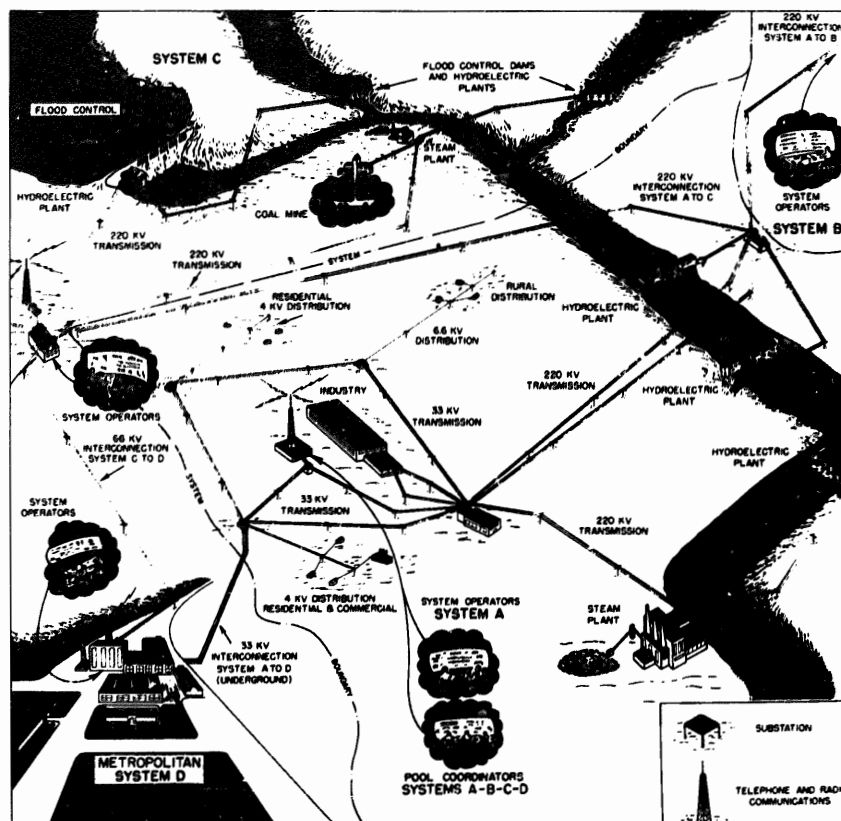


Figure 11: Power Transmission Line Network

types, presence of swamps, and presence of corrosive alkali agents), modifications for navigation clearance for rivers and lake crossings, and local climatic conditions affecting line design (yearly temperature ranges, wind velocity ranges, expected ice thickness, and the presence of corrosive sea salts, smoke, or fog).

The operating voltage and current of the line and the environmental concerns determine the type of pylon construction; the size, number, and type of conductors and insulators; and the required clearances (including vertical height of the tower) around the line.

The conductor carrying the electrical current must be able to handle the demands of the circuit. Smaller electrical loads allow the use of smaller conductors. The type of conductor (size and insulation), line voltage, and span lengths dictate the required safety clearance. Every power line has certain minimum clearances dictated by the line voltage. Small shielded cables carrying low voltages can be mounted on short poles. Unshielded conductors carrying high voltages must be placed high above the ground surface. These high voltage conductors have large ceramic insulators, which may be up to one foot in diameter and several feet long. The basic insulator dimension in the U.S. is 146 mm (5 3/4 in) thick by 254 mm or 267 mm (10 in or 10 1/2 in) in diameter. Multiple insulators are linked to protect from shorting and arcing. Smaller voltage circuits only require the small insulators commonly seen on the small distribution poles. The design of the insulators is based on the three major considerations of the 60 Hz voltages: actual power frequency operating voltage, voltage transients from lightning strikes, and those transients caused by switching (switching voltages). These constraints also dictate the height of the transmission tower.

A 3-phase voltage carries the electric current, with one conductor carrying each phase. Therefore, each 3-phase circuit requires three conductors. The size of the conductor is determined by the voltage, conductor surface (solid vs. stranded and construction material such as copper, steel, or aluminum), and altitude (relating to corona loss, power loss, to the atmosphere). Additionally the line must maintain integrity during stress loading by the mechanical forces from line tension, wind, and ice loading. The most economical conductor is steel reinforced aluminum. Conductor size varies from .5 centimeter (for a low voltage line) to more than 2.2 centimeters (for a very high voltage line). A pylon can carry more than

Line Size kv	Span Length (distance between pylons) m (ft)	Basic Clearance m (ft)	Minimum Horizontal Clearance to Structures m (ft)	Minimum Right-of-Way Width m (ft)
69	213 (700)	3.048 (10)	3.048 (10)	21 (70)
	305 (1000)	3.048 (10)	3.048 (10)	28 (90)
115	213 (700)	3.048 (10)	3.249 (10.66)	23 (75)
	305 (1000)	3.048 (10)	3.249 (10.66)	29 (95)
138	213 (700)	3.048 (10)	3.389 (11.12)	24 (80)
	305 (1000)	3.048 (10)	3.389 (11.12)	31 (105)
161	213 (700)	3.048 (10)	3.532 (11.59)	27 (90)
	305 (1000)	3.048 (10)	3.532 (11.59)	34 (110)
230	305 (1000)	3.048 (10)	3.956 (12.98)	41 (135)
	366 (1200)	3.048 (10)	3.956 (12.98)	47 (155)
	427 (1400)	3.048 (10)	3.956 (12.98)	55 (180)
345	305 (1000)	3.048 (10)	4.666 (15.31)	48 (155)
	366 (1200)	3.048 (10)	4.666 (15.31)	54 (175)
	427 (1400)	3.048 (10)	4.666 (15.31)	61 (200)

Figure 12: Span Length and Clearances for Medium Load Circuit (U.S.)

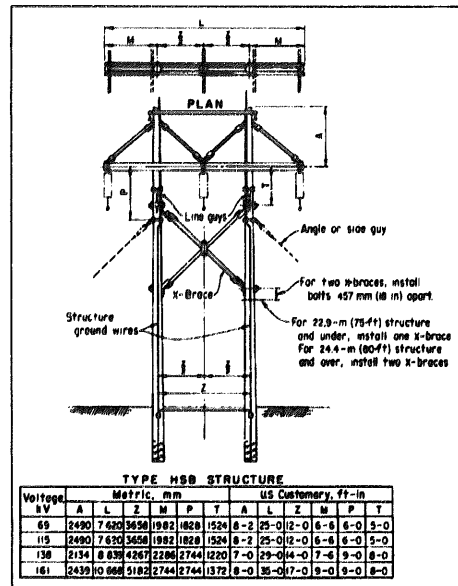


Figure 13: U.S. 'H' Pylon Construction

one circuit, two high voltage circuits can be carried or one high and one low voltage circuit. In addition, one or two sets of smaller wires are placed on an extension at the top of the tower to protect against lightning strikes and to form the overhead ground for the circuit. Overhead ground wires run in size from .914 cm (.360 in) to 1.387 cm (.546 in). Low voltage lines often use an earth-contact ground instead of overhead grounds. The spacing of the conductors (distance from conductor to conductor) is also critical. In high wind conditions, closely spaced conductors can gallop (and touch), causing intermittent shorting resulting in actual damage to the line. Additionally electrical equipment using the circuit can also be severely damaged.

Electrical transmission towers (pylons) carry the suspended electrical conductor along the route of the power line. These towers are spaced at regular intervals. The regularly spaced pylons are much easier to detect than conductors. The towers are classed according to three functions.

These functions are tangent, angle, and

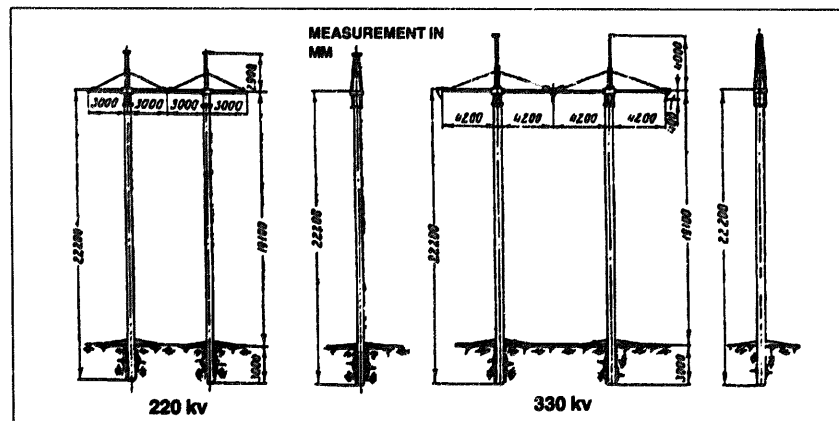


Figure 14: Russian 'H' Pylon Construction

Line Size (kv)	Conductor Size cm (in)	Insulator Length m (ft)	Distance of Outside Phase Wire to Structure Centerline m (ft)
69	.52 (.205)	.869 (2.5)	3.048 (10)
115	.66 (.260)	1.219 (4.0)	3.658 (12)
138	.88 (.347)	1.372 (4.5)	4.267 (14)
161	.88 (.347)	1.676 (5.5)	5.182 (17)
230	1.24 (.488)	2.286 (7.5)	7.620 (25)
345	1.24 (.488)	3.658 (12.0)	9.144 (30)

Figure 15: Conductor and Insulator Size, Medium Load Circuit (U.S.)

tension structures. This refers to the method used to suspend the conductor from the tower. From 80% to 90% of the pylons in a power line are of the tangent class, that is, the conductor is suspended from the tower. The end towers (and often where the line changes directions) of the line are tension type. That is, the tower must be built to accommodate the additional tension (or pull) placed upon the tower since the line is actually affixed to the conductor in a solid connection. Angle towers are also placed under additional stress from the conductor leading off at an angle from the tower. Typically accommodation is through tower guying. The interval between towers varies with tower size and the terrain crossed, ranging from 25 meters to more than 500 meters. Clearcuts within forested areas provide protection against vegetation shorting the conductors. Power pylons are placed clear of buildings and structures.

Local economics and the availability of materials determine the composition and configuration of the pylons. The configuration of the pylon varies, several shapes of pylons are commonly used. Pylon classification is by their resemblance to letter shapes. The pylons are classified according into 'A' type, 'H' type, 'T' type, or 'Y' type. Rarely, other shapes ('V' type for example) can be found.

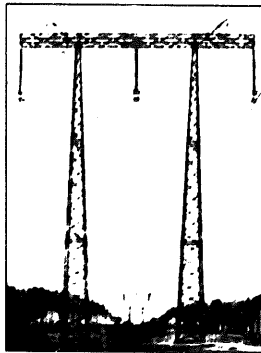


Figure 16: Tangent

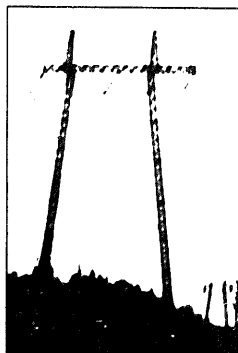


Figure 17: Angle

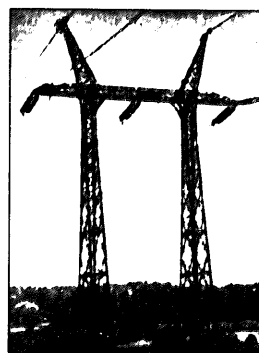


Figure 18: Tension

Power lines, no matter which pylon type is predominant, usually use 'A' type or reinforced 'H' type pylons at the terminal points (tension) and at turns (angle). Construction materials vary depending on availability and strength requirements. Common materials are wood, concrete, and steel. Steel pylons are in the form of latticework towers or solid poles. Concrete towers are pre-cast material, usually around a solid steel core. Steel and concrete towers are standard heights (within a system). The height of wood towers varies more than steel and concrete towers. Power lines using wooden pylons will have steel towers at turns and terminal points (substations). Wood pylons will have more cross-bracing and guy lines than other types. This provides added structural support.

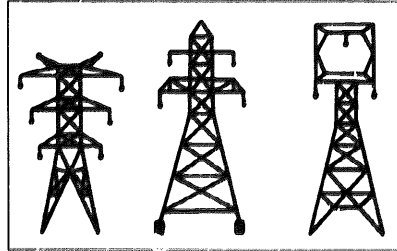


Figure 19: 'A' Pylons

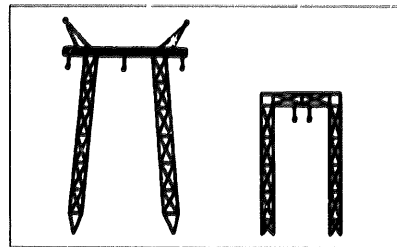


Figure 20: 'H' Pylons

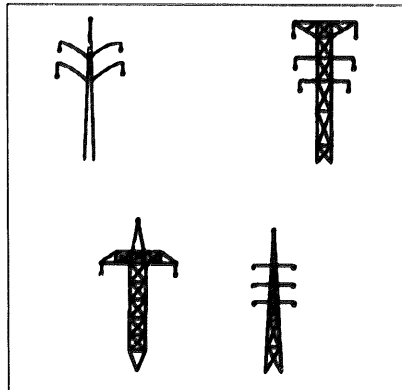


Figure 21: 'T' Pylons

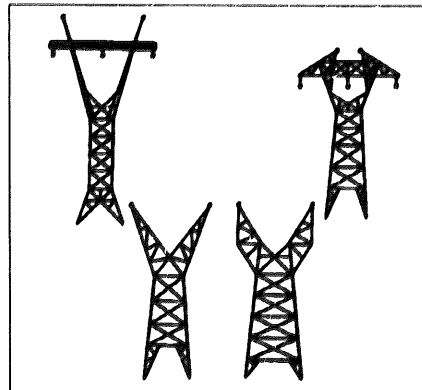


Figure 22: 'Y' Pylons

Line Size kv- # circuits	Span Length m (ft)	Pylon Type	Construction Material	Height m (ft)
6-1		I (pole)	Wood or Concrete	6 (20)
10-1		I (pole)	Wood or Concrete	6 (20)
35-1,-2		I	Wood	13.2 (42.7)
35-1,-2		I	Concrete	19.6 (64)
35-1,-2		H	Wood	13.15 (43)
35-1,-2		Y	Wood	10.5 (34.4)
35-2		A	Steel Lattice	21.9 (72)
110-1,		I	Wood	13.2 (42.7)
110-1,-2		I	Concrete	19.6 (64)
110-1,-2		I	Concrete (steel extension mast)	21.8 (71.7)
110-1		H	Wood	13.15 (43)
110-2		H	Steel Lattice	27 (88.6)
110-1		Y	Wood	10.5 (34.4)
110-1		A	Steel Lattice	21.3 (70)
110-2		A	Steel Lattice	25.9 (85)
154-1		I	Wood	13.2 (42.7)
154-1		I	Concrete	19.6 (65)
154-1		H	Wood	13.15 (43)
220-1		I	Wood	13 (42.7)
350 (1150)		H	Wood	13.15 (43)
220-1		H	Concrete w/ or w/o concrete foundation	22 (72.2)
450 (1475)		H	Steel Lattice	27 (88.6)
220-1		Y	Steel Lattice	28 (92)
220-2		A	Steel Lattice	36.9 (121)
330-1		I (guyed)	Concrete (13.2 m steel lattice mast) w/ or w/o concrete foundation	38.7 (127)
330-1		H (guyed)	Concrete (w/ or w/o mast extension) w/ or w/o concrete foundation	23.1 (75.8)
400-1,-2		H	Steel Lattice	56.4 (185)
500-1		H (guyed)	Concrete (steel extension mast)	27.45 (90)

Figure 2.3: Typical Russian and CIS Pylon Usage

Power Generation

Internal Combustion

Internal combustion power plants provide power for peak load demands. They are used for electric power in isolated areas (without a power grid), base power for industrial plants, or standby (emergency) power for installations. Internal combustion plants use gasoline, diesel, methane gas, or natural gas for fuel. The power output for an internal combustion plant is around 2800 kilowatts per generator unit (for a large gas turbine generating unit).

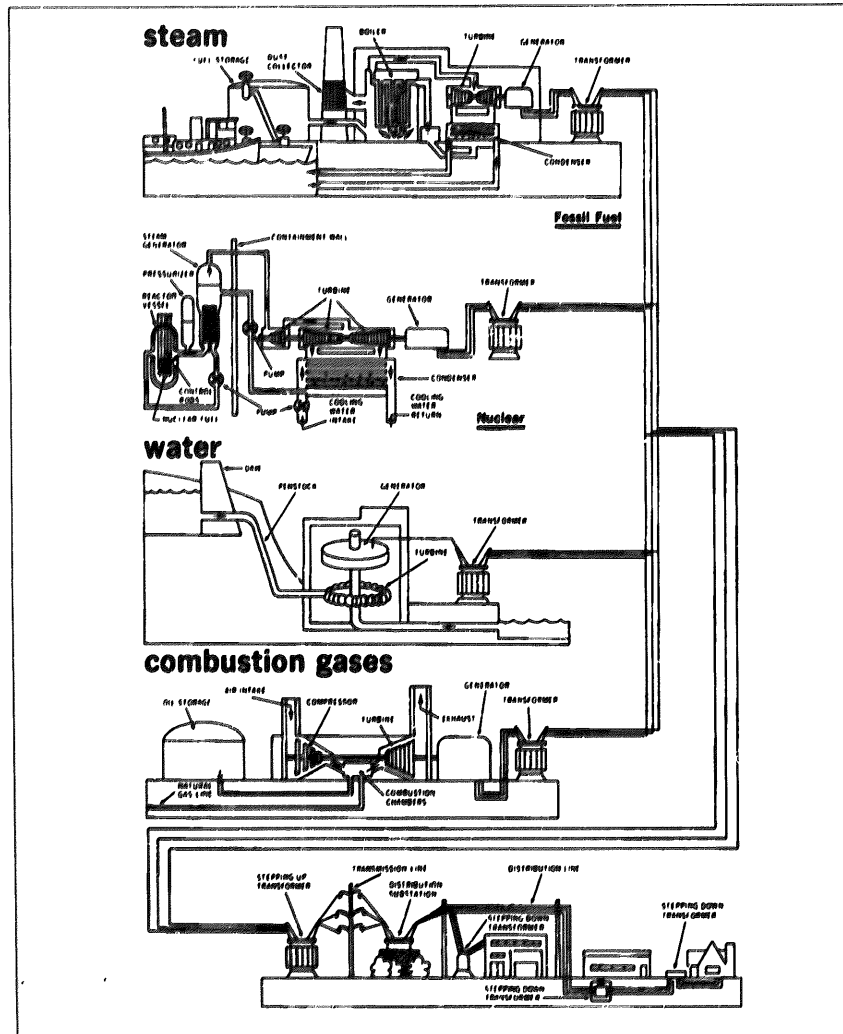


Figure 24: Generation of Electricity

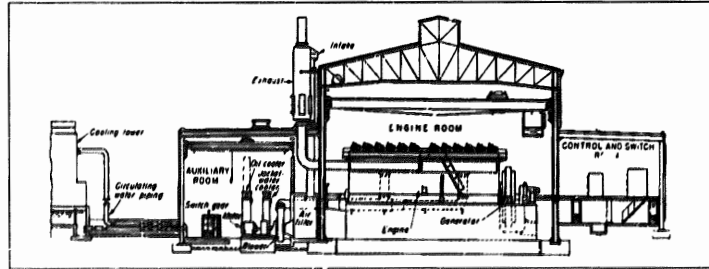


Figure 25: Components of an Internal Combustion Power Plant

The generators can be housed in a building, or may be open to the weather. Each unit will consist of an internal combustion engine coupled to a generator. The engine will have air intakes, exhausts, and mufflers. Gas (jet) turbines have large intakes and exhausts accommodating the large amounts of air required for operation. Reciprocating engines will have cooling facilities, in the form of radiators or other means, available. Gas turbines require no cooling. Fuel cell power plants (using a entirely different technology from internal combustion plants) look like a very clean small gas turbine plant without any exhaust provisions. This technology is in limited use at present.

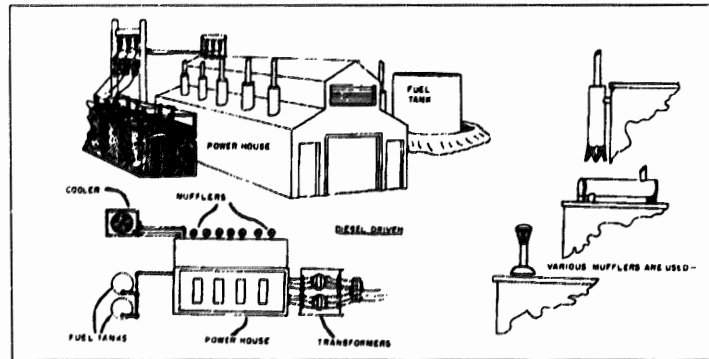


Figure 26: Reciprocating Engine Power Plant

Thermal Power Plants and Turbines

All thermal power plants use steam driven turbines, a boilerhouse (equipment to generate heat and steam), and a generator hall. The daily operation of the plant requires large amounts of water. Most thermal power plants are located next to bodies of water. At least minimal water treatment facilities are necessary at the plant.

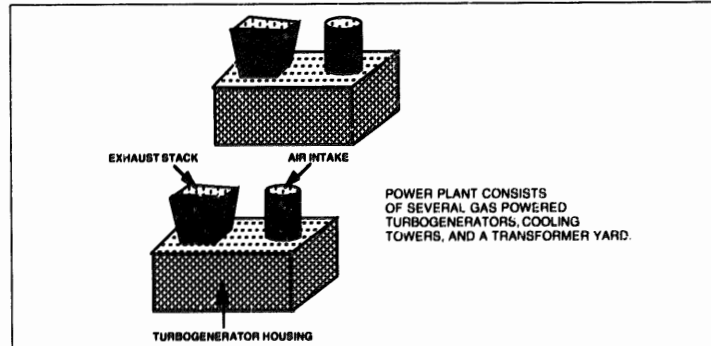


Figure 27: Gas Turbine Power Plant

High pressure water is injected into the boiler for conversion to high pressure steam. The steam drives the steam turbine, which is connected to the generator by the turbine shaft. The electricity generated is passed to the power plant's transformer yard. There the voltage is stepped up for transmission.

The steam exhausted from the turbine is extracted under a vacuum and sent to condensers for conversion to water. Fifty percent of the heat generated at the power plant is waste heat. The power plant uses one of two systems to dispose of the heat. In the open system, the condenser water is discharged directly to a lake or river (the water is used once and discarded). In the closed system, cooling towers and ponds cool the water for reuse.

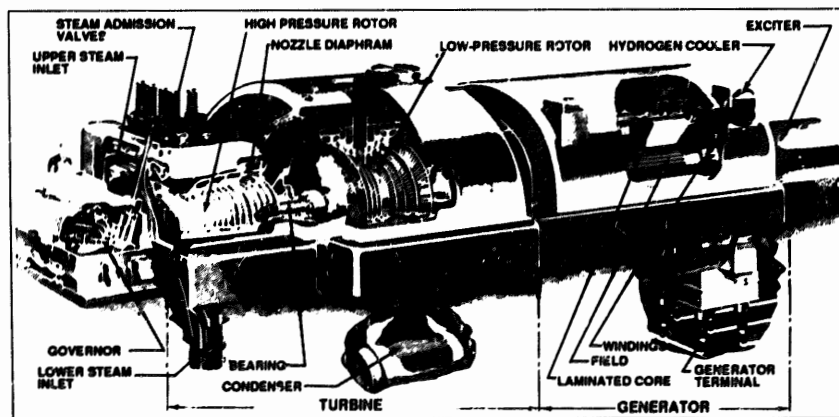


Figure 28: Steam Turbogenerator Components

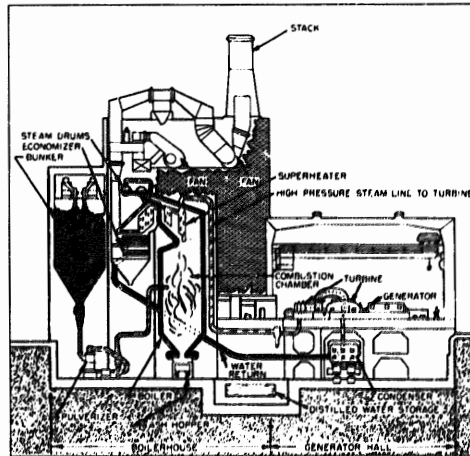


Figure 29: Thermal Power Plant Components

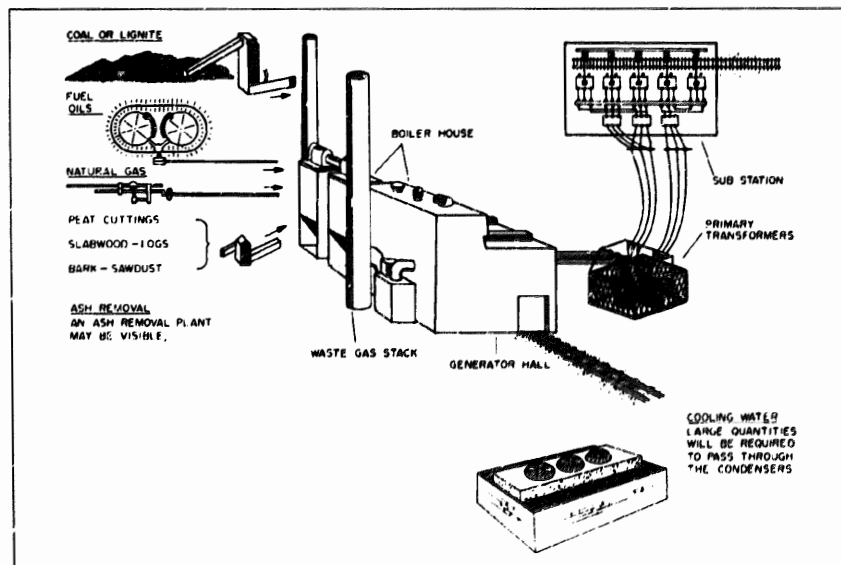


Figure 30: Thermal Power Plant Fuel Sources

Fossil Fuels

Power plants can use coal, oil, natural gas, peat, wood, trash, or a mixture of fossil fuels. These plants have in common the same components and requirements. These are fuel handling equipment, boilers and steam turbines, condenser systems, a feedwater heating system, a system to handle flue gases and wastes, and a control system.

The typical power plant has a 30-180 day fuel supply stockpiled. Rail, barge, pipeline, and/or trucks deliver the fuel. Specialized equipment unloads and stockpiles the fuel. This equipment varies by the delivery method, but includes metering stations (oil and gas), conveyors (transport fuel from unloading to storage areas), coal tipples, and cranes or power shovels. The fuel is stored in tanks, bins, hoppers, or in open storage yards. Coal is stockpiled in large open storage yards. Oil is stored in bermed tank batteries. Power plants fed by natural gas pipelines may not have an on site storage facility. Peat and other low BTU fuels are stockpiled in parallel rows in open storage. Conveyors and pipelines retrieve the fuel, and the fuel is prepared for burning. Conveyors for low BTU fuels are wide and of the open type, compared to the narrow, closed conveyors used for coal. Oil is pumped to a day tank (a one day supply for the boiler) where the oil is heated before injection into the boiler. The oil is atomized immediately before injection to increase fuel efficiency. Coal is pulverized at the storage yard and sent by pneumatic conveyors into the plant. Gas is piped directly from the pipeline or from adjacent storage tanks. Fossil fuel plants using peat, wood, or trash as primary fuel require more fuel preparation and larger fuel storage areas.

In the plant the boiler burns the fuel to produce the steam needed to run the turbines. The tall boilerhouse is often attached to the smaller generator hall. Feedwater heating equipment preheats the water before use in the

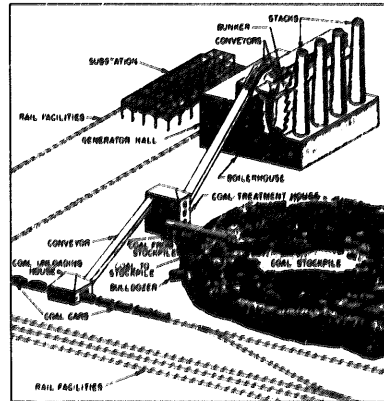


Figure 31: Coal Thermal Power Plant

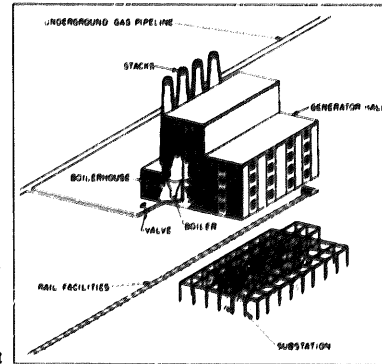


Figure 32: Gas Thermal Power Plant

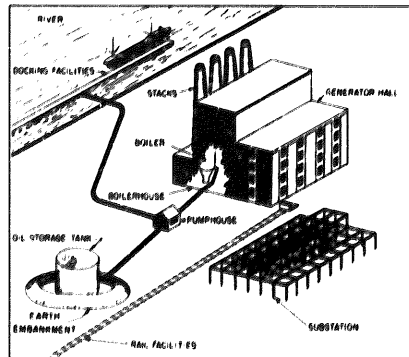


Figure 33: Oil Thermal Power Plant

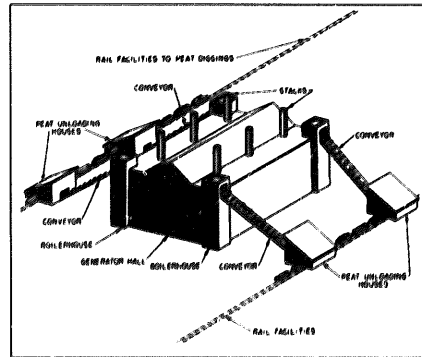


Figure 34: Peat Thermal Power Plant

boiler. After the steam passes through the turbine, it is condensed (condenser located under most boilers) and cooled for re-use.

Electrostatic precipitators treat the exhaust gases from the boilers to remove particulates. Scrubbers remove sulfur dioxide and nitrogen oxides. The waste gases are discharged through tall smokestacks. Ash handling equipment removes the ash (cinders) from the boilerhouse for disposal.

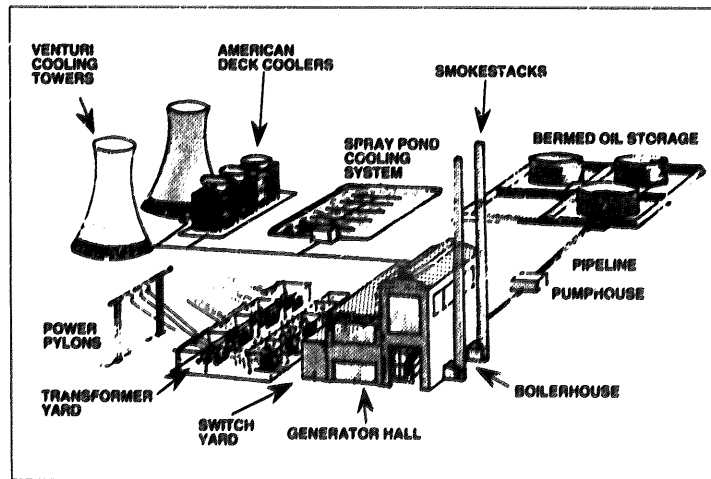


Figure 35: Oil TPP Components

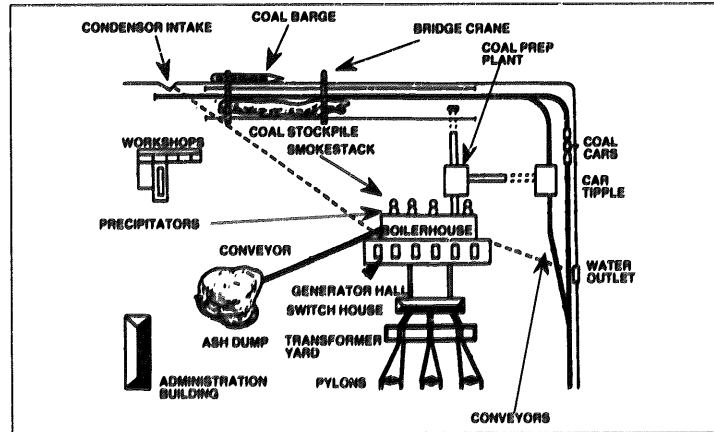


Figure 36: Coal TPP Components

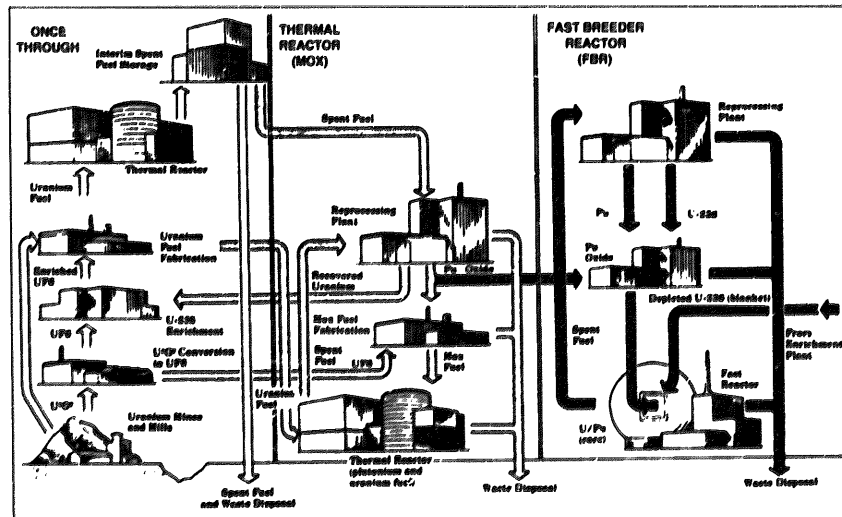


Figure 37: Nuclear Fuel Cycles

The control room at the plant can be a separate building, or it can be contained within the boilerhouse and generator hall buildings.

Nuclear

Nuclear power plants use a fission pile (nuclear reactor) to produce the heat needed to run the steam turbines (reactor replaces the boilerhouse). Nuclear power reactors use uranium, plutonium, or a uranium-plutonium oxide mixture (MOX) for fuel. Three basic types of fuel cycles are common. One type uses uranium in a once through operation in the reactor. Then the fuel is discarded. A MOX facility uses an oxide mix of plutonium and uranium. The fuel can be re-processed. The fast breeder reactor during power production concurrently produces an excess of plutonium. The plutonium is then processed into more fuel. The reactor configuration varies greatly. There are numerous reactor designs for different fuels and using various heat transfer and cooling schemes.

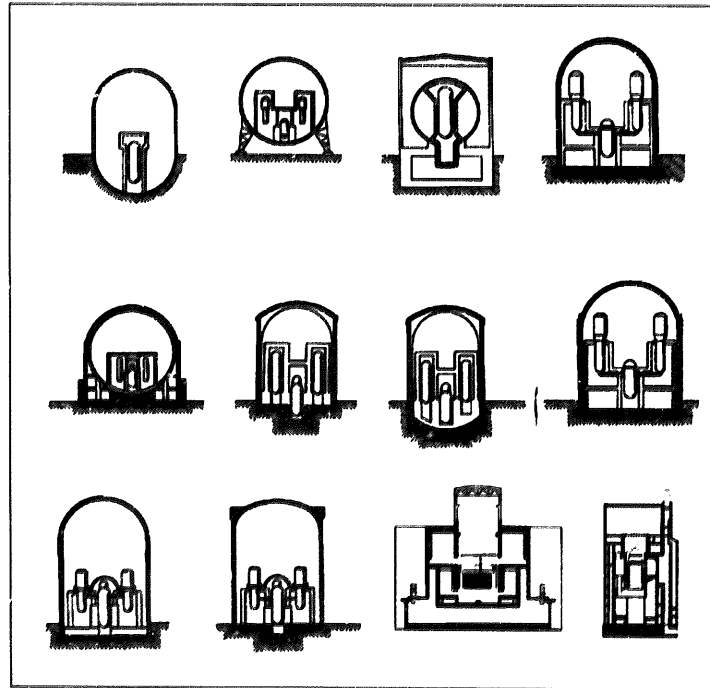


Figure 38: Containment Vessel Profiles

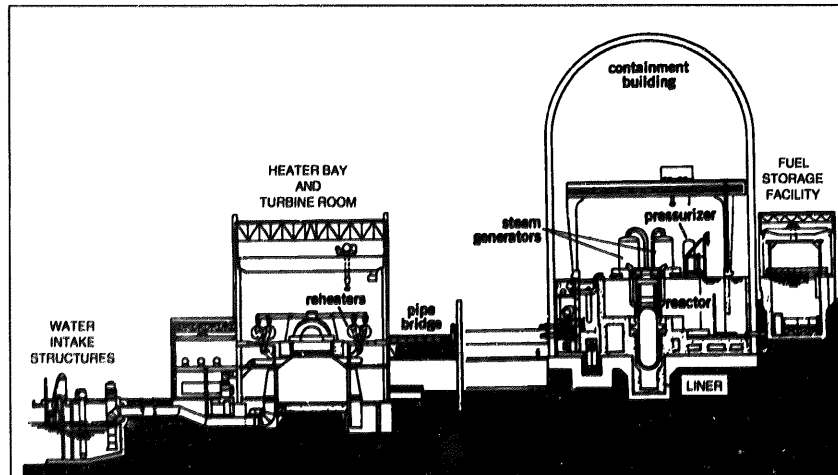


Figure 39: Pressurized Water Reactor (PWR) Power Facility

The shield building covers the reactor's primary containment structure. This is the largest and tallest building in the complex. Thermal energy is circulated from the primary cooling system to a secondary cooling loop in one scheme, the pressurized water reactor. The generator hall can be attached to the shield structure or can be a separate building. Another auxiliary building, attached to the shield building, handles the fuel rods and houses the reactor controls.

Waste heat and the electricity produced are handled the same as other power plants. A major problem with nuclear power plants is the handling and disposal of the fuel rods, which are highly radioactive after use. One quarter of the fuel rods is replaced yearly. Once fuel rods are removed from the reactor through the

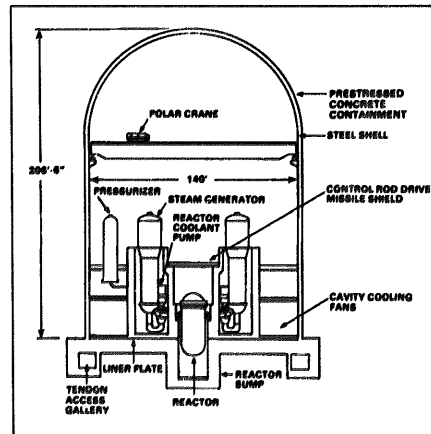


Figure 40: PWR Containment Building

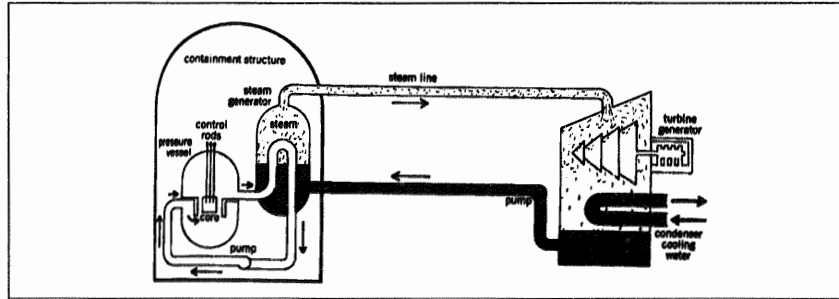


Figure 41: PWR Steam Generation

auxiliary building, they are stored in pools (situated next to the reactor, with high load overhead cranes) and eventually shipped for reprocessing or disposal.

Another waste produced is the waste gases vented from the reactor. To minimize exposure to these gases, they are vented through a waste gas stack, usually an extremely tall stack next to the reactor. The stack also vents gases during emergency reactor excursion.

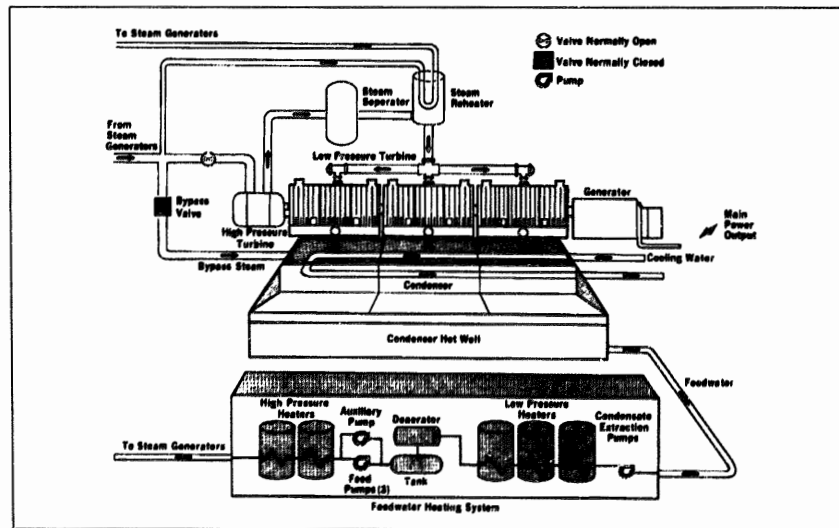


Figure 42: PWR Generator Building

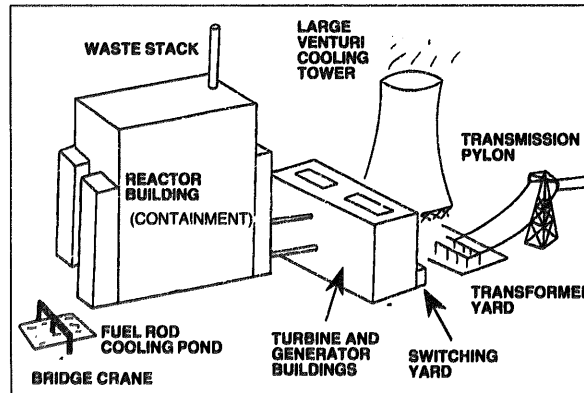


Figure 43: Nuclear Plant Components

Nuclear power plants have heavy security with at least one row of security fencing around the area. A nuclear power plant is identified by its neat and clean appearance and the containment facility. Reactor facilities in most countries use an environmental containment structure. This structure isolates the reactor vessel and any produced gases and radiation leakage from the outside. Some reactor facilities, most notably in Russia and the CIS, use a bio-hazard type contain-

ment facility. These structures isolate the nuclear material only during normal operation. Any breach of the reactor vessel (core melt-down, explosion, or coolant loss) will result in leakage into the atmosphere. Reactors without a transformer yard (or a small yard) are not being used for power generation. Such reactors are used for research or production of the special nuclear material (SNM) used in weapons production.

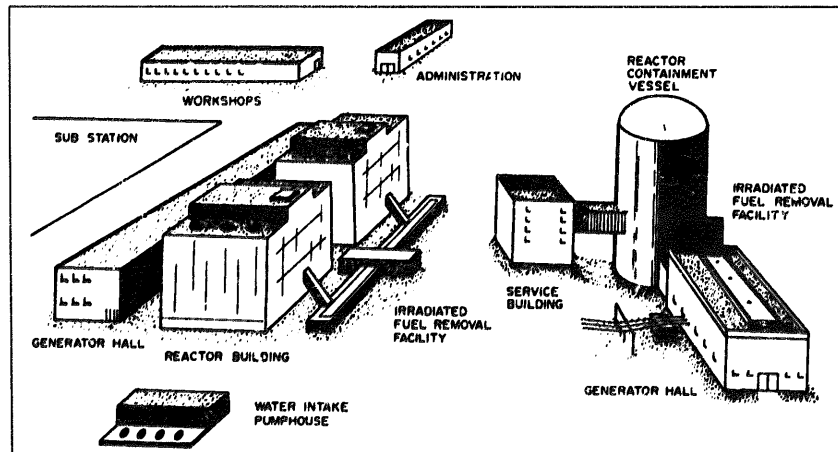


Figure 44: Nuclear Power Plants

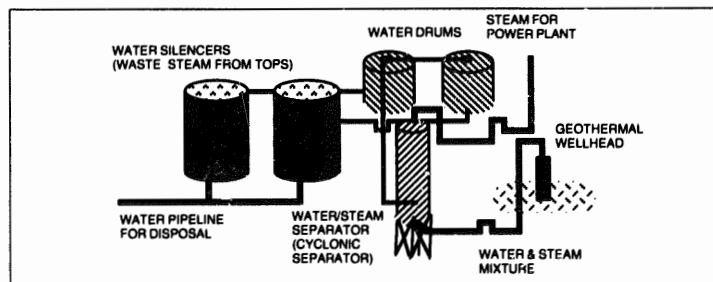


Figure 45: Geothermal Well Components

Geothermal

Geothermal plants use heat derived from subsurface waters as a heat source. Wells bring the geothermally heated water to the surface. Heat transfer loops extract the heat for use in the turbogenerator. There are three types of geothermal plants. In hydrothermal plants, hot subsurface rocks heat water and a well extracts this heated water for use at the plant. Hot pressurized water runs geopressured plants. In a petrochemical plant, wells inject cool surface waters into

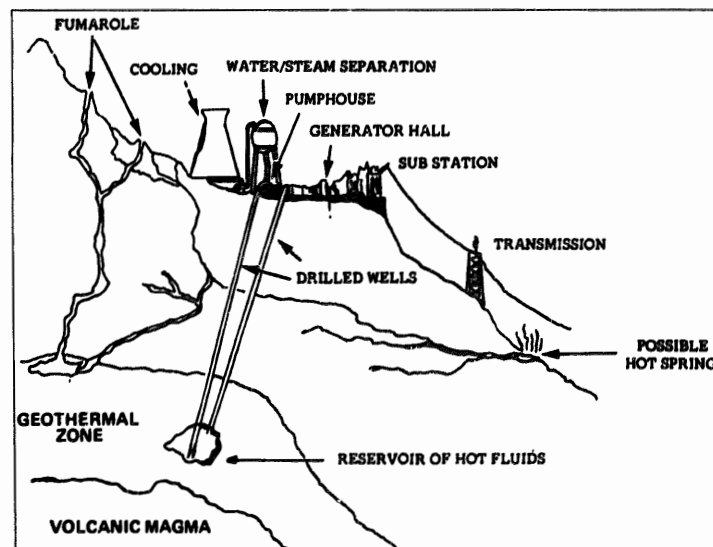


Figure 46: Hydrothermal Power Plant

the ground, hot subsurface rocks heat the water, and the extracted water runs the turbines.

Other

Solar energy can be directly used to heat water for a power plant. A series of mirrors concentrates the sun's rays on a central tower, water (or a suitable material) is heated, and the heat is transferred to steam turbines connected to generators. Another method uses fields of solar concentrators, mirrored troughs containing pipes, which absorb the heat for transfer to the turbogenerators.

Direct conversion of solar energy to electricity is used in small scale, isolated electricity production. A series of photocells produces electricity that is immediately used or stored in arrays of batteries.

Another method of generating electricity is the magnetohydrodynamic generator. This is a method using thermally ionized gas (passed through a duct under high temperature, pressure, and velocity) **directly** generating electricity. The duct is contained within a transverse magnetic field. The induced magnetic field produced is tapped by electrodes placed within the ductwork. Heat to operate the generator is produced from nuclear

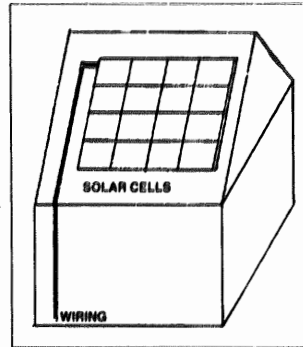


Figure 47: Solar Electric Cells

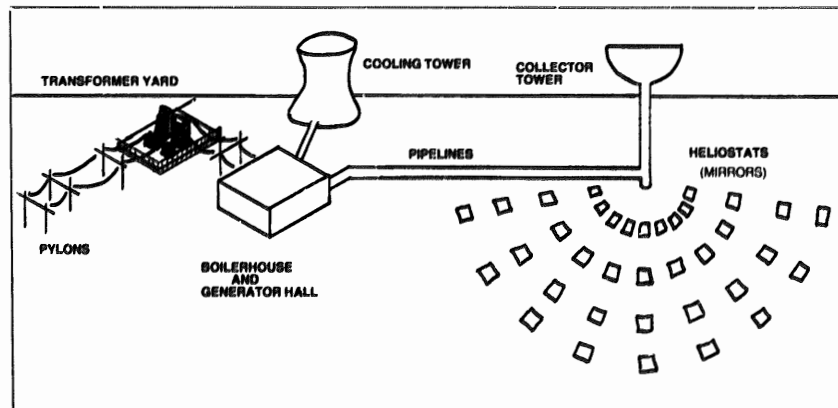


Figure 48: Solar Collector Tower Power Plant

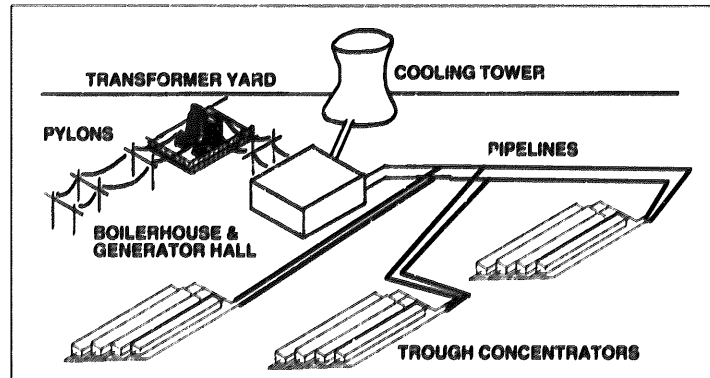


Figure 49: Trough Concentrator Power Plant

reactors or fossil fuels. This system has the advantages of no moving parts, high efficiency (greater than 85%), and the waste heat may be used to power a secondary conventional thermal power plant.

Prototype plants are operating on a small scale. Since this type of plant requires about 15% of the power output to sustain the magnetic field, the magnetohydrodynamic plant is suitable for a base load plant only.

Hydroelectric

Hydroelectric plants use the hydraulic head (water under pressure) to turn turbogenerators and produce electricity. The plant requires a dam (to impound and store water), waterways (to transport water), and turbogenerators (hydraulic turbines running generators).

Hydroelectric plants are classified by the extent of the impound (storage, pumped storage, or run-of-river plants), the plant's intended usage (peak load, base load, or isolated plant), or the type of hydraulic head used (high head of 150 meters or greater, low head of less than 15 meters, and medium head between the two extremes). Plants are also classified by the relation of the impound water to the generators. A separated plant's dam is at a different location from the generators. The consolidated plant has collocated generators and dam. The construction of the dam depends on the topography of the site, the character and extent of the drainage area, the expected flow variation, and the purpose of the dam. High dams are dams with a height exceeding 30 meters. Low dams are those with a height under 30 meters. The height of the dam does not necessarily correspond to the head produced. Run-of-river dams are constructed to take advantage of 30% to 40% of the expected maximum flow.

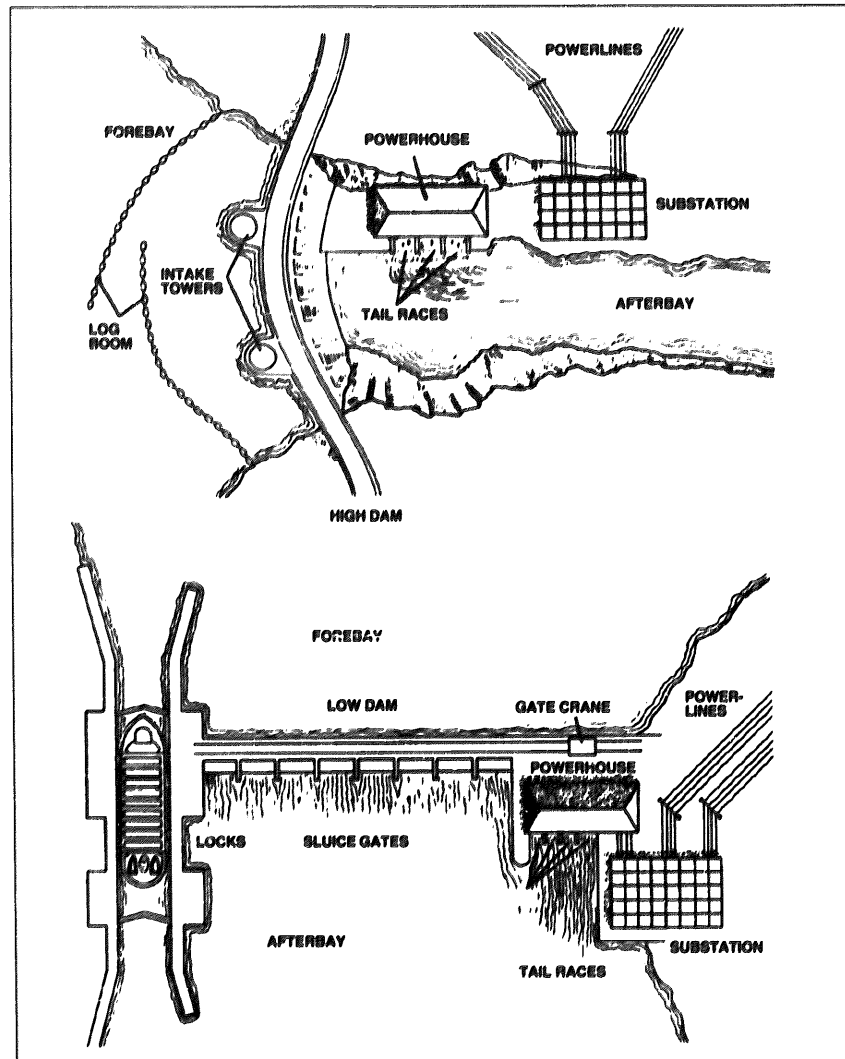


Figure 50: Consolidated Hydroelectric Power Plants

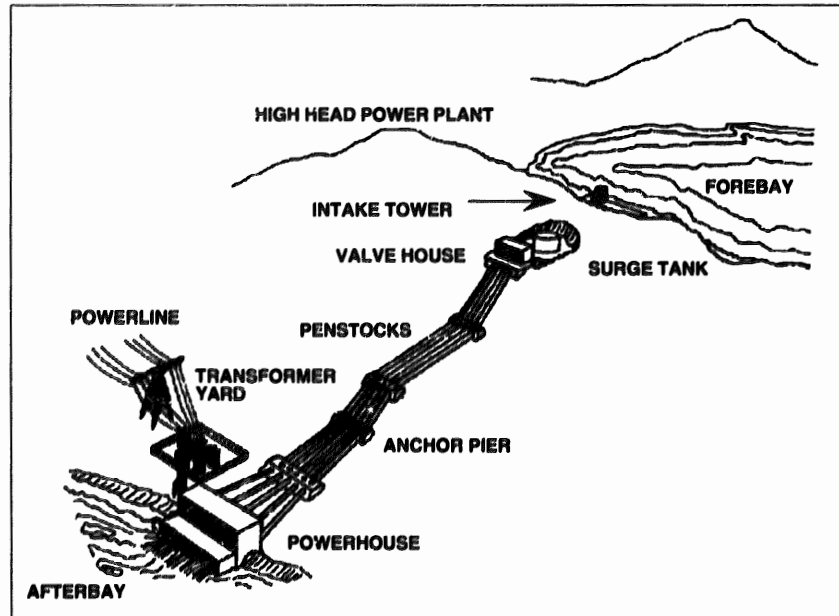


Figure 51: Separated Hydroelectric Power Plant

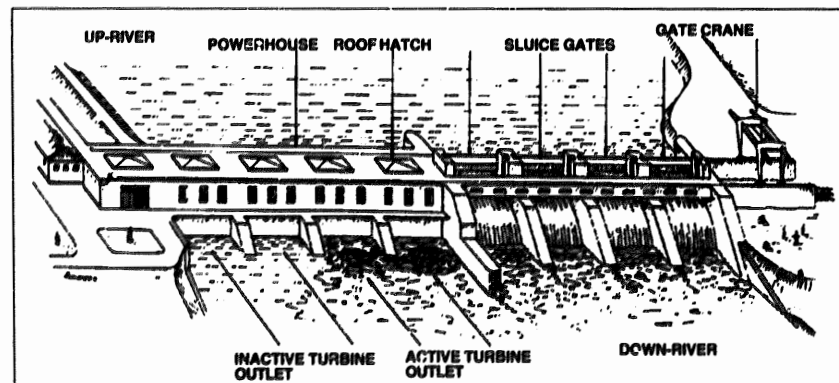


Figure 52: Run-Of-River Low Dam Hydroelectric Power Plant

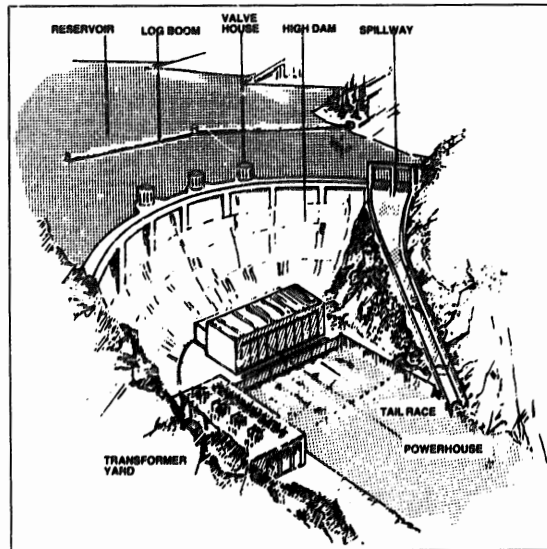


Figure 53: High Dam Storage Hydroelectric Power Plant

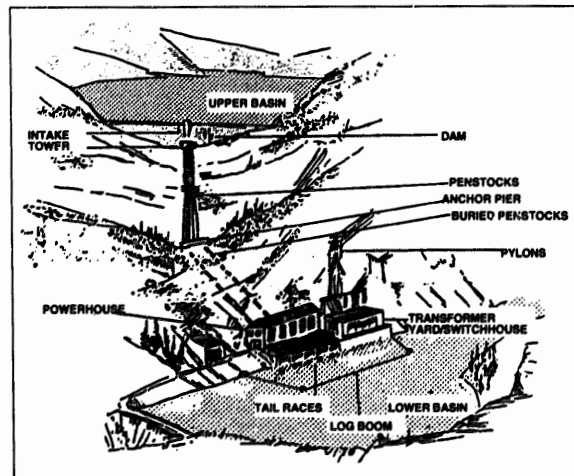


Figure 54: High Head Pumped Storage Power Plant

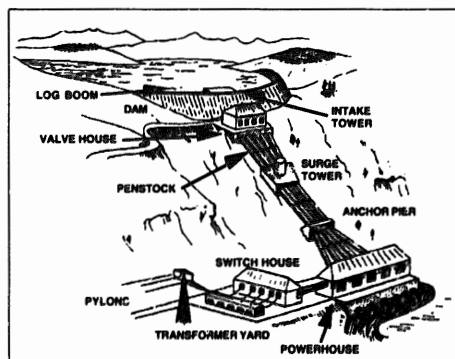


Figure 55: Penstock Cross-Sectional View

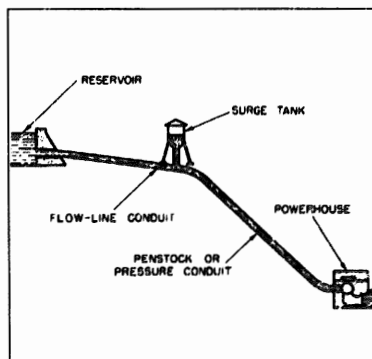


Figure 56: Penstock and Power Plant

A storage dam impounds larger amounts of water behind the dam to use 50% to 75% of the expected flow. Pumped storage facilities pump water uphill to an impound basin and dam for use during peak demand.

The waterways linking the dam to the turbines can be in the form of tunnels, open canals, flumes, or enclosed penstocks. Water enters the waterway through intake towers that also control the water flow.

A penstock is a large pipe originating at the water source and terminating at the turbine. Changes in flow rate and pressure can cause damaging shock waves within the pipe. Surge tanks are located at the midpoint of the penstock to protect from hydraulic jump and to provide constant flow to the generators. Large concrete anchor blocks are spaced along the penstock. The water from the penstock drives the turbines in the powerhouse. The pure velocity of the water drives impulse turbines (Pelton Wheel). A mixture of pressure and pressure converted to velocity drives reaction turbines (Francis turbine and propeller turbine). The used water is exhausted back to the watercourse through draft tubes (pulling water out under vacuum, increasing turbine efficiency and converting the velocity head back to a pressure head), tailraces, or tunnels.

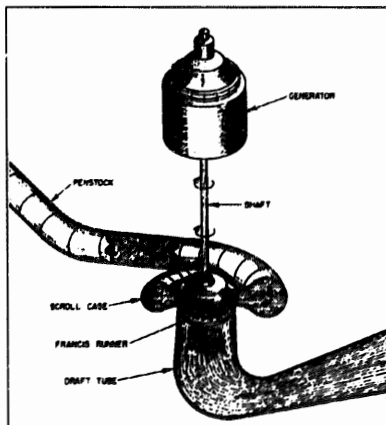


Figure 57: Draft Tube and Reaction Turbine

The turbogenerators can be contained within a building at the dam, placed on top of the dam, or contained within the dam structure. The power output of the turbogenerator is a function of the volume of flow and the hydraulic head available for use ($P \text{ (kW)} = Qh/k$, where Q is the volume of flow in cubic feet per second, h is the height water falls in feet, and the constant k is 11.8, a dimensionless number).

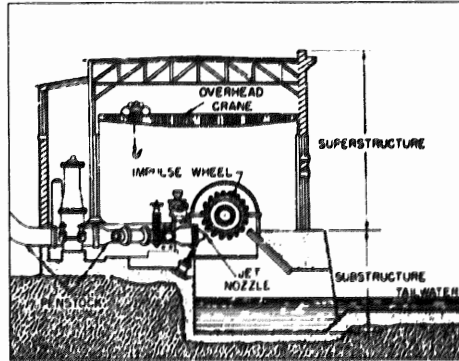


Figure 58: Powerhouse and Impulse Turbine

Tidal plants operate exactly as any other hydroelectric plant. The tidal plant has its dam placed across a bay or estuary, usually in an area with large tidal variation, and the difference in tidal levels runs the turbines. Most tidal plants have bi-directional turbines (turbines operate in either direction).

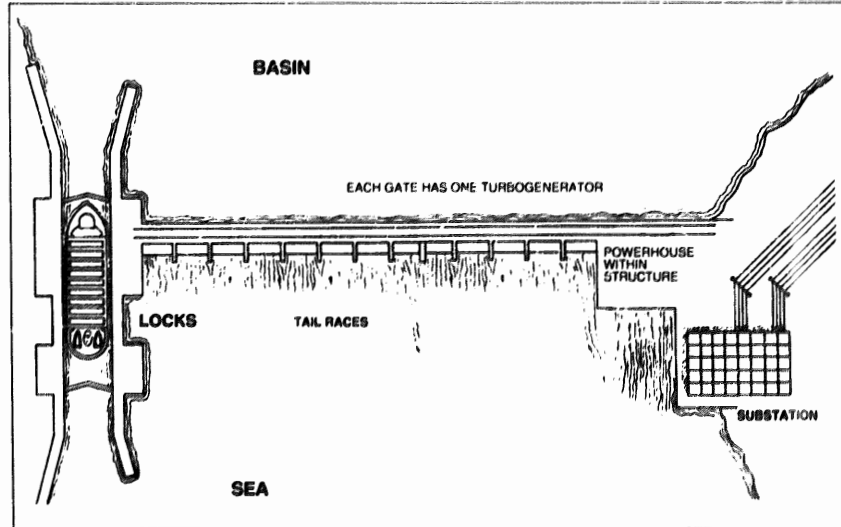


Figure 59: Tidal Hydroelectric Power Plant

Wind

Most wind power generators produce electricity at a small scale in isolated locations. Some large scale generating plants are operational. Power output for a single large aerogenerator (with a rotor diameter of 120 meters) can be 3.5 megawatts. These plants use fields of wind turbines (numbering in the hundreds) to generate large amounts of electricity. Aeroturbogenerators use a wind powered blade coupled directly to the generator. The wind generator has a bulbous housing around the turbogenerator. An aerogenerator lacks the mechanical coupling necessary to operate a pump, differentiating the aerogenerator from a windmill used to pump water.

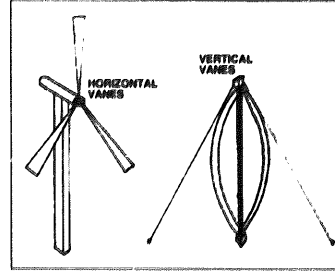


Figure 60: Aeroturbogenerators

Heat and Steam Plants

Some plants provide only heat (in the form of steam) for district heating purposes or for industrial processes. These plants normally use oil or coal for fuel. A steam plant has no transformer yard. These plants are centrally located in urban areas, or are associated with manufacturing. The plant consists of fuel storage (not as much storage as a power plant), fuel handling equipment, a boilerhouse

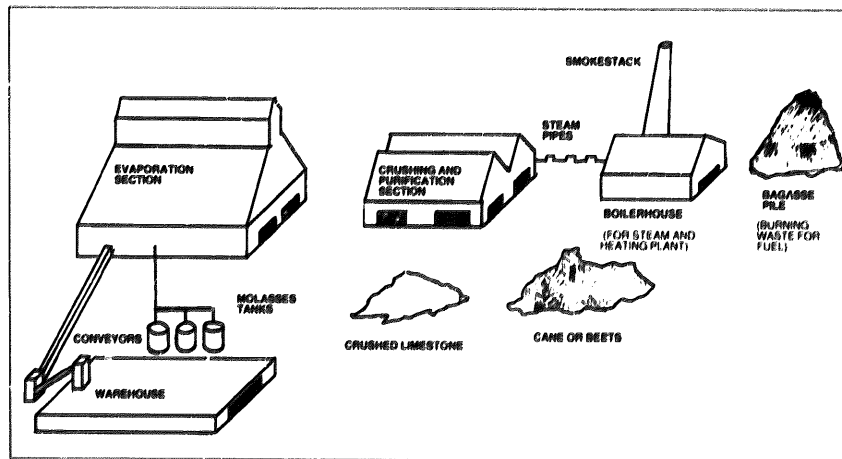


Figure 61: Steam Plant at Sugar Processing Plant

with smokestack, and numerous steam pipes. Steam pipes have heavy insulation and frequent expansion joints. The pipes are sometimes suspended clear of the ground surface. Some systems only have a feed line with no return line (the condensate discharges into the sewer).

Processing

Water

The sources of water are reservoirs, lakes, streams, and wells. Some water sources such as wells, upland lakes, and stream headwaters are fairly clean and non-polluted. Other sources such as the middle and lower reaches of rivers and reservoirs usually require treatment because of pollution and sediments (turbidity) in the water. Even rain water collects impurities from the atmosphere in the form of dust and gases. Water entering the supply system carries pollutants ranging in size from very coarse (leaves, wood, and fish) to very fine. Pollutants can be in suspension (rock and organic debris), in colloids (clay particles and living organisms), and in solution (minerals and gases). Some pollutants only cause unpleasant tastes and texture, while others cause disease or toxic effects. The result of water treatment is an assured supply of safe water in ample amounts

Collection

Main sources of water are unprotected surface waters (streams, rivers, and lakes), protected surface waters (reservoirs and lakes with no polluting activities allowed within the watershed), and sub-surface waters (wells).

Collection of surface waters (lakes, streams, and reservoirs) is from intakes. The intakes withdraw water from the least polluted level of the water source.

Different levels beneath the surface have varying amounts of sediment, debris, and organic contaminants. The

intake can be a simple pipe extending into the middle of the stream, a complex of intake towers, or vertical piping with adjustable gates at various levels. Coarse screens to remove large objects and a series of finer screens to remove smaller objects cap the intake pipe. Cribbs are intakes protected by timber works set in rock at the

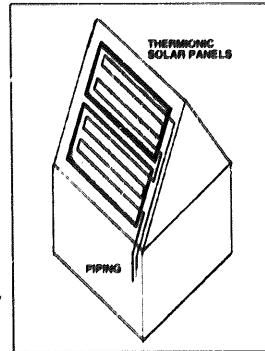


Figure 6.2: Solar Heating Panels

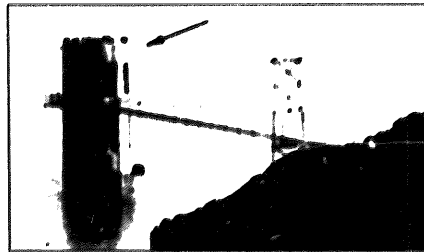


Figure 1.1: Intake Tower

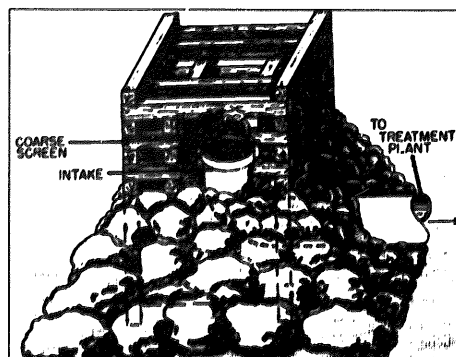


Figure 1.2: Intake Crib

end of the intake pipe. Reservoirs use intake towers either placed in the middle of the impound or attached to the face of the dam structure. Canals divert water to intake ponds in some instances. Overflow dams impound water in rivers with erratic and low flow. Another method of intake involves the use of infiltration galleries. Infiltration galleries extend either from the shoreline into the stream (below the surface) or they extend along the shoreline. They consist of a series of perforated pipes surrounded by gravel and sand.

Access to sub-surface waters is by drilled or dug wells or by tapping natural springs. Wells have pipes leading from the wellhead to a pumping station or central collection point for water treatment.

Storage

The water supply must have sufficient storage capacity to meet the system needs. Storage is available for untreated water (to compensate for periods of low water flow) and treated water (to counter interruptions in the distribution systems). Raw water storage is in the form of storage reservoirs, lakes, and catchment basins. Water systems using large rivers (sufficient flow assured) and lakes will not need a large amount of raw water storage.

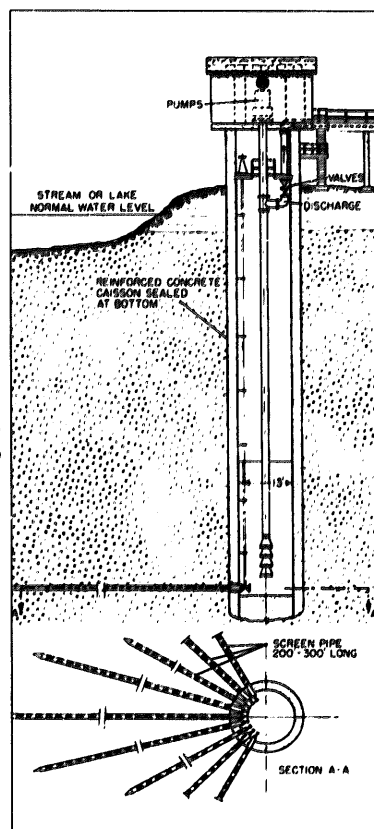


Figure 1.3: Infiltration Gallery

Treatment

Water treatment destroys disease causing biological agents, eliminates organic matter affecting taste and odor, and eliminates harmful chemicals. The treatment involves a sequence of mechanical and chemical processes. Mechanical cleaning is by a series of coarse and fine screens to remove large particulate matter. Desedimentation basins remove suspended material. Chemical purification removes and neutralizes bacteria and fine organic materials. Flocculation removes colloidal substances and precipitation removes dissolved chemical material. Final treatment is the addition of chemicals to maintain water quality during transportation and to reduce the corrosiveness of the water.

Potable water treatment consists of mixing with coagulants (various sulfate compounds) to force aggregation and flocculation of suspended organic materials. Clarification tanks separate the flocculated solids from liquids. Diatomaceous earth or sand filters remove any remaining solids. Treatment with ozone or chlorine disinfects the water. Additional treatment by softening agents, activated carbon filters, and aeration equipment completes the cycle.

The actual facilities at a water treatment plant vary depending upon the water source. Water from polluted sources requires complete treatment systems. Water from relatively clean sources requires minimal treatment. Water solely intended

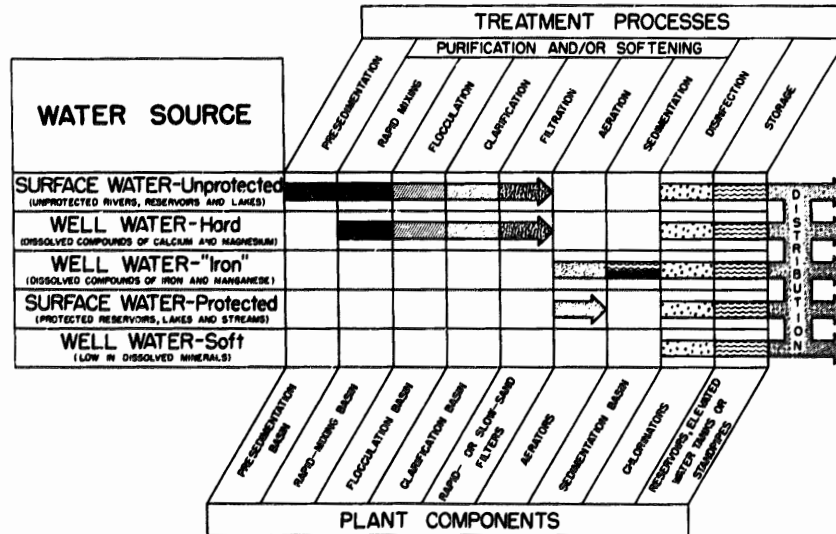


Figure 1.4: Water Treatment Components and Processes

for industrial use doesn't require complete treatment. All treatment consists (to some extent) of sedimentation, coagulation, flocculation, clarification, and filtration. The age of the facility determines the equipment configuration. Modern plants combine several operations in one equipment structure, i.e., multiple operations such as mixing and settling occur in the same location rather than at separate locations.

Presedimentation Treatment for water from a highly polluted and turbid water source begins with presedimentation basins. Presedimentation basins are large open rectangular or circular structures a few feet tall. The water sets for 4 to 8 hours, allowing suspended clay, sand, and heavy solids to settle to the bottom of the vessel. Continuously operating sludge collectors remove debris from the basin. Basins without sludge collectors use multiple parallel presedimentation basins. This allows the operation of some basins during cleaning of the others.

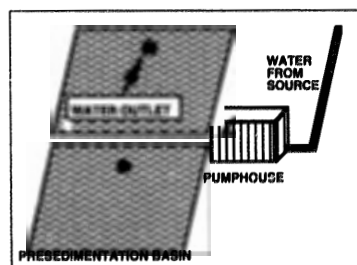


Figure 1.5: Presedimentation Basin

Rapid Mixing Water free of gross suspended and heavy solids still contains micro-organisms, colloidal materials, and dissolved substances. The removal of these substances is the aim of the purification and softening processes. Rapid mixing, flocculation, clarification, filtration, aeration, and sedimentation are the steps involved in purification and softening. The first step is rapid mixing.

Water mixes with chemicals in rapid mixing basins. This mixing causes the fine impurities to coagulate (forming flocs). Alum is the coagulant chemical. Lime and soda ash cause the flocs to precipitate out of the solution. The rapid mixing

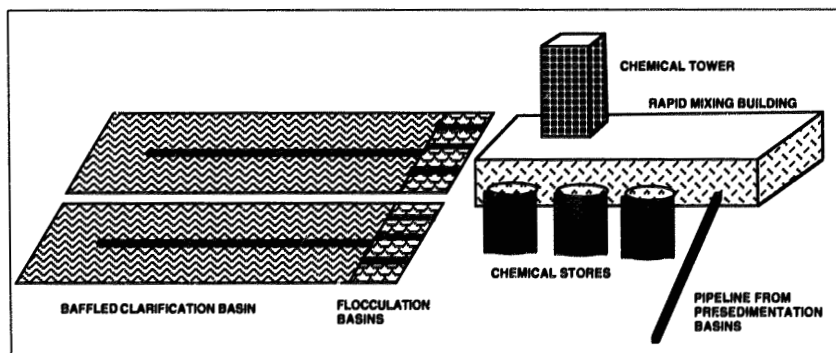


Figure 1.6: Rapid Mixing Building, Flocculation Basin, and Clarification Basin

(addition of the chemicals) occurs either on the suction side of the operating pumps or in a separate small mixing tank. The separate tanks are small, open, circular or rectangular concrete structures. Often the tanks are next to the flocculation basins. Otherwise the tanks are within the tall multistory chemical tower (containing the gravity fed chemical storage tanks) associated with the chemical treatment building.

Flocculation Basins After rapid mixing, the mix flows into flocculation (settling basins) where the mixture has time to entrap additional material. The flocs grow in size while paddles stir the water. The slow mixing allows added softening chemicals additional time to react. The flocculation basins are large (usually open) rectangular tanks (circular tanks are possible). Most tanks are concrete, although steel construction is possible. The flocculation basins are between the rapid mixing basins and the clarification basins.

Clarification Basins The water and floc mixture flow into clarification basins. The mixture settles for 2 to 6 hours. This allows sufficient time for the floc to settle. The clarification basins are two to four times larger than the flocculation basins. Two types of clarification basins exist. One type is a simple large open rectangular basin with a baffle. The baffle extends three quarters of the way across the basin. Built in pairs, one is in operation while the other is undergoing sludge removal.

The second type of clarification basin uses mechanical scrapers to remove the settled flocs. Scraper equipped basins are circular or rectangular concrete tanks. Often the flocculation basin is attached directly to the end of the tank.

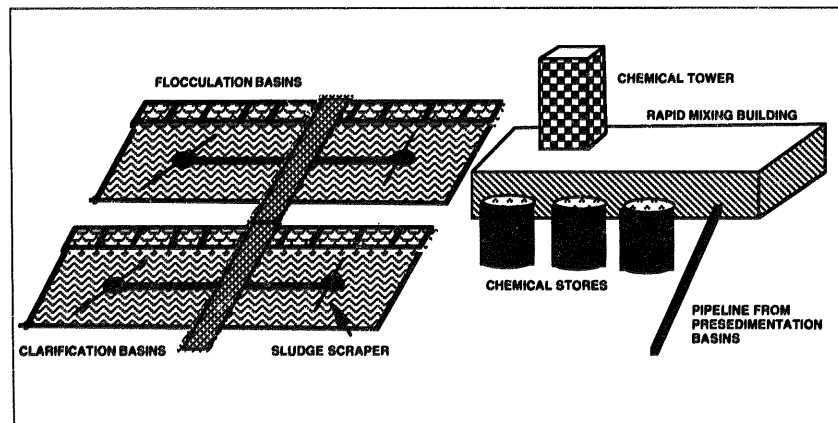


Figure 1.7: Clarification Basin With Scrapers

Filters Filtration systems are the primary processing operation in water treatment. Filtering units remove the very fine floc particles and any suspended colloidal material (such as bacteria) which did not settle in the clarification basin. The two types of filtration systems are the rapid sand filter and the slow sand filter.

Large modern treatment plants use rapid sand filtering systems. Water will be pretreated by sedimentation or clarification basins before filtration. Gravity type rapid sand filtration systems consist of a series of 6 meter square (20 feet square) rectangular basins. The basins contain layers of sand (70 cm thick), gravel, coarse stone, and a mix of coagulant chemicals (fixed to the sand), all over an underdrain substrate system. Water passes through the filter at the rate of 100 to 250 million gallons

per acre (of filter) per day. Floc entrapment in the gelatinous coating and in the interstices of the sand filters the water. The clean water passes into the underdrain system and on to the clearwater basins for storage. The vast amount of water would soon clog the filter, so frequent cleaning is a requirement. Back flowing (backwashing) clean water through the sand cleans the rapid sand filters. The backwash water flow direction is reverse to the operational flow direction. The reverse flow carries entrapped debris out of the filter for disposal. Elevated water tanks store the clear water used in the back flow operation. A long narrow building often houses the entire filter system.

Pressure type rapid sand filters are horizontal or vertical tanks (enclosed) containing the sand and chemicals. Pumps force the water, under pressure, through the sand. The treatment rate is 250 million gallons per day for a tank of 2.5 by 4 meters (8 by 14 feet).

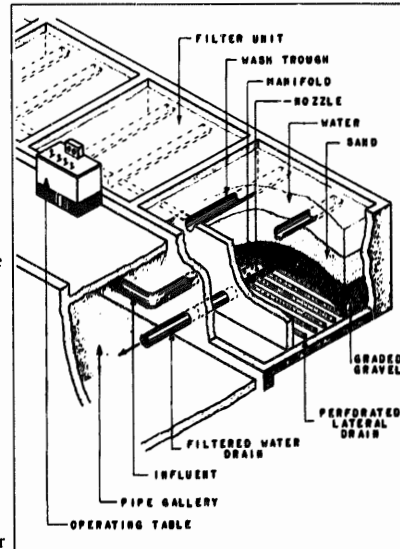


Figure 1.8: Rapid Sand Filter Cross-Section

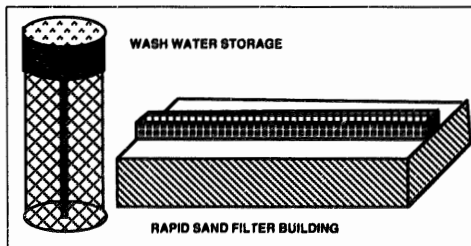


Figure 1.9: Rapid Sand Filter Building

Photo Interpretation Training Course

Slow sand filters operate on the same principle as rapid sand filters. However, the water filters through thicker layers of sand. Because of the reduced flow, there will be more acreage of slow sand filters to filter an equivalent amount of water. Slow sand filters consist of a series of quarter acre open basins, 62 by 15 meters (205 by 50 feet) in size, and 1.8 to 3 meters (6 to 10 feet) in depth. In cold climates a roof and an earthen berm cover the slow sand filter. Manholes provide access to the filters below. The slow sand filter consists of sand (120 cm thick) over a gravel substrate through which water passes to collector basins below. Clean sand (stored in sand towers located on the sides of the filter) replaces dirty sand when required. Slow sand filters are common in Asia, Africa, and Eastern European countries. Water that has already undergone sedimentation filtration and chemical treatment filters at a rate of 10 million gallons per acre per day (1 acre = 43,560 ft², 1 hectare = 10,000 m², 1 acre = .4047 hectare). Turbid river water without presedimentation filters at 3 million gallons per acre per day. Clear river water filters at 4 to 6 million gallons per acre per day. Lake water filters at 8 million gallons per acre per day.

Rarely, roughing filters treat water from the presedimentation basins. These filters are small units, resembling slow sand filters, removing large particulate matter. Roughing sand filters prevent overloading of the slow sand filter.

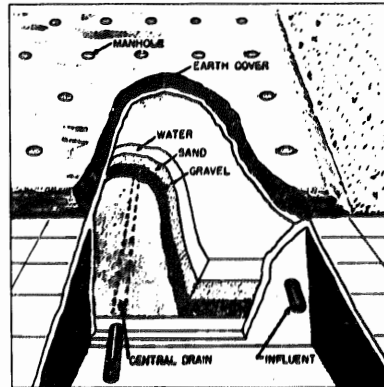


Figure 1.10: Slow Sand Filter Cross-Section

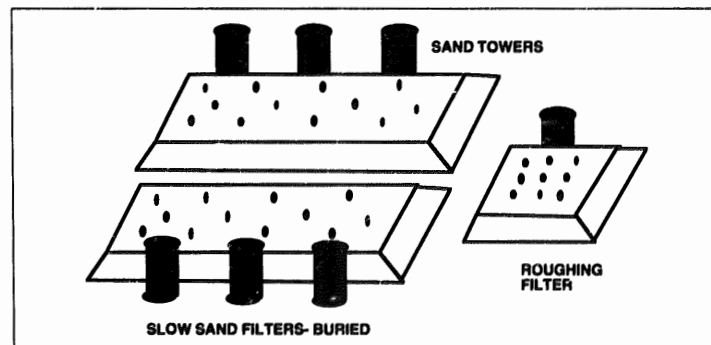


Figure 1.11: Slow Sand and Roughing Filters

Multiple Purpose Purification

Units Multiple purpose purification units are pieces of equipment performing multiple functions within one unit. The unit treats the water by flocculation, clarification, and rapid sand filtering. Usual deployment is in groups of four to six purification units and a washwater storage tank. The multiple purpose unit is a small, compact, circular concrete or steel tank. The principle of operation is the same as separate basins.

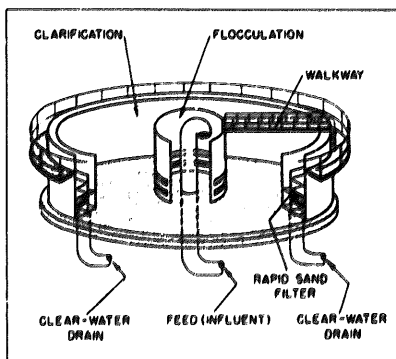


Figure 1.12 Multiple Purpose Purification Unit

Aerators and Sedimentation

Basins Aerators remove objectionable odors, flavors, iron, and manganese from the purified water. Taste and flavor improve from mixing with oxygen. Release of carbon dioxide allows the iron and manganese to fall out of solution. Most aerators are a grid system of pipes equipped with spray nozzles. The nozzles spray

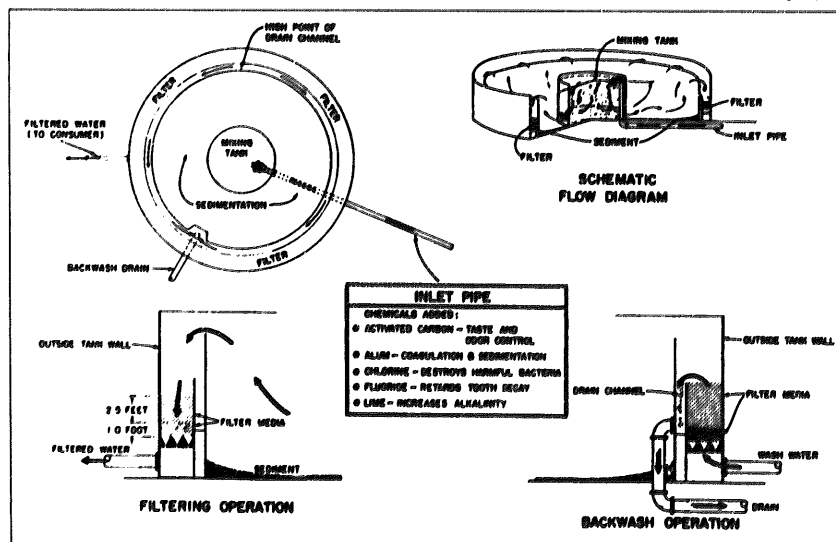


Figure 1.13: Purification Unit Operation

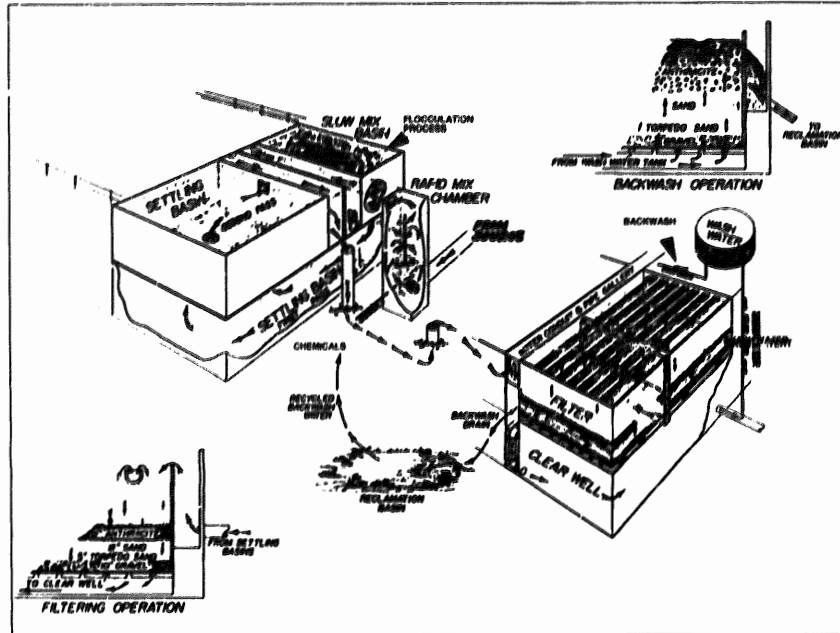


Figure 1.14: Multiple Purpose Mixing, Flocculation, and Clarification Unit

the water (up to 30 feet into the air), aerating the water. River water usually does not require aeration.

The precipitated iron and manganese settle out of solution in small rectangular sedimentation basins (tanks) sited near (or under) the aerators.

Disinfection The final step in water treatment is disinfection. Chlorine, ozone, and other chemicals added to the water eliminate any surviving bacteria. Fluoride is another chemical added at this time. One of the treatment plant buildings contains these small pieces of equipment. Storage tanks hold the chlorine solution.

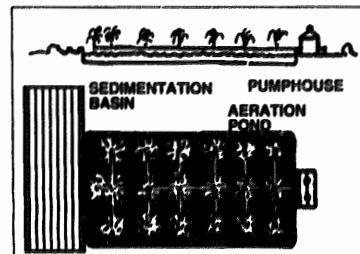


Figure 1.15: Aerators

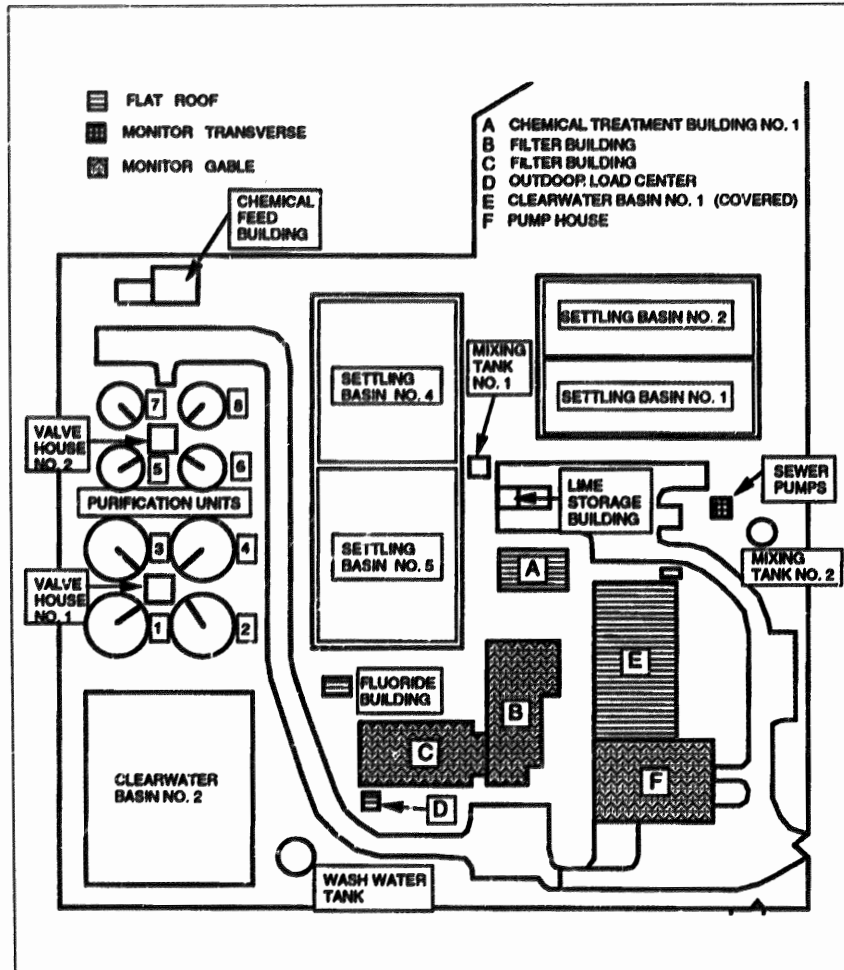


Figure 1.16: Modern Water (Quality) Treatment Plant

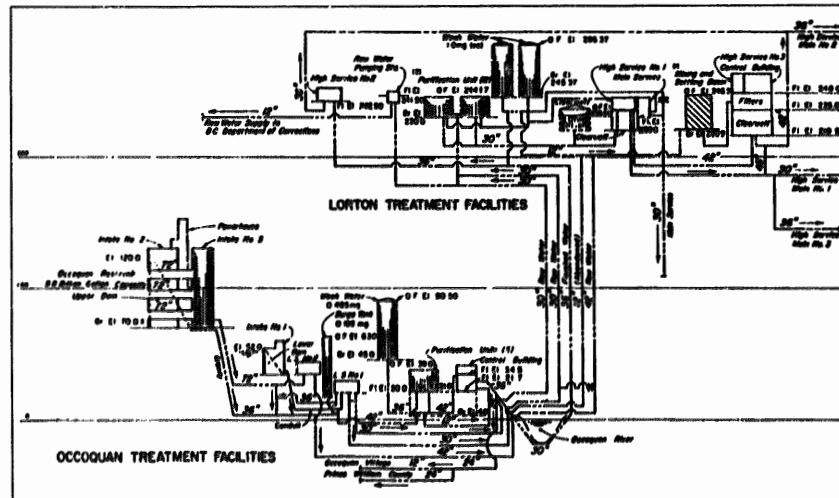


Figure 1.17: Water Treatment Plant Schematic

Storage Clean water storage is in reservoirs, water tanks, and standpipes. Pure-water storage is at the treatment plant. Additional storage locations are throughout the distribution system. Most reservoirs of clean water are covered, rectangular or circular, earth-bermed basins. Water towers provide both water storage and the capacity to maintain pressure (in the case of pump failure) in the distribution system. A water tower is a cylindrical or spherical tank on top of a steel or wood supporting framework. Standpipes provide limited storage and a pressure backup capacity. Standpipes are vertical cylindrical steel or concrete towers.

Desalination

Processing in desalination plants produces water for industrial and residential use. Desalination is a very expensive process. The location of most desalination plants is

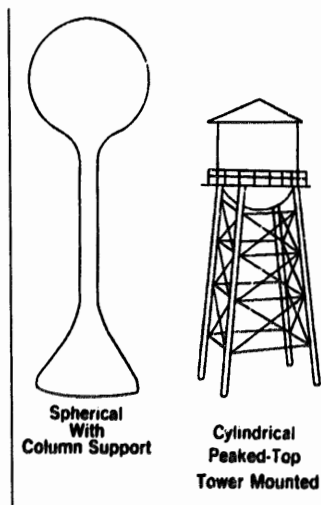


Figure 1.18: Water Towers

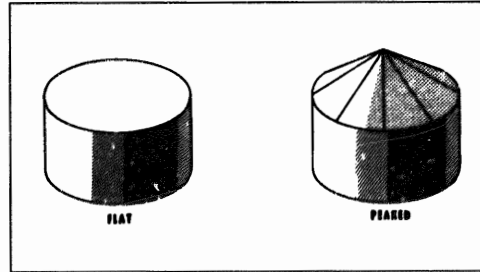


Figure 1.19: Water Tanks

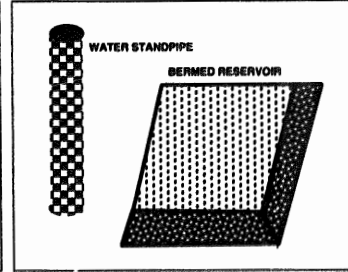


Figure 1.20: Standpipe and Clearwater Reservoir

in coastal areas that do not have an adequate fresh water supply. An additional requirement is a source for the large amount of electrical energy necessary for the operation of the desalination equipment. Most desalination plants use multiple stages of evaporation and condensation in the distillation process. A typical multistage flash distillation plant produces over 7.5 million gallons per day of potable water. Electrodialysis produces potable water from brackish water. Semi-permeable membranes produce water in the reverse osmosis system. A disadvantage for this system is the requirements for high pressure equipment. The hydrate chemical processing, direct freezing and vapor compression (very high cost), and ion exchange columns are also systems producing potable water.

Transportation

Aqueducts are the pipelines, canals, and tunnels transporting water. Aqueducts transport water from the intake facility to the treatment plant and from the treatment facility to the storage and distribution points. Aqueducts can be open as in

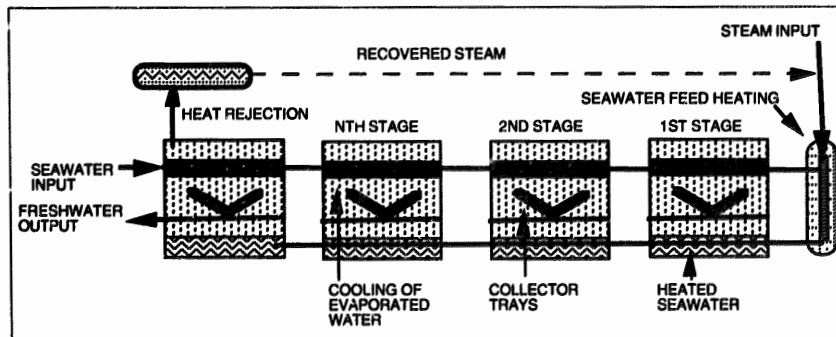


Figure 1.21: Multistage Flash Distillation Desalination Operation

canals or closed as in pipelines and tunnels. The water flows under the force of gravity or under pump pressure.

Distribution

The water distribution system is the complex of distribution reservoirs (water tanks, water towers, and standpipes), water mains (arterial, feeder, and street), pumping stations, and valve systems. The distribution system delivers water to the user and assures minimal disruption to the flow. Several service areas make up a large water system. Each service area has its system of reservoirs, tanks, and pumping stations. The separate distribution reservoirs insure a temporary supply of water in case of shutdown due to repair, maintenance, or emergency. The water mains form the distribution lines for the system.

Deep burial protects the water lines from freezing or damage. The water mains are most often buried under the streets. The usual patterns are dendritic, grid, or belt. In the dendritic pattern, arterial mains are along main roads. Feeder lines branch off along secondary roads. Street mains, off the feeder lines, connect to service lines to individual consumers. The grid pattern has an interconnecting pattern of arterial, feeder, and street mains. Proper valve placement assures no interruption to service will occur. The grid pattern is commonly found in the central sections of large cities. One great advantage to the grid system is the ability to maintain high flow rates and water pressure, useful during fire-fighting. The belt system forms a ring of arterial and feeder mains around the city. The street and service mains branch off the main loop and dead-end at the consumer.

Arterial mains are usually concrete and have a diameter of 1.2 meters (48 inches), 1.5 meters (60 inches), or 1.8 meters (72 inches). The concrete, cast iron, or steel pipe feeder mains are from 0.6 to 0.8 meters (24 to 30 inches) in diameter. The cast iron and steel street mains range from 0.3 to 0.6 meters (12 to 24 inches) in diameter. The size of the service connection (pipe connecting the street main to the consumer plumbing) varies, but are normally only a few centimeters in diameter. Mains are buried from 0.6 to 2.1 meters (2 to 7 feet) beneath the surface. Every interconnection point and change in pipe size along the distribution system has at least one valve. The number of valves throughout a typical system is in the tens of thousands.

Ferrous Metals

Steel (the generic term for ferrous metals) production is ten times greater than the combined production of all other metals. Virtually all construction, manufacturing, and transportation industries require steel.

Ferrous metals consist of pure iron (ingots and wrought), cast iron (iron and 2% to 5% carbon), steel (iron with less than 2% carbon), and alloy steel (iron,



Figure 1.22: Aqueduct Crossing Stream

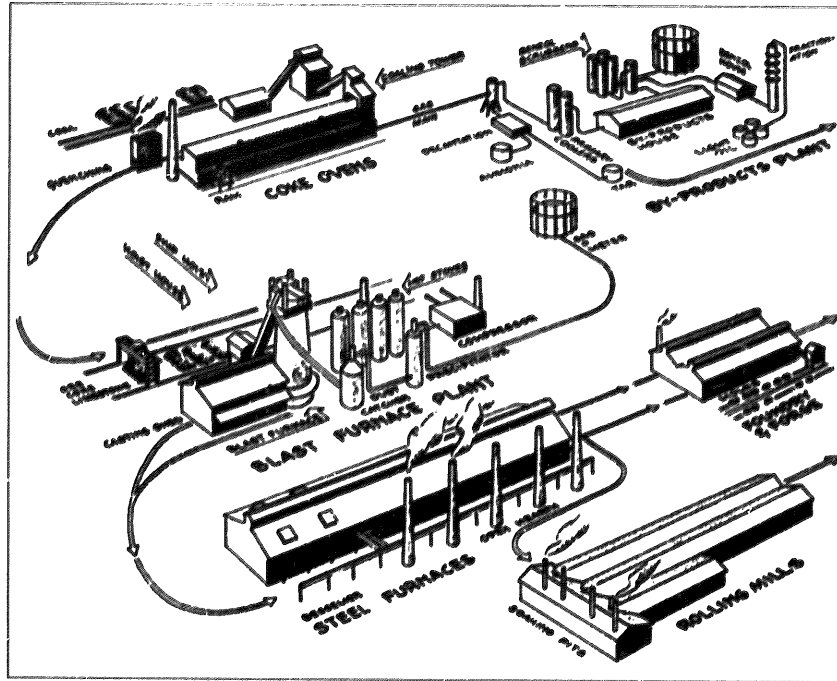


Figure 2.1: Integrated Coke, Iron, and Steel Plant

carbon, and additional alloying elements). The production of ferrous metals is in large complexes consisting of coke plants, iron production plants, steel plants, and steel forming and finishing plants. Steel production requires considerable plant integration to minimize the cost. Integrated plants will possess all the facilities to take raw ores and produce the finished steel product (coke plants, iron plants, steel production, and rolling and blooming mills). Semi-integrated plants have steel plants and the rolling and blooming mill complexes. Non-integrated plants have a few components of the process.

Coke

Coal supplies 65% of the energy requirements of steel production. Almost all (95%) of the coal goes into the production of coke. Coke is the distillation of bituminous coal into a solid carbon product. The coke forms the fuel for blast furnaces, which require 454 kilograms (1000 pounds) of coke per 1000 kilograms (1 ton) of pig iron production. The coke, in the form of carbon monoxide,

produces a reducing atmosphere in the furnace. This prevents oxidation of the iron. The coke provides a porous bed in the furnace for the iron ore charge. Blast furnace operations use 90% of the coke produced; foundry operations use 4%; 1% goes toward water gas production; and carbide, nonferrous metals, and phosphate production use the rest.

The preparation of coke from bituminous coals is by dry distillation (pyrolysis). As heating proceeds from 100° C. to 510° C. (220° F. to 600° F.); water, hydrocarbon gases (methane, carbon monoxide, and hydrogen), hydrogen sulfide, and hydrocarbons (light oils) evolve from the coal. Above 400° C. (750° F.) the framework of the coal breaks down and the mass becomes plastic. The escape of the volatile components leaves a porous structure of coke behind. The final temperature of the coke determines both the residual volatiles and the ignition temperature. Coke heated to 538° C. (1000° F.) forms low temperature coke (for the manufacture of city gas). Coke heated to 1000° C. (1850° F.) forms a high temperature (metallurgical grade) product. Not all coal is suited for coking. Coal high in sulfur, low ash melting point, and friable coals are not suitable for coke production.

Coal Preparation

Coal arrives at the coke plant in railcars, ships, and barges. Car dumpers unload the railcars and clamshell buckets unload ships and barges. Conveyors transfer the coal from the unloading area to a storage area (normally a 60 day supply for the plant). Most coke plants have a coal preparation area between the coal storage and the coke plant proper.

Breakers reduce the size of the coal to 2.5 centimeters (1 inch) and remove foreign material. The hammer mill accepts the pulverized coal and reduces it to a fineness of 80%, or a diameter of .318 centimeters (.125 inch).

Two methods remove mineral impurities from the coal. Froth flotation removes impurities from fine coal. Coal, mixed with chemicals, separates from impurities under the action of bubbled air. Coal, attached to froth, rises to the surface and skimmers remove the coal. The Heavy-Medium Cyclone method removes impurities from crushed coal. Coal, mixed with water and magnetite, separates from its impurities in a tilted cone. The heavy impurities, attracted to the magnetite, exit the bottom of the cyclone. The lighter coal exits the top of the cyclone cone. Dryers remove water from the coal after both processes.

Next, conveyors transport the coal to charging bins located above the ovens. The bins hold a one day supply of coal. Hoppers within the charging bin hold enough coal to fill one charging car (lorry car).

Beehive Coking

An older method of coking is the beehive coking method. Beehive coking produces very high quality coke (high metallurgical quality), but this method is not as economical as the by-product method. Most beehive coking operations are in

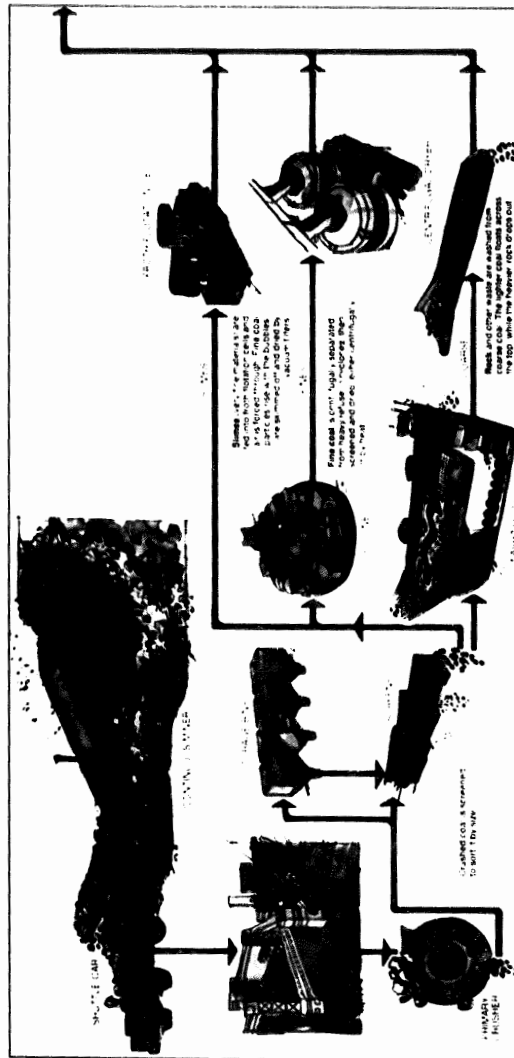


Figure 2.2: Coal Preparation

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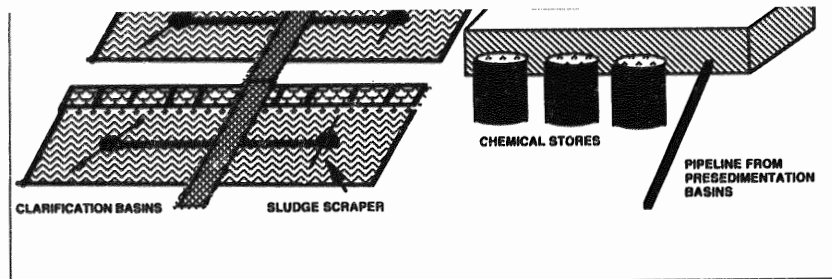


Figure 1.7: Clarification Basin With Scrapers

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Chapter 4

344 Cultural Features

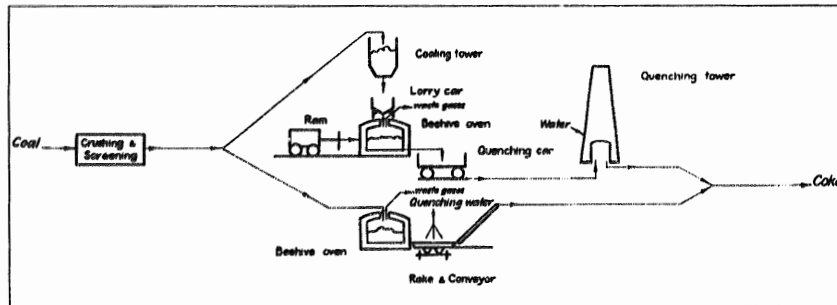


Figure 2.3: Beehive Coke Production Flow

underdeveloped countries. A plant shut-down (and oven cool-down) does not damage the beehive plant. Many plants worldwide have been deactivated until again needed (peak production in wartime or for high grade coke production). The location of the beehive plant is close to the coal source (bituminous coal mine), making the plant competitive with by-products coke.

The beehive coke ovens are hemispherical structures built in individual units or oven batteries. The domed shape is not visible since the area around the oven is built up, allowing passage of charge cars. A charge port situated at the top of the oven allows the unloading of coal into the brick or stone lined horizontal oven. Heat retained in the oven from the previous charge begins the distillation process. The released volatiles burn in the space above the charge. Heating continues for 48 to 72 hours. Waste gas and smoke pass out through the charging ports. This provides sufficient heat to drive off remaining volatiles and completes the carbonizing process. Removal of the finished coke is through side doors or through the charging port. Modern plants remove the coke with a ram (mounted on rails). Water quenches the coke (the coke burns upon exposure to air) before screening and sizing.

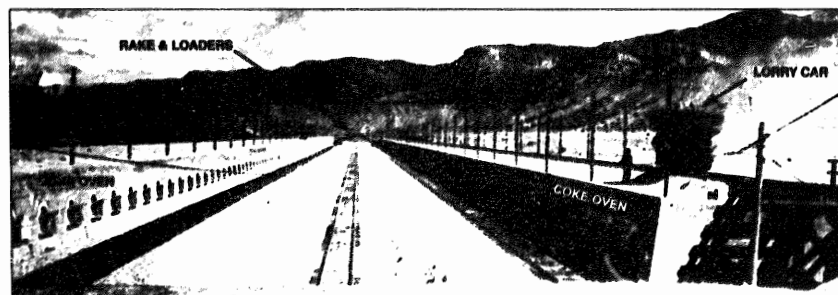


Figure 2.4: Beehive Coke Production with Machine Charging and Discharging

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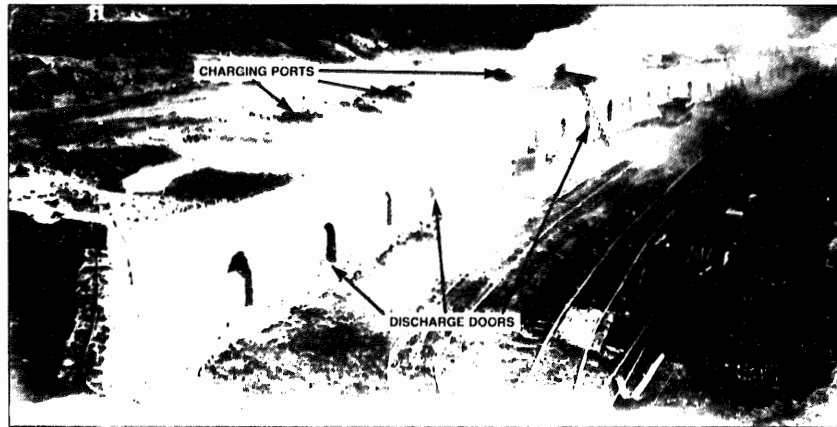


Figure 2.5: *Beehive Coke Production with Manual Charging and Discharging*

By-Products Coking

By products coking involves the production of coke and the recovery and use of the by products generated by the coking process. The by-products, in the form of vapors, produce chemicals, plastics, and explosives. The resale of the by products defrays some of the production expenses. The associated industries use the coal gas produced from the coking process. By-products coking is cheaper than beehive coking, but produces a lower quality product.

Two major areas in the by-products plant are the coke oven batteries and the by products area. The coke oven battery is a long, thin, very dark rectangular structure with adjacent coal stockpiles, coal preparation area, and conveyor systems. The by products area is collocated with the coke oven battery. The by products area has many storage tanks and an extensive piping network.

The coke oven chamber is 12 meters long, 6 meters high, and .4 to 1 meter wide (10 feet long, 20 feet high, and 17 to 36 inches wide). The tongue and groove silica brick lining has a taper of 8 centimeters (3 inches) to facilitate the ram operation during coke removal. Self-sealing doors form the ends of the oven. The oven has three or more charging ports on the top. Short vertical (standpipes) pipes on the top or ends connect the oven to horizontal manifolds (mains) that collect the by-product vapors and transport the gases to the by-products reclamation area. A central cooling tower links pairs of coke oven batteries. The cooling tower is a tall rectangular structure centrally mounted on the top of a pair of coke oven batteries. A conveyor links the cooling tower to the coal preparation area. A long line links several pairs of batteries. A coke plant has more than 160 ovens.

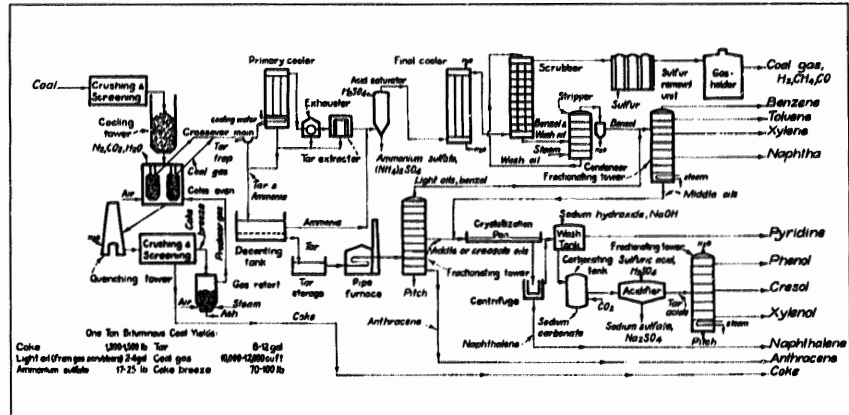


Figure 2.6: By-Products Coke Production Flow

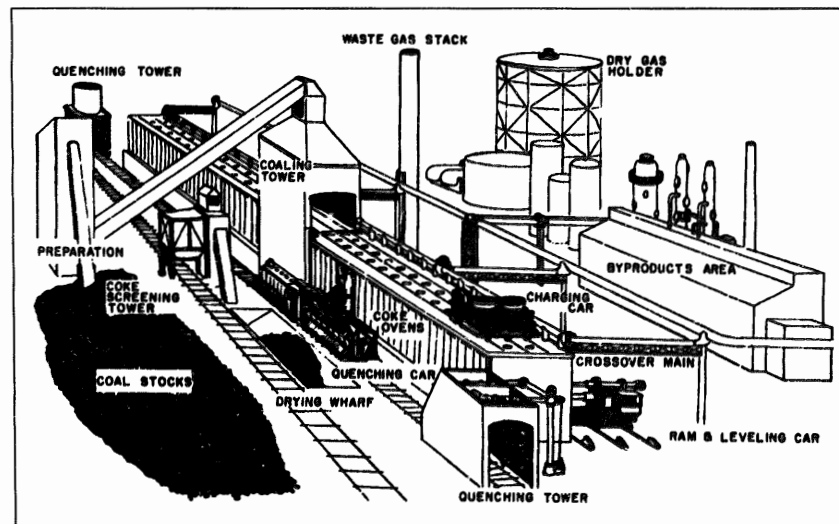


Figure 2.7: By-Products Coke Plant

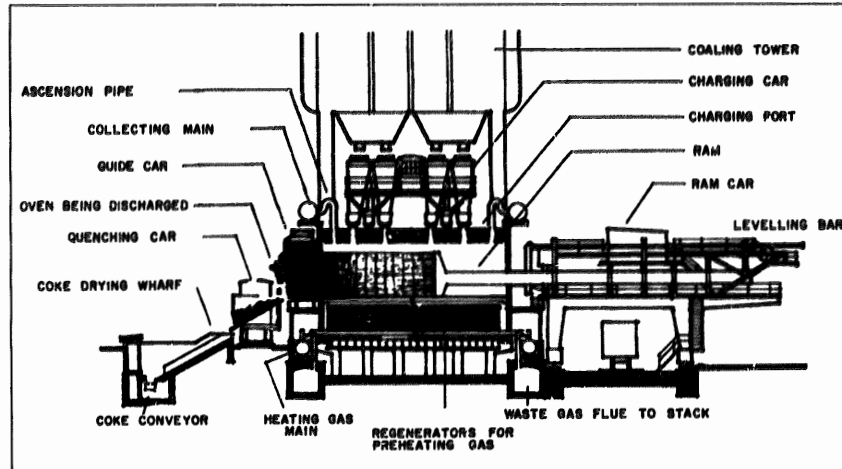


Figure 2.8: Coke Oven Battery Components

A charging car, with 18,000 kilograms (20 tons) of coal per charge, dumps the coal into the oven. A bar on the pusher machine levels the coal charge. The pusher machine is a rail mounted apparatus moving along the side of the oven battery. The machine moves along the pusher side of the oven. The machine has a door extractor for removal of the pusher side door, a leveling bar, and a ram for pushing the red hot coke out of the oven. Leveling provides sufficient gas space in the charge. Excess coal returns to a hopper on the pusher machine.

Burning chambers (flues), supplied with fuel from a dry gasometer, surround each oven. Burning fuel gas heats and carbonizes the coal (destructive distillation). Hot waste gases circulate through regenerators, located beneath the coking chambers, and the retained heat in the checkerwork preheats incoming fuel gas. Waste gas from the combustion vent to the tall waste gas stacks at the plant. Heating of the coal continues for approximately 18 hours. During this time 25% of the coal converts to volatile materials. The ascension pipes and crossover mains collect the gases and transport them to the by-products area. The ovens are kept at operational temperatures throughout the life of the oven. Cooling destroys the oven lining.

The pusher machine (or ram car) removes (pushing with a hydraulic ram) the finished coke from the coke oven. A door machine and a coke guide travel on tracks (on the coke side of the battery). After removal of the coke side door, the coke guide allows the coke to fall into the quenching car (another rail guided vehicle). The quenching car transfers the hot coke to the quenching station. The

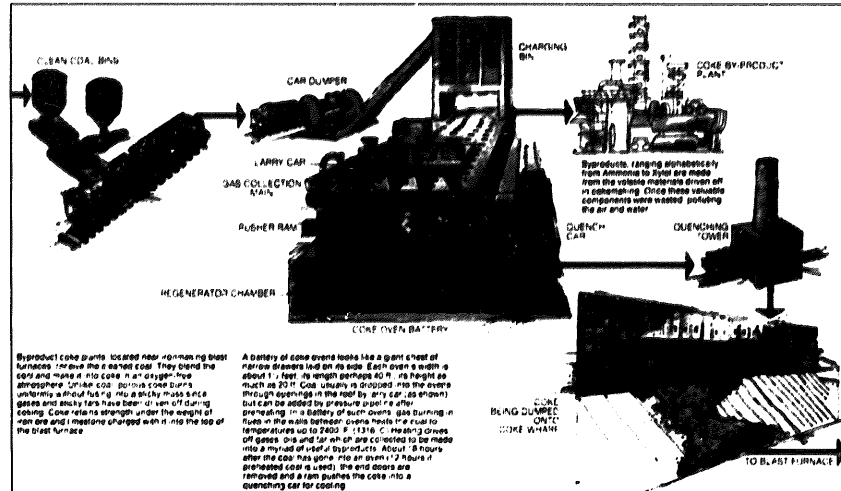


Figure 2.9: Coke Oven Battery

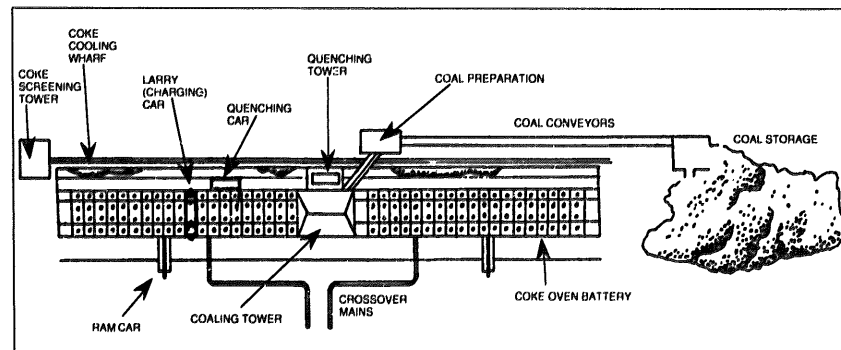


Figure 2.10: By-Products Coke Oven Area

quenching station (quenching tower) is a fairly tall rectangular structure (with an open or stack vented top) located at the end of the battery. The quenching station showers the coke with several thousand liters of water. The partially cooled coke continues to the cooling wharf. At the cooling wharf (a flat sloping structure) several charges of coke, spread in thin layers, cool. The cool coke moves



Figure 2.11: Environmental Modifications to By-Products Plant

by conveyor to the separating and screening station for sorting. Vibrators and shakers separate and sort the coke before use. Conveyors or rail cars transport the finished coke to the blast furnace.

Modifications made to coke by-products plant reduce harmful emissions and pollutants.

Coal Chemical Recovery

The by-products area looks like a small petroleum refinery. The area has numerous tanks, columns, and a network of pipes.

The volatile and gaseous by-products from the carbonization process include: tar, light oils, and ammonia. Recovery processes for these substances include: cooling, condensation, scrubbing, and electrostatic precipitation. The recovered tar is a component of many industrial products. Refining of the light oil component yields benzene, toluene, and zylene. Ammonia processing yields ammonia gas and ammonium sulfate (commercial fertilizer components). The recovered gas is re-used at the coke plant or used in furnaces at the steel plant.

Collection of the volatiles generated during the coking process begins as the gases rise through the chamber into the ascension pipes. The gases pass to collection mains, which extend the length of the battery. Liquid ammonia, sprayed into the gases at the pipe junction, condense some of the ammonia and tar. The condensed liquids flow into decantation tanks for recovery. Large crossover mains (larger piping) connect the collection mains from the batteries to the by-products recovery plant.

First the gases pass through primary coolers and condensers that extract the ammonia and tar. The next section is the by-products building. Here, exhausters maintain a partial vacuum on the mains and force the gases into a tar extractor. Changes in the gas flow direction remove any remaining tar. Instead of tar extractors, Cottrell electrostatic precipitators can remove the remaining tar.

Acid saturators receive the gas from the condenser and the ammonia liquor from the decanting tanks. A sulfuric acid reaction converts the ammonia to ammonium sulfate. Fertilizer and explosive manufacturers use the dried crystalline ammonium sulfate.

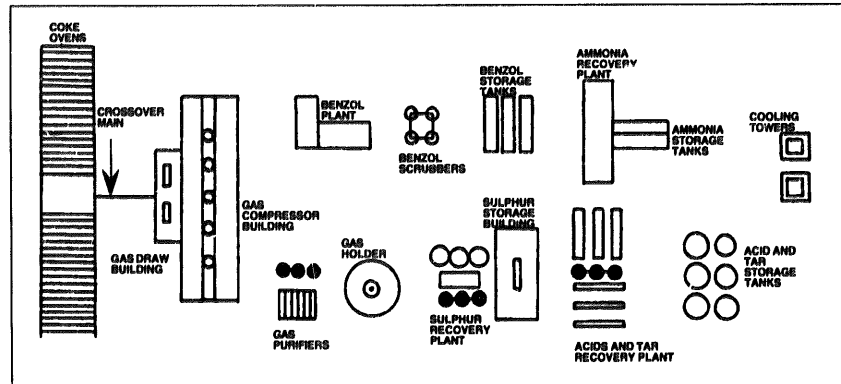


Figure 2.12: Coke By-Products Recovery Plant

Cooling towers cool the gases from the saturators. Benzol scrubbers spray the cooled gas with heavy wash oil. Strippers vaporize and separate the light oils (benzol) from the heavy wash oil (the wash oil returns to the scrubbers). Scrubbers remove sulfur from the gas, making it suitable for fuel usage. Large gasholders store the gas until ready for use or sale. Fractionating towers separate benzene, toluene, xylene, and naphtha from the condensed benzol. Additional refining yields standard commercial grades of these chemicals.

Pipe furnaces heat the tar from the mains, coolers, and tar separators. Fractionating towers flash the tar and separate pitch, heavy anthracene oils, creosote oils, and light oils. Middle oils (creosote oils) cool in shallow pans, yielding crystalline naphthalene. Centrifuges process the crystalline naphthalene. Wash tanks treat the crystalline naphthalene and liquid naphtha with caustic soda, yielding salts from the tar acids in aqueous solution. Neutralizer (or carbonating) tanks treat the aqueous salts with carbon dioxide forming tar acids. Sulfuric acid treatment separates the tar acid into a tar acid layer and an aqueous sodium sulfate layer. Another fractionating tower separates excess water from the tar acids and separates crude phenol, cresol, and xylenol from the solution.

The non-aqueous solution yields neutral oils, from which additional purification yields pyridine.

Ore Processing

Concentration increases the percentage of metal in extracted ore. Additional processing allows recovery of the metal from the ore. Reduction, refining, and forming processes produce a usable product from the metal-bearing ore. The presence of a particular sequence of processing often identifies the metal under treatment.

METAL	REDUCTION	REFINING	FORMING
IRON	Blast Furnace Smelting	Reveratory or Electric Furnace	Rolling Mills and Fabrication Uses
COPPER	Smelting- Reveratory, Electric, or Blast Furnaces and Converters	Electrolysis or Heat	Fabrication- Alloying and Electrical Industry
LEAD	Blast Furnace Smelting	Refining Kettles	Fabrication- Building and Construction, Batteries, Ammunition
ZINC	Electrolytic, Retort, or Blast Furnaces	Very Complex	Fabrication- Alloying, Steel Galvanizing
TIN	Smelting- Reveratory, Electric, or Blast Furnaces	Electrolytic or Heat Treatment	Fabrication- Protective Coatings, Alloying, Electrical Industry
NICKEL	Electrolysis, Smelting, and Leaching Complex	Not Required	Fabrication- Alloying, Electroplating
URANIUM	Chemical	Chemical	Reactor Fuel, Weapons
ALUMINUM	Electrolysis	Not Required	Rolling Mill, Fabrication Uses
MAGNESIUM	Electrolytic or Carbothermic (heating in retorts)	Not Required	Limited Rolling and Extruding, Fabrication as Ingots, Alloying
TITANIUM	Leaching or Electrolytic	Electric Arc Furnace	Aerospace Industry, Welding Materials

Figure 2.13: Metal Ore Processing Methods

Iron – Raw materials

Coke, limestone, and iron ore are the raw materials used in iron production. Steel is iron with additional refining to reduce carbon content.

Coal could provide fuel for iron production. The preferred fuel for iron production is coke. Coke has greater compressive strength, porosity, and higher carbon purity than coal.

Limestone serves as a flux in iron production. Limestone also combines with the non-gaseous impurities in the iron ore during smelting. Limestone storage is in large open piles (with a light gray to white tone).

The most abundant and common iron ores are hematite and magnetite. Each particular iron plant (and each ore) has its own set of pre-processing requirements. Beneficiation of iron ores (the processes improving the chemical or physical properties) includes crushing, screening, grinding, screening, classifying, concentrating, and agglomeration. Concentration occurs by flotation and magnetic separation. Sintering and pelletizing are major agglomeration methods. Briquetting and nodulizing are other agglomeration methods.

Undesirable components of iron ores include oxygen, silica, phosphorus, and sulphur. The blast furnace eliminates the excess oxygen and some of the other

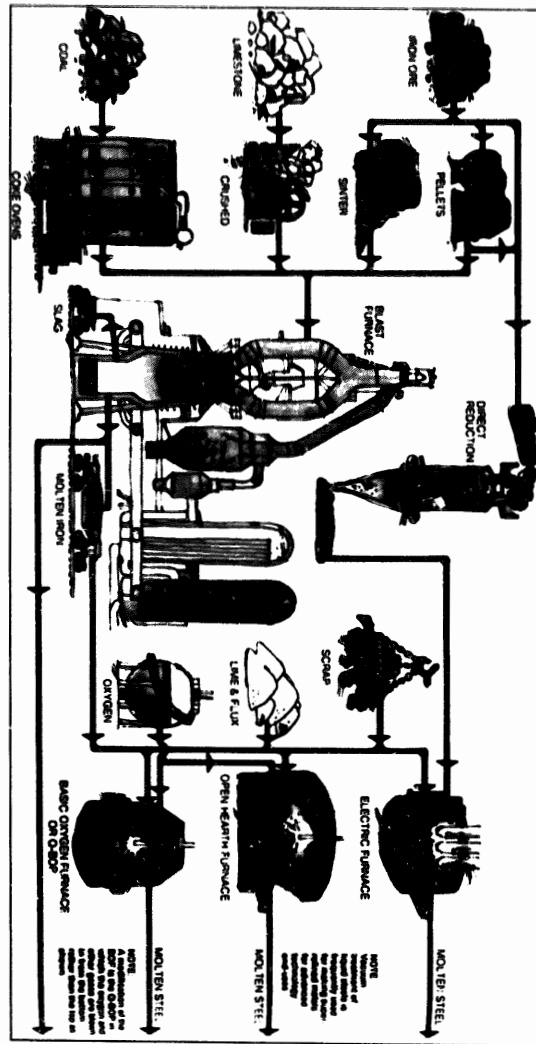


Figure 2.14: Steel Production

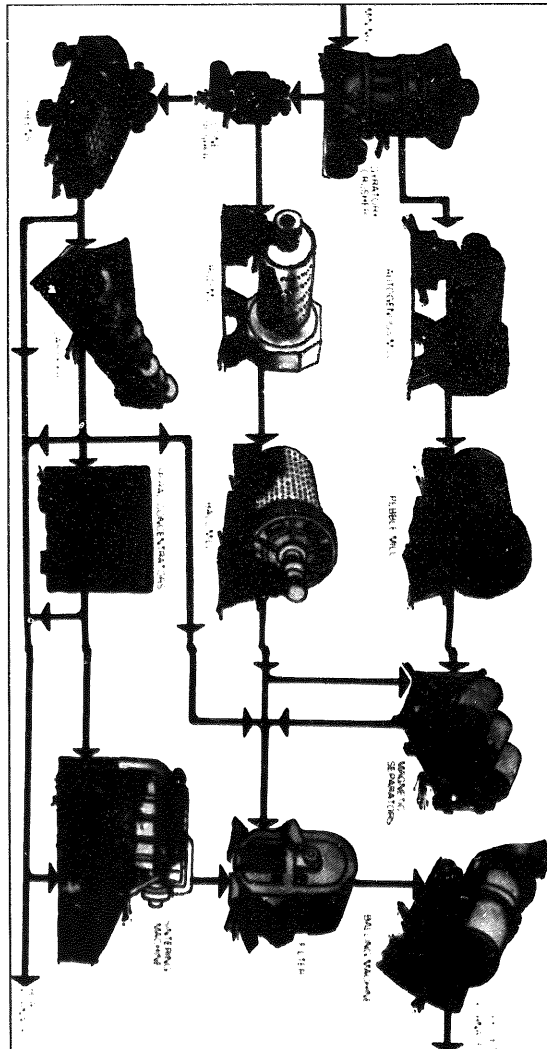


Figure 2.18: Iron Ore Preparation

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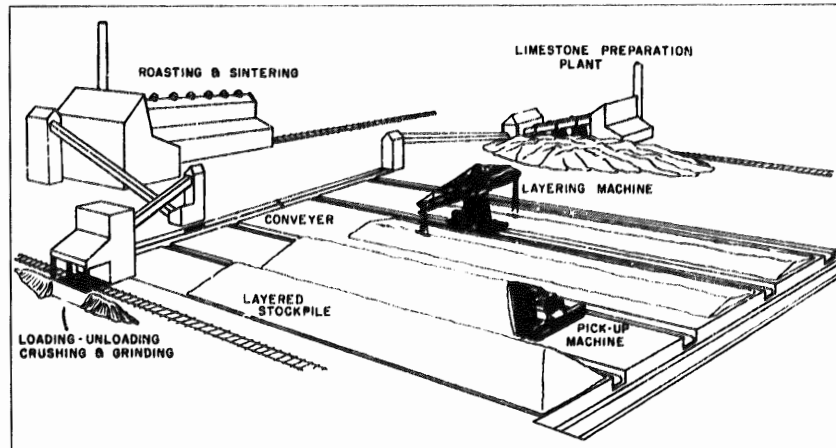


Figure 2.19: Ore Layering and Preparation Yard

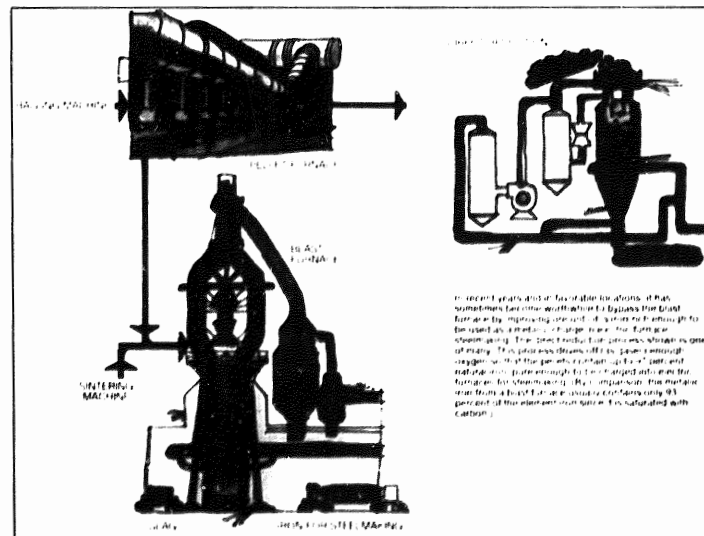


Figure 2.20: Direct Reduction of Iron Ore

Iron Production

After the ore goes through the beneficiation process, the iron oxides are reduced to pure iron. The common reducing agents include carbon, carbon monoxide, and hydrogen or hydrocarbon gases. The common reduction processes are smelting in blast or low-shaft furnaces or electric smelters, direct reduction processes, and melting scrap metal in various furnaces.

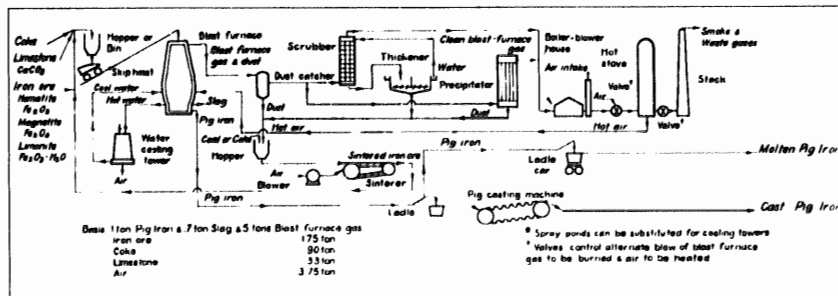


Figure 2.21: Flow Diagram of Iron Production

Blast Furnace

The most prevalent method of reduction is the blast furnace. Iron ore and limestone, heated by burning coke, produce molten iron metal. Hot air, pumped through the coke, accelerates the combustion process. The production of one ton of iron requires two tons of iron ore, one ton of coke, one half ton of limestone, and four tons of hot air. Another requirement is cooling water, pumped through the furnace wall, to cool the brick furnace lining (temperature exceeding 1650° C [3000° F]). The blast furnace is large, brick lined, steel vessel of 3-15 meters (10-50 feet) in diameter and 15-100 meters (50-300 feet) in height. A typical blast furnace produces 1800-7300 metric tons (2000-8000 tons) of iron a day.

The iron ore (in suitable form of pellets, briquettes, or sinter), coke (carbon and heat source), and limestone (fluxing material) are charged into the stack of the furnace from hoppers (by the skip hoist). Hot air introduced into the bottom of the furnace (through nozzles called tuyeres) from hot stoves aids in complete combustion of the coke. Blast houses pump cool air into the hot stoves for heating. Additionally, the hot air prevents heat dissipation and creates the overpressure necessary for the blast. A hot stove is a cylindrical structure 5-9 meters (18-30 feet) in diameter and upwards of 50 meters (150 feet) tall. Four hot stoves (one in use while other three buildup charges) feed preheated air to turboblowers. Firebrick lining in the hot stove provides thermal mass (interior temperature in excess of 1000° F). The usual fuel is gas from the coke oven batteries and waste

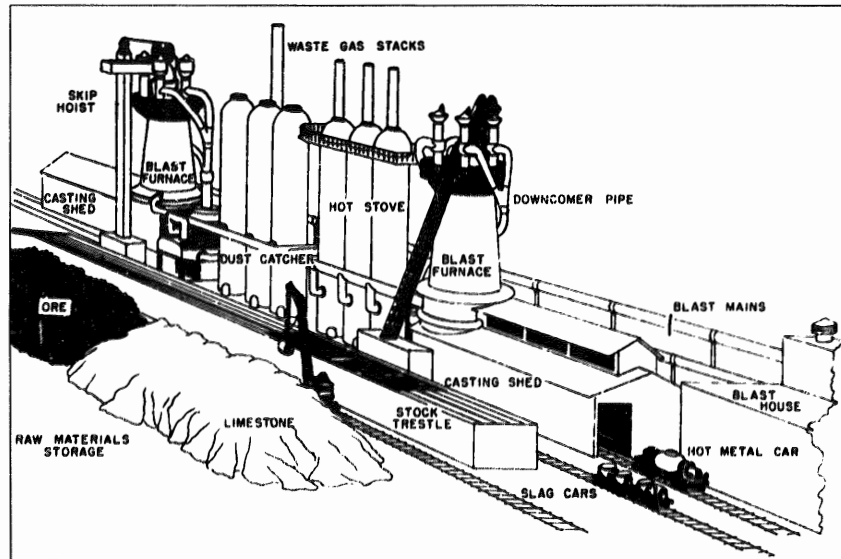


Figure 2.22: Iron Smelter- Blast Furnace

gases from the blast furnaces. The heated air is piped into the bustle and on to the furnace by way of the bosh (encircling the vessel).

The resulting heat melts the furnace charge and reduces the iron oxides. Carbon from the coke combines with the oxygen impurity in the ore, forming carbon monoxide. The carbon monoxide and other gaseous impurities vent through the downcomer pipe. The charge descends through the furnace and halfway down the limestone melts and combines with the non-gaseous impurities. The impurities form a slag,

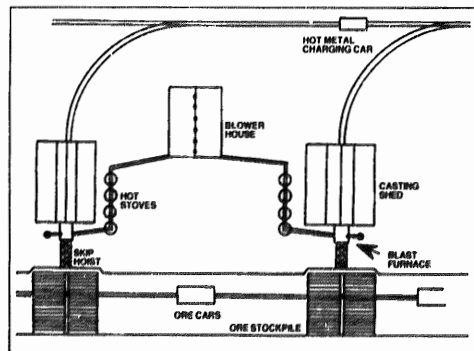


Figure 2.23: Hot Stove Configuration

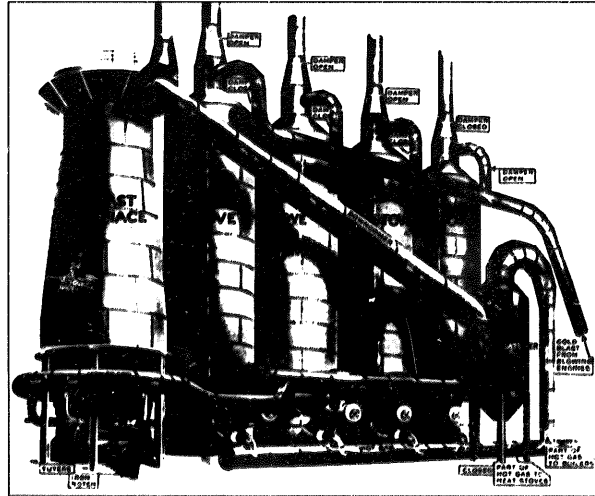


Figure 2.24: Hot Store Operation

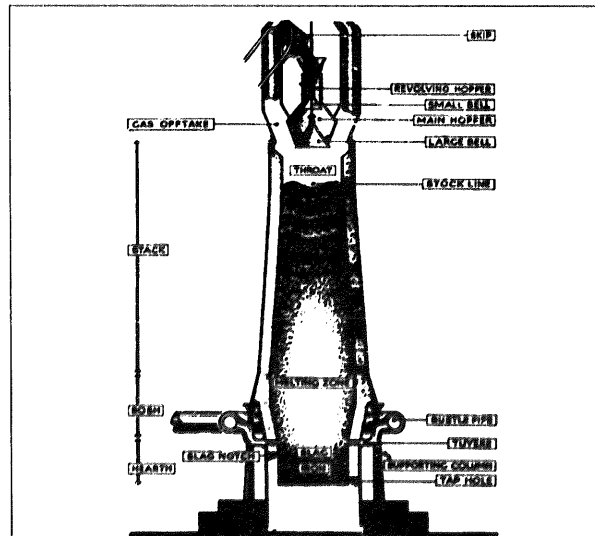


Figure 2.25: Blast Furnace Components



float to the surface of the melt, and are tapped from the furnace. The purified iron settles to the bottom of the furnace.

A two level building (casting shed) surrounds the lower portion of the blast furnace. Casting operations occur on the upper level and tracks on the lower level allow movement of rail cars. The blast furnace has two casting holes (notches), the upper casting hole produces slag once a hour. The lower hole produces 100-400 tons of iron every 4-5 hours. The torpedo (bottle) car receives the molten iron (up to 10,000 tons per day) from the hearth for transport to the steelmaking furnaces. Or the iron is cast into small molds (pig iron). The slag car removes slag (from the surface of the melt) to the slag pits. The downcomer carries the carbon monoxide and the waste dust away from the blast furnace. The hot stoves receive the carbon monoxide as additional fuel. The dust catcher and dorr thickener remove and recycle the dust.

Other Iron Production Methods

The low-shaft furnace operation is similar to the operation of the blast furnace. These squat circular or oval structures handle low grade coke and fine ores.

Areas with plentiful, low-cost electric power can use the electric smelter for reduction. Additionally, the electric smelter is able to use low grade coke in the process. The circular or rectangular furnace uses submerged arcs powered by transformers supplying 60 mega-volt amps of current.

Less common reduction methods include the SL/RN process; the HYL process; the Purofer, Mildrex, and Armeo processes; and the Fior and U.S. Steel processes. In the SL/RN process high grade ores (pellets or lumps) and solid anthracite coal reductants are mixed with flux and reduced in rotary kilns. Screens and magnetic

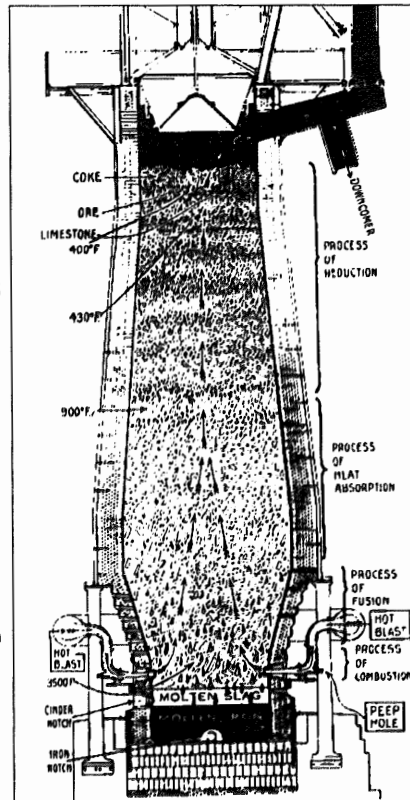


Figure 2.26: Iron Metal Production

separators separate the resulting sponge iron (sponge iron is porous or fine reduced iron). The batch-cyclic HyL process requires four fixed-bed reactors (necessary for continuous operation). Suitable gases provide reductants. The four stage process includes: removal of produced sponge iron and charging the reactor, preheating and treatment with partially used reductant gas from adjacent reactor, the primary

reduction process to produce sponge iron, and cooling the iron with fresh gas. The Purofer, Midrex, and Armco processes use shaft furnaces in a continuous operation. Suitable gases reduce top fed iron ore and pellets. The Fior and U.S. Steel processes use fluid-bed reactors fed with reducing gases.

Direct reduction processes produce highly reduced iron. Usually the iron replaces

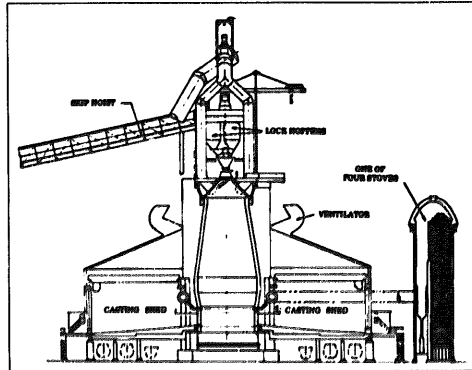


Figure 2.27: Casting Shed

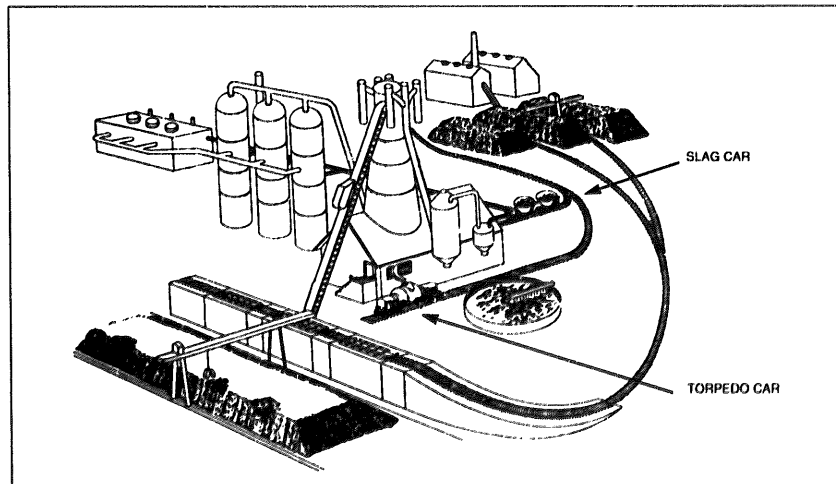


Figure 2.28: Torpedo and Slag Cars



scrap steel and iron in additional processing. Kilns, furnaces, and fluid bed reactors using various reductants are suitable in direct reduction applications.

Cupola furnaces melt previously reduced sponge iron, scrap, and pig iron for use in casting at a foundry. The cupola is a type of vertical shaft furnace producing 2-75 tons per hour. The furnace burns coke using forced air supplied by injection. Limestone provides fluxing material.

Once the iron ore is converted into metallic iron, it may be poured and cast as pig iron. If steel is the ultimate product, more processing is required to reduce the carbon content of the iron.

Steel

The major methods for converting liquid iron, pre-reduced sponge iron, and scrap steels to steel are the open hearth process, the Bessemer process, the basic oxygen process, the electric furnace, and the Kaldo and Rotor process. Additional processes produce specialized steels. The type of steel desired determines which method is used in the production process. The Bessemer converter produces high nitrogen and high phosphorus steels. The open hearth process accepts a wide range of iron as raw material and produces steel suitable for drawing. The basic oxygen process requires a substantial outlay for iron oxide recovery equipment due to the tremendous amount of oxides produced during processing. The electric furnace produces all

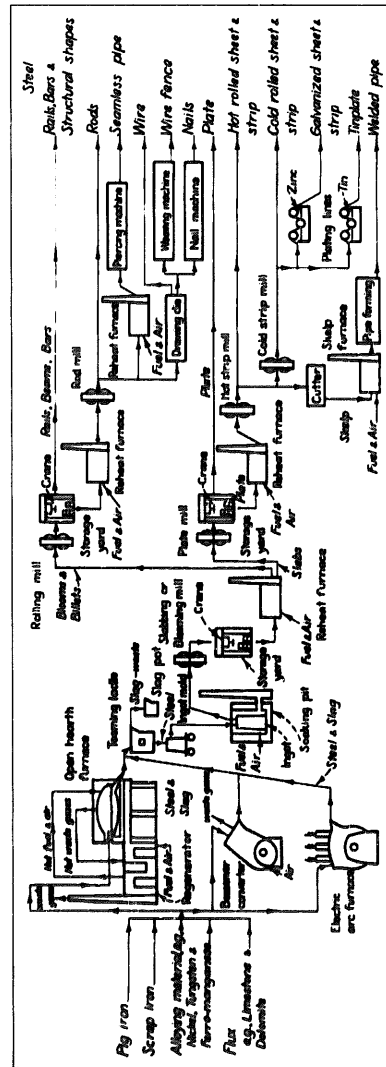


Figure 2.29: Flowchart for the Steel Industry

types of steel (especially alloy steel production). However, its drawback is the requirement for very high temperature in operation.

Steel is a combination of iron, carbon, and various elements in trace amounts. The trace elements are manganese, phosphorus, sulphur, silicon, and alloying elements. Steelmaking consists of refining molten iron and scrap steel by the removal of undesirable elements (primarily carbon). Then alloying element added to the mixture determine the metallurgical characteristics of the steel. Hot metal cars (or metal in solid ingot form) transfer the molten iron to the steel plant. There one of the four steelmaking methods (Bessemer Converter, Open Hearth Furnace, Basic Oxygen Furnace, or Electric Arc Furnace) converts the iron into molten steel.

The processes have similar concepts, but different applications. The result is the production of molten steel, poured into ingots. The ingot is then stripped and soaked. Further processing produces blooms, billets, and slabs from the ingots. At the rolling mills, blooms produce structural shapes, billets produce bars, and slabs become sheet, strip, and plate steel forms. Additionally, foundries require pig iron in their operation, so steel mills often cast pig iron (merchant iron). The merchant iron casting building is a small building (with inclined conveyors extending from the structure).

Steel Production Processes

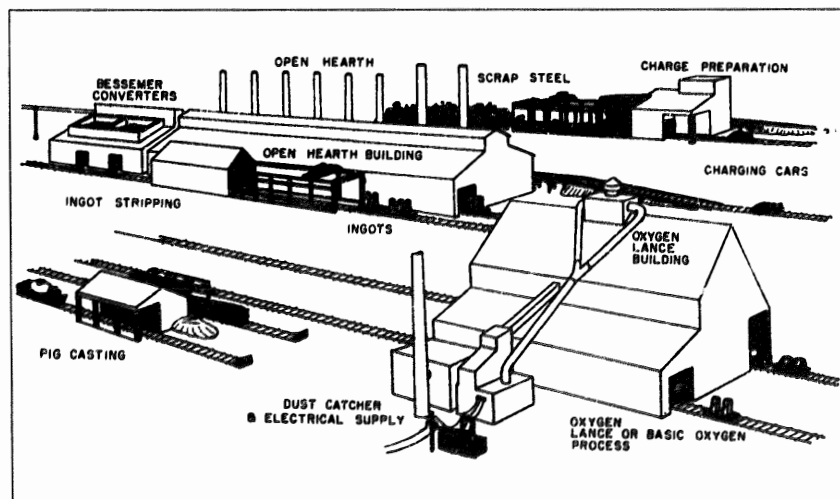


Figure 2.30: Steel Production



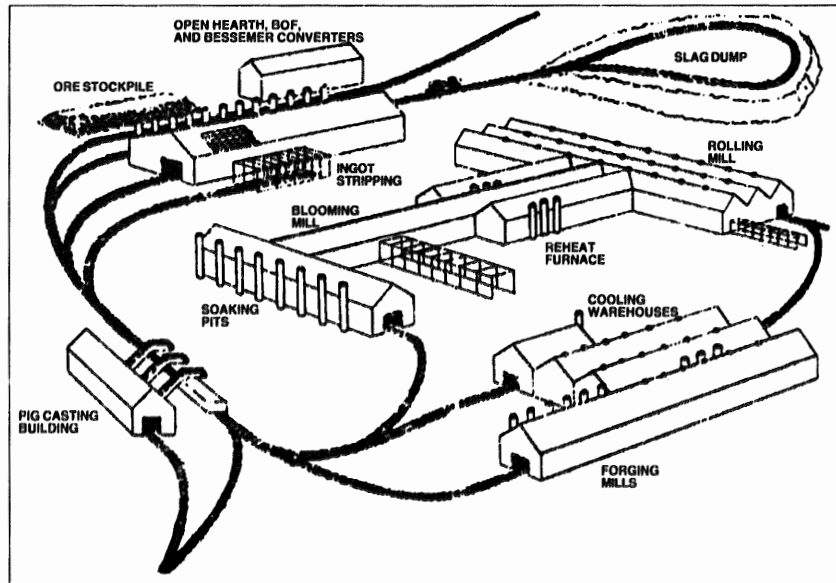


Figure 2.31: Merchant Iron (Pig Casting) Building

Bessemer Converter

The Bessemer converter produces low quality steel and represents a dated technology. Bessemer converters are large, 3 meter (10 feet) high, pear shaped vessels lined with fire brick. A trunnion mount allows the charging of the vessel with 14-23 metric tons (15-25 tons) of hot metal. Jets of air (blown through bottom orifices) oxidize undesirable elements. The processing (blow) lasts about 15 minutes. The waste heat and gases exhaust through large openings in the roof of the building (large open vents are a critical identification clue to Bessemer converter operation). The open top converter can handle only 5% to 10% scrap steel (due to heat loss). Rotation of the converter allows pouring and casting of the steel into ingot form. An oxygen and carbon dioxide mixture replaces the blown air in the production of high quality low-nitrogen steel.

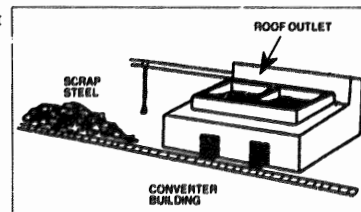


Figure 116: Bessemer Converter



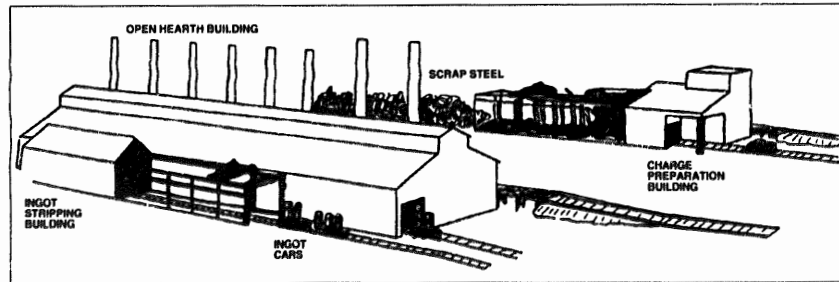


Figure 2.33: Open Hearth Steel Production

Open Hearth Furnace

The open hearth furnace is an open saucer-shaped floor positioned over the flame. The lining is a refractory lining (fire brick) supported by heavy structural steel. A checkerboard arrangement of firebrick under the hearth allows the flow of heated fuel and air. The fuel burns above the hearth at about 1650° C (3000° F). The hearth is the size of a two story house. Water-cooled oxygen lances allow

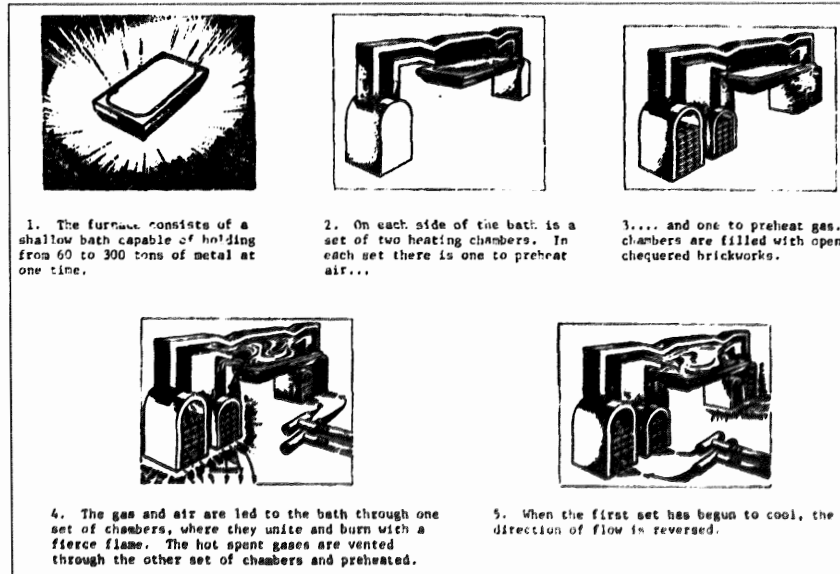


Figure 2.34: Open Hearth Furnace Operation

the introduction of gaseous oxygen into the molten steel in some modern open hearth furnaces.

A steel plant usually has several open hearth furnaces within one long building. All the furnaces face in the same direction. Doors on one side permit charging the furnace. Removal of the batch of steel (called a heat, from 270-545 metric tons (300-600 tons) of metal) occurs on the opposite side (and on a lower level of the building). A batch of steel takes 5-8 hours (unless oxygen lances reduce the time).

Basic Oxygen Furnace

The basic oxygen furnace (BOF) produces high grade steel in large amounts. The furnace can produce 225-315 metric tons (250-350 tons) of steel in under an hour. Additional benefits include reduced maintenance costs, longer furnace life, reduced construction cost, and reduced manpower requirements (compared to the open hearth furnace). The large amount of excess heat generated in the process allows the use of up to 30% scrap steel during processing.

Molten iron, poured into the furnace, melts the scrap. An oxygen lance blows pure oxygen across the top of the melt at supersonic velocity. The oxygen burns the carbon and impurities in the iron, converting it to steel. A lime flux, added to the melt, forms a floating layer of slag. After removal of the slag, a ladle taps the steel from the furnace. Alloying materials, added to the steel, produce the desired steel alloy. Steel, poured into molds, forms steel ingots. The BOF produces higher quality steel and less pollution than the open hearth furnace (BOF totally enclosed).

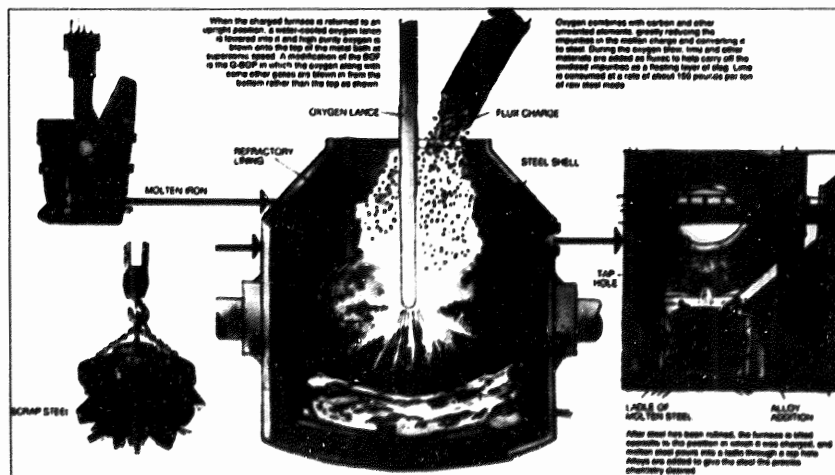


Figure 2.35: BOF Operation Cross-Section

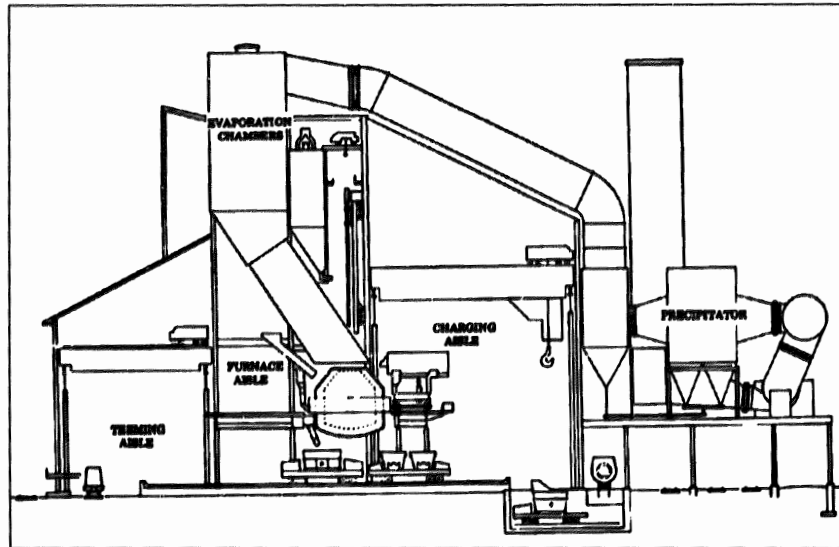


Figure 2.36: BOF Building Cross-Section

The large gas and dust collection pipes extending from the top of the tall BOF building to gas cleaning equipment allow the identification of the BOF plant. The pipes form a "Y" shape across the roof of the structure.

Onsite plants produce the oxygen for the BOF. Railcars and tank trucks may supply smaller plants with oxygen. Gasifiers convert the liquefied stored oxygen to gas form as needed for production.

Several modifications to the BOF process improve the steel quality the furnace produces. One modification of the process (Q-BOP) involves bottom blowing of oxygen and hydrocarbon gases instead of top blowing. The Kaldo process uses a rotating pear-shaped furnace with a water cooled lance blowing oxygen across the charge. Or the lance, inclined at 15°, rotates across the top of the furnace. The carbon monoxide produced burns inside the converter vessel. The stirring action results in a complete combustion of carbon and generates more excess heat. The process produces enough excess heat to allow charging with 40% scrap steel. Another modification, the Rotor process, uses a long cylindrical rotating furnace. Two lances inject oxygen into the furnace. A low-purity oxygen flow burns carbon monoxide (produced during processing) and a high-purity oxygen flow (injected into the bath) refines the charge.

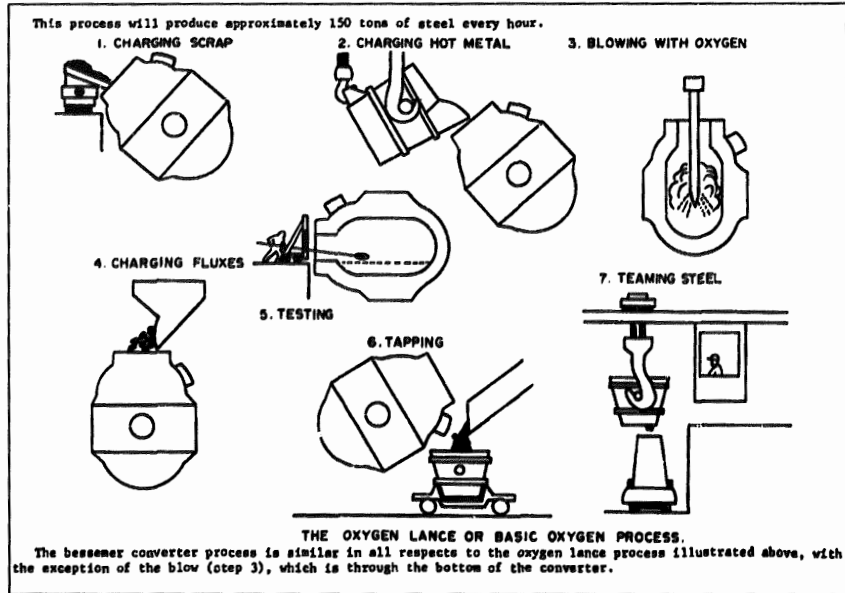


Figure 2.37: Operation of Basic Oxygen Furnace (BOF)

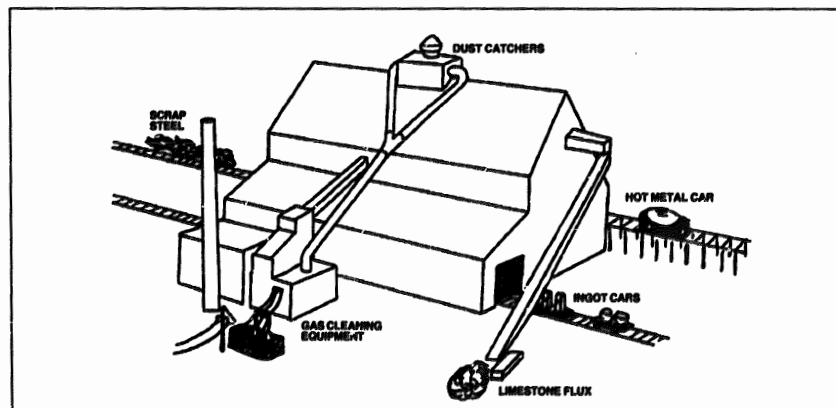


Figure 2.38: Gas and Dust Collection Pipes on BOF Building

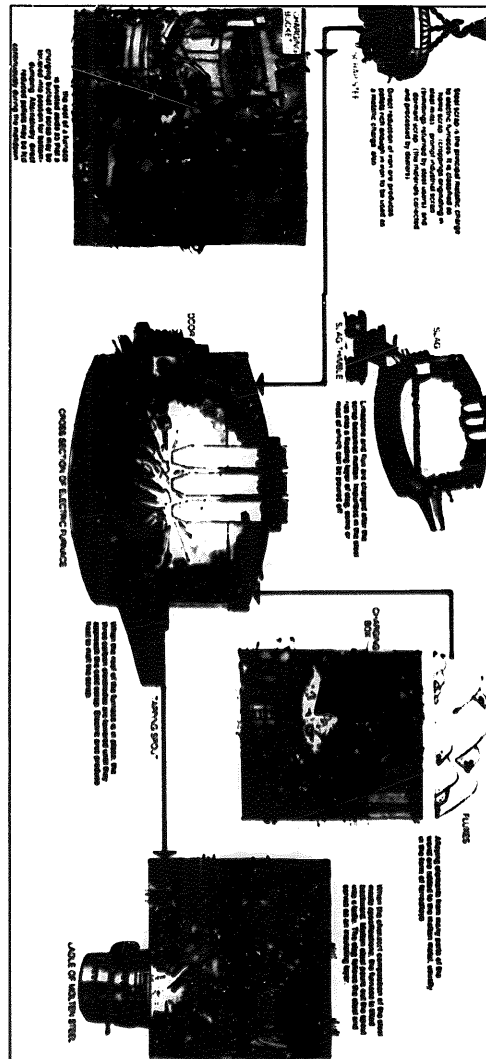
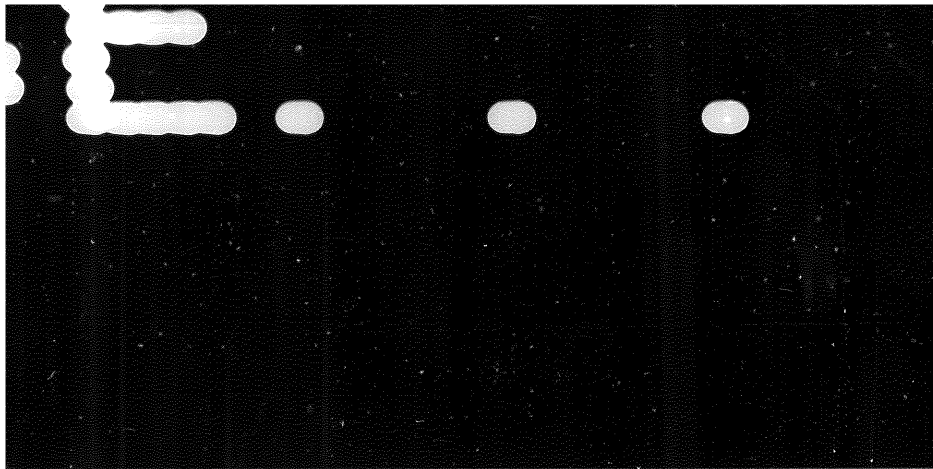


Figure 2.39: Electric Arc Furnace Operation



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Electric Arc Furnace

The electric arc furnace consists of a firebrick lined round steel shell. Three graphite electrodes conduct electricity through the contents, heating the furnace. The arcing electricity heats the furnace to 1925° C (3500° F). Raw material can be liquid iron, scrap steel, or pre-reduced pellets.

The lack of open flame allows total enclosure of the furnace. The furnace can operate in oxidizing, reducing, or neutral conditions. This allows the production of high-alloy (tool) steels. A heat produces 45-270 metric tons (50-300 tons) of steel per charge.

Initial Steel Forms

After steel production, casting allows working into the required form. A ladle (refractory lined car for transport of molten metals) taps the liquid metal from the furnace. At this point alloying material and deoxidants mix with the molten steel. Treatment of the molten metals includes vacuum processing to remove hydrogen,

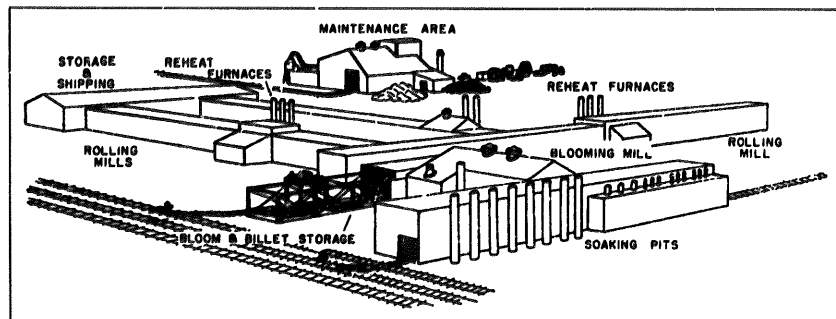


Figure 2.40: Steel Forming and Finishing

oxygen, nitrogen, and nonmetallic elements from the mix. Stirring treatments and heat treatments (for 2-3 weeks) perform the same function. Rolling and finishing mills require a solid form of steel for processing.

Remelting and refining produce special alloy products before production of steel forms. These methods include argon-oxygen decarburization, electrosag refining, vacuum arc remelting, and vacuum induction remelting.

Ingot and Castings

Ladles pour (teem) the molten steel into ingot molds of various sizes and shapes. Stools below the molds allow cooling of the steel. Ingot molds are of cast iron construction. The molds are very large 3 meters by 1 meter (9 feet by 3 feet) for structural shape production and very small for tool steel ingot production.

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Extremely large molds, holding several hundred tons, receive molten steel for special applications. Hydraulic presses form these steels into stressed products (such as turbine shafts and machine parts).

In casting-pit operation the molten metal teems from the ladle into single or multiple molds (large scale operations). Direct casting of intricate shapes uses sand molds (on small scale). Compressed air forces molten metal upwards into molds in the pressure-pouring process.

Stripping and Soaking Pits

The ingot mold has a coating, insuring that teemed steel doesn't stick to the mold (spoiling the surface quality or interfering with mold removal). Tongs grip the top of the mold while a plunger holds the ingot steady on the stool. The tongs lift the mold clear of the ingot (where it cools for reuse). Recasting of worn out molds is common.

The removed ingots cool from the outside towards the center. Transfer of the ingots to the soaking pits (by way of ingot cars) occurs while the interior is still molten. Soaking pits are large furnaces (long low buildings with multiple smokestacks). The ingots remain in the pits until they reach a uniform temperature of around 1260° C (2300° F). A special buggy (car) carries the soaked ingot from the soaking pits to the roughing mill (usually located immediately next to the pits).

After casting or pouring, reworking the steel produces a semi-finished form. Additional processing converts the semi-finished form into a usable steel product. After treatment in the soaking pits, roughing mills produce semi-finished forms of steel (blooms, billets, and slabs). The reworking mostly involves mechanical processing, altering the shape and size of the ingots into blooms, billets, and slabs. A bloom is a solid form with a cross-sectional area of around 92 square centimeters (36 square inches). A billet is a solid form longer than a bloom with a smaller cross-section. A slab is wider and flatter than a billet.

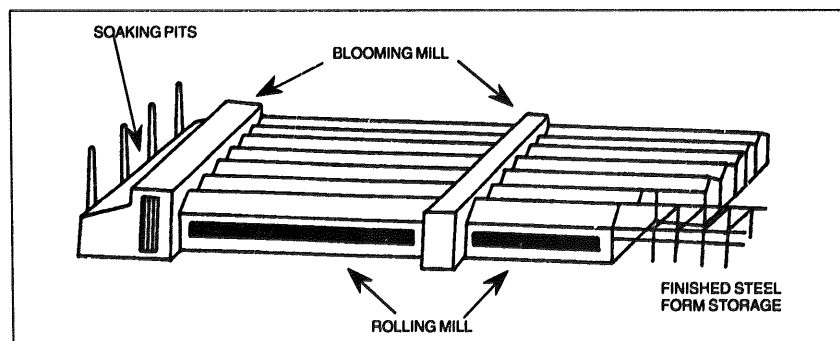


Figure 2.42: Ingot Soaking Pits

Blooming, billet, and slab mills (primary mills) form the ingots into the steel forms. The mills operate in a similar manner. For example, a blooming mill rolls a white hot ingot into a bloom shape. A mill forms an ingot 48 by 58 centimeters (19 by 23 inches) in cross-section into a bloom with a cross section of 15 square centimeters (6 square inches) in 5 minutes. Once the bloom forms, shears cut the still hot bloom into the required length. Storage of finished blooms, billets, and slabs is in parallel rows of open storage (cluttered appearance).

Strand Casting

Continuous casting of the steel eliminates the requirement for heavy mill equipment. The finished product of a continuous casting operation is a semi-finished shape (billets, blooms, and slabs). Strand casting (continuous casting) bypasses ingot teeming, stripping, soaking, and rolling to produce the semi-finished steel form. A strand casting machine receives the molten steel metal and converts it into the semi-finished solid product.

A ladle carries the molten steel from the furnace to the top of the strand caster. A removable stopper allows the metal to flow from the ladle into the tundish of the caster. The tundish provides for the even flow of metal (a reservoir for the steel) into the casting machine. After passing through the molds (from the tundish), the

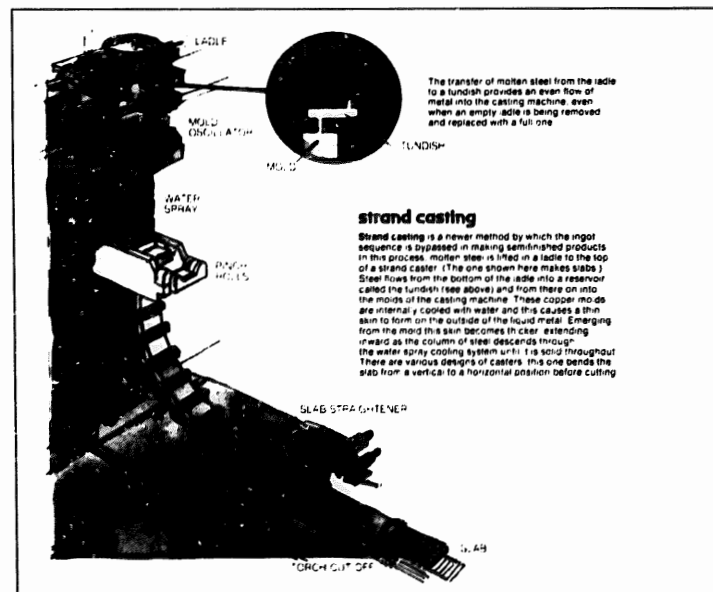


Figure 2.43: Strand Casting Machine

steel cools slightly and passes through a series of rollers and cooling plates. Water jets cool the steel as it forms the required shape. Eventually, torches (at the cutting station) cut the cooled steel in the necessary lengths. A strand caster forms steel at about 3 meters (15 feet) per minute.

Forming Finished Steel Products

Hot forges and rolling mills (secondary mills) convert the semi-finished blooms, billets, and slabs into finished usable steel products. Forging, extrusion, and rolling methods produce the steel product.

Hot Forging

The definition of forging is using compressive force along the lines of metal flow to put the greatest strength where needed. Steel forging involves hammering and pressing. Hydraulic hammers working on hot steel resting on anvils perform hammering. In press forging, hydraulic presses push the heated steel block into the required shape. There are two types of hot forging, the open-die and the closed-die. Open dies forge very large parts. Large presses squeeze steel ingots (up to several hundred tons) between two flat surfaces.

Closed-die forges use steam hammers. A steam hammer strikes sections of steel (cut from semi-finished steel, such as a billet) placed between toolsteel dies. The hot metal flows into the desired shape when struck. A ram (or heavy weight) provides the necessary force in the drop hammer method of closed-die forging. Extrusion processing involves hydraulically operated rams pushing the heated steel through dies to produce wires, bars, or tubular goods.

Hydraulics drive most large forge presses. Mechanically driven presses (rotating flywheels transfer energy by way of mechanical linkage) run medium and small forges. Additional forging methods include upsetting and roll forging. These methods knead the steel into denser structures requiring minimal additional cutting.

Rolling Mills

Rolling mill complexes rework most (90%) of the steel into usable form. The rolling mills reduce the cross sectional area of the steel to produce a variety of shapes (sheets, rails, beams, etc.). The rolling mill complex is a large expanse of long narrow buildings. They are the largest buildings at the steel plant. The buildings often connect at 90°, forming "L" and "T" shapes. A rolling mill is a series of horizontal rollers (rolls), one placed above the other, turning in opposite directions. The heated semi-finished steel, passing through the rollers, becomes longer, thinner, and wider. Additional vertical rollers, placed on the side, limit the amount of horizontal spread. Multiple passes produce the finished product.

Each type of semi-finished steel (bloom, billet, and slab) produces a particular variety of finished products. Rolling mills produce structural shapes from blooms. Structural shapes are rolled flanged sections such as I-beams, H-beams, rails, and

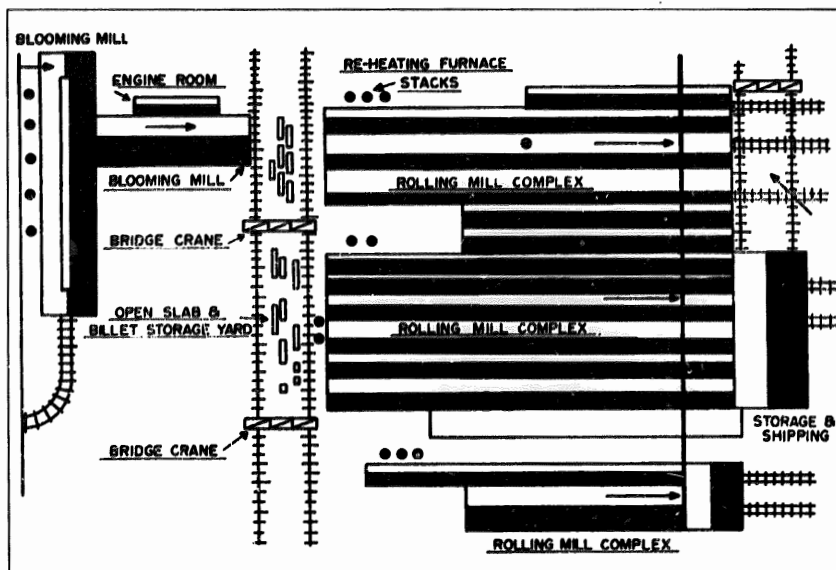


Figure 2.44: Steel Rolling Mill Complex

columns. Bar mills produce bars from billets. Grooved rollers produce bar stock from the heated billets. Bar mills produce a variety of bar and rod shapes. Additional processing produces wire from rod stock. The cold drawing of bars (pulled at room temperature through a die) produces bar stock that is strong, polished, and hard.

Continuous sheet mills roll slabs into sheet steel and strip steel. Strip steel is narrower than sheet and produced to a more exact tolerance. The hot continuous strip mill is several blocks long. The processing produces 1070 meters (3500 feet) per minute of coiled strip steel from a slab 18 centimeters (7 inches) thick. Cold rolling of strip and sheet steel produces a base for coated products (tin plate).

Plate mills produce plates from slabs. Heavy construction (bridge floors and oil tanks) uses plates. A plate is a piece of steel between 15 and 120 centimeters (6 and 48 inches) wide and .6 centimeter (.25 inch) thick, or, more than 122 centimeters (48 inches) wide and more than .5 centimeter (.1875 inch) thick.

The finished steel product cools in long narrow (with vented roofs) cooling warehouses before storage and shipping.

Non-Ferrous Metals

Aluminum

Aluminum production is second only to iron production. The electrolysis of alumina (reduction) in cryolite produces aluminum. The chemical, ceramic, and petroleum industries use alumina. The construction, vehicle, aero-space, electrical, and durable goods industries use aluminum metal.

Alumina

The Bayer Alumina and the Lime Soda Sinter processes produce alumina. The four production steps (both processes) are digestion, clarification, precipitation, and calcination. The Lime Soda Sinter process also has rotary kilns, soda ash and limestone storage, and crushing and leaching areas.

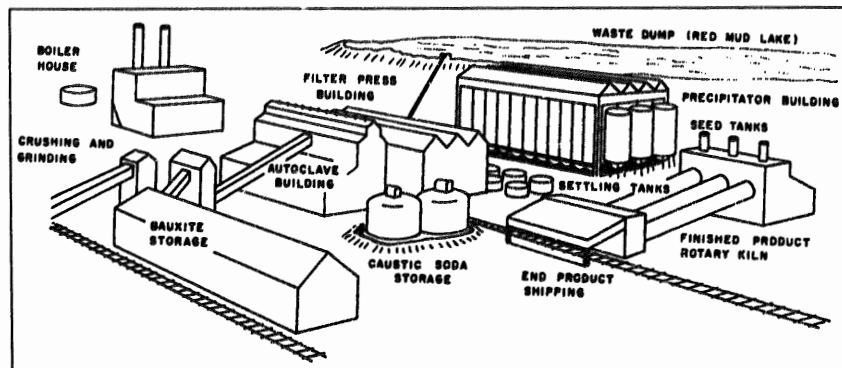


Figure 3.1: Bayer Alumina Plant

Pre-drying bauxite ores (in rotary kilns) reduces transportation cost, therefore, long single story gable roofed building hold the ore before processing. Rod or ball mills crush and screen bauxite ore (containing aluminum oxide) to the required consistency. Digestion takes place in the autoclave building. The autoclave building is an irregularly shaped stepped structure with full length ventilators in the uppermost section. Rarely, lattice framework surrounds open air digestors (tall cylindrical tanks collocated with flash cooling tanks). Here the slurry (a mixture of ore and caustic soda) reacts with superheated pressurized steam (170°C at 100 psi in the autoclave) and the ore dissolves. The caustic soda (sodium hydroxide) and the alumina (hydrated aluminum oxide) react forming a solution of sodium aluminate (sodium aluminum silicate) and insoluble impurities (silica, titanium and iron ores).

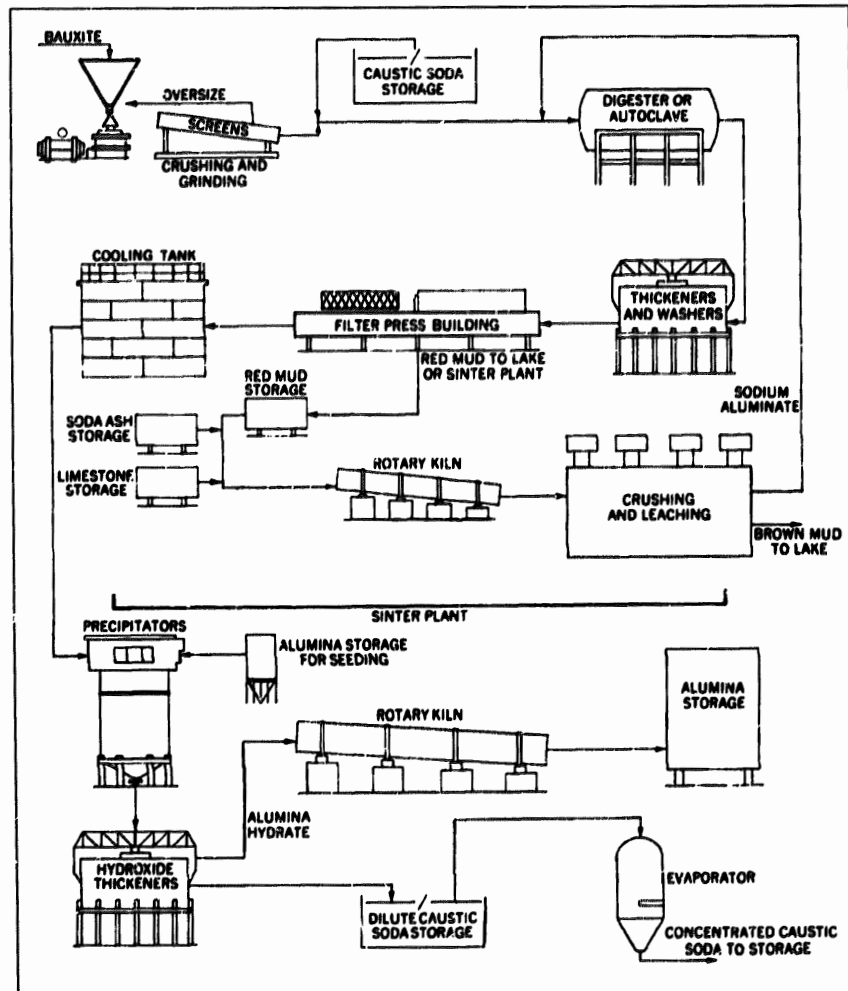


Figure 3.2: Alumina Industry Flowchart

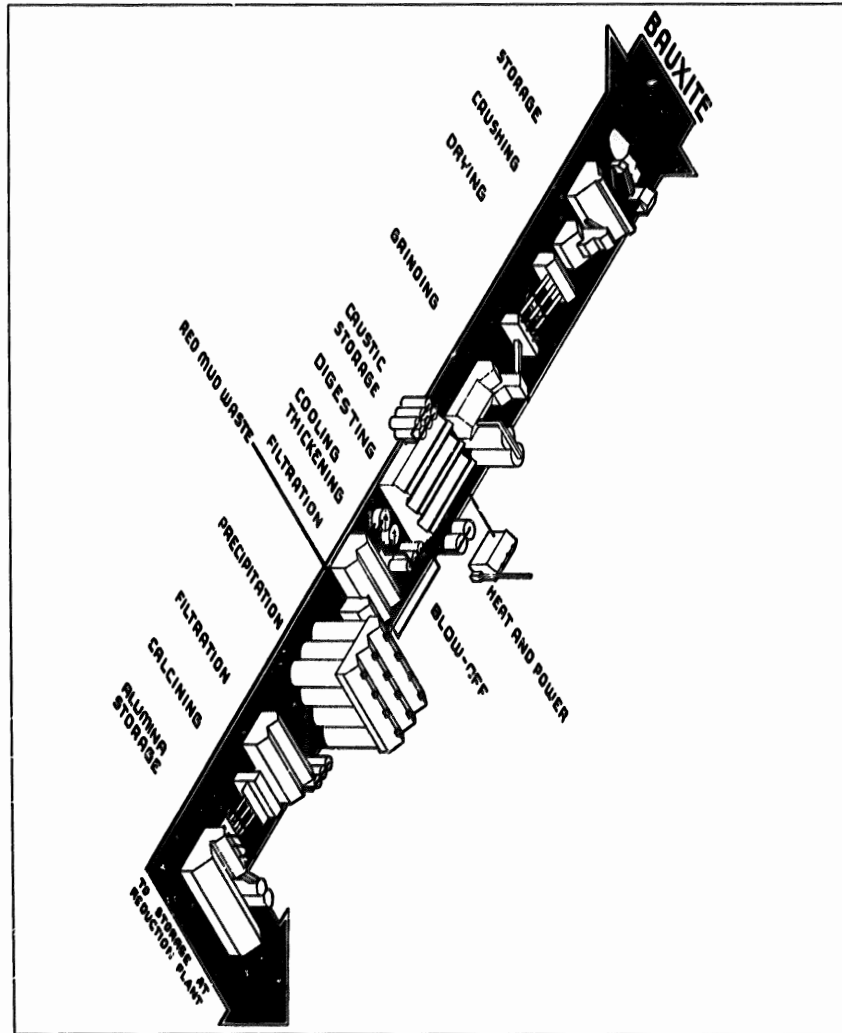


Figure 3.3: Processes at Alumina Plant

Filtration occurs in the filter building, usually situated next to the autoclave or precipitation building. It is a long rectangular sawtoothed roof structure with many ventilators. Settling and washing tanks and filters remove the waste material (red mud) from the slurry. Thickening removes excess water before filtration of the wastes from the mixture. Thickeners are numerous low cylindrical tanks with agitators located between the autoclave and filter buildings. First filter tanks separate most of the red mud from the sodium aluminate. Next, passage through a series of wash tanks (using water) removes any remaining aluminate from the mix. Pumps transfer the waste material to the disposal area (red mud lake). The green liquor (overflow from the tanks) is a mixture of water and sodium aluminate. Filter presses (located in the filter building) remove impurities from the green liquor (using large cloth filters). Heat exchangers cool the green liquor before transfer to the precipitation building.

Precipitation produces aluminum hydrate from the green liquor. The precipitation tanks are tall conical bottom silo-like structures arranged (more than 100 tanks) in rows and columns. Each tank is 7 meters (24 feet) in diameter and up to 30 meters (100 feet) tall. The structure covering the tanks has numerous vents on the gable roof tops (frequently largest structure at the plant). The sodium aluminate decomposes into sodium hydroxide and aluminum hydroxide as cooling progresses. The cooling liquid in the tanks precipitates aluminum hydrate

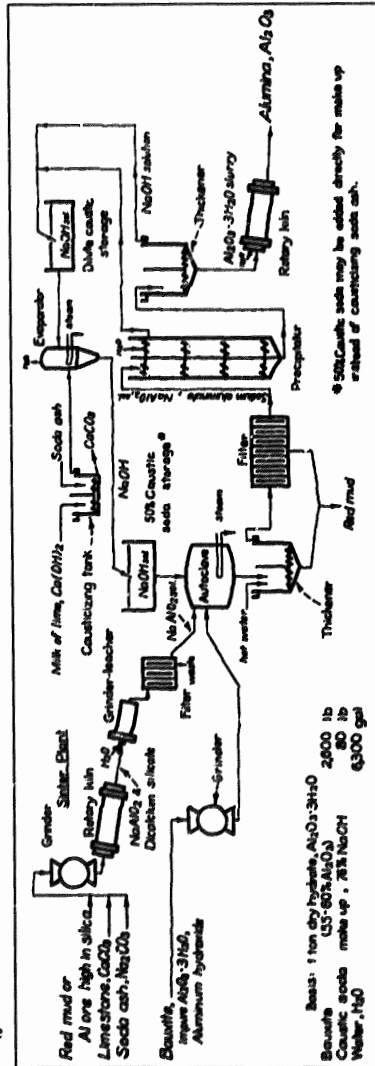


Figure 3.4: Alumina Reactions

crystals that settle out of solution. Hydrate aluminum crystals (from storage silos at the end of the precipitator building) seed the solution, aiding in the rapid formation of additional crystals.

Hydroxide thickeners separate the alumina crystals. The hydroxide thickeners are tall cylindrical tanks with dome roofs. Multiple effect evaporators recycle the remaining liquid (caustic soda) back to a 50% caustic soda solution. Caustic soda storage tanks retain the caustic soda until use at the autoclave section. The precipitation period is 36 to 48 hours.

Gas fired rotary kilns heat the resulting crystals to 1100° C (2012° F) in the calcination process. Rotary kilns are long parallel tubes with buildings at both ends. The typical rotary kiln is 3 meters (10 feet) in diameter and 75 meters (250 feet) long. The building nearest the precipitation building houses the furnaces and has numerous stacks, vents, and dust control equipment. The building on the opposite end will have a light appearance due to settling alumina dust. The heat drives off water, leaving pure alumina (aluminum oxide). The alumina can be stored in silos before transport or processing at the aluminum plant.

The Lime Soda Sinter (also known as the Combination process) process is an addition to the Bayer Alumina process. This process treats low grade aluminum

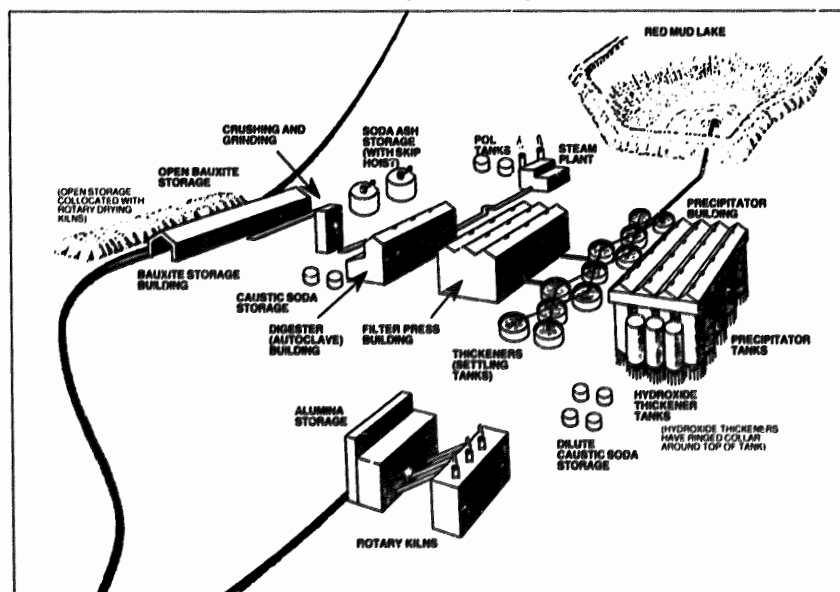


Figure 3.5: Storage at Alumina Processing Plant

ores containing high percentages of silica. The process reclaims alumina (combined with silica during digestion). Instead of discarding the red mud, calcining (in rotary kilns) with limestone and soda ash produces additional sodium aluminate. Crushing and leaching allows recycling the material back through the digesters. The process produces brown mud waste instead of red mud waste.

Aluminum Metal

Aluminum reduction is by the electrolysis of alumina in a solution of molten cryolite (sodium aluminum fluoride, a snowy white mineral). The two main reduction methods are the Hall-Heroult and the Soderberg processes. The Hall-Heroult process uses a pre-baked carbon anode and the Soderberg process uses a continuous anode. The process used only affects the configuration of the electrode plant associated with the aluminum plant. Some modern innovations in aluminum production include a Hoopes cell process producing a very high purity aluminum metal, a low temperature method utilizing chlorine in a sealed reduction cell, and a thermal reduction method producing a low quality aluminum metal product.

Main components of an aluminum plant are the potrooms (long parallel buildings), cryolite and alumina storage, rectifier and casting buildings, carbon electrode plant, and the fluorine recovery unit. Raw materials include alumina,

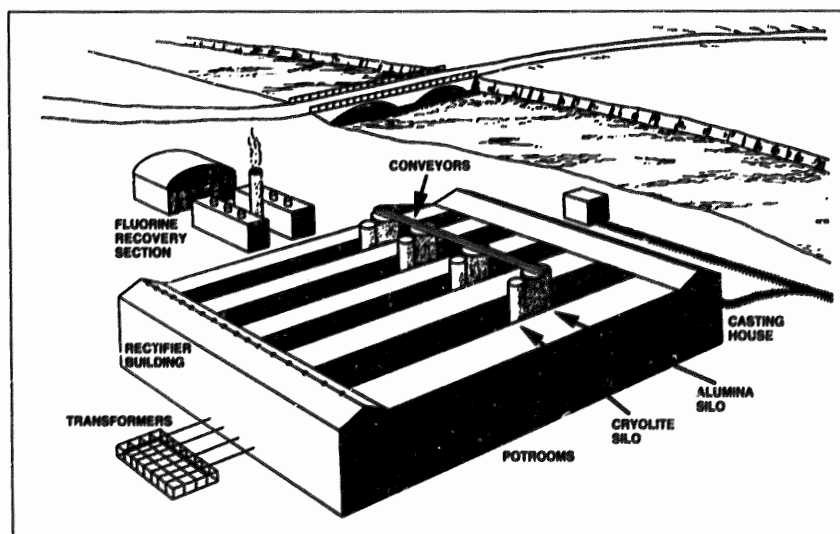


Figure 3.6: Aluminum Processing Plant

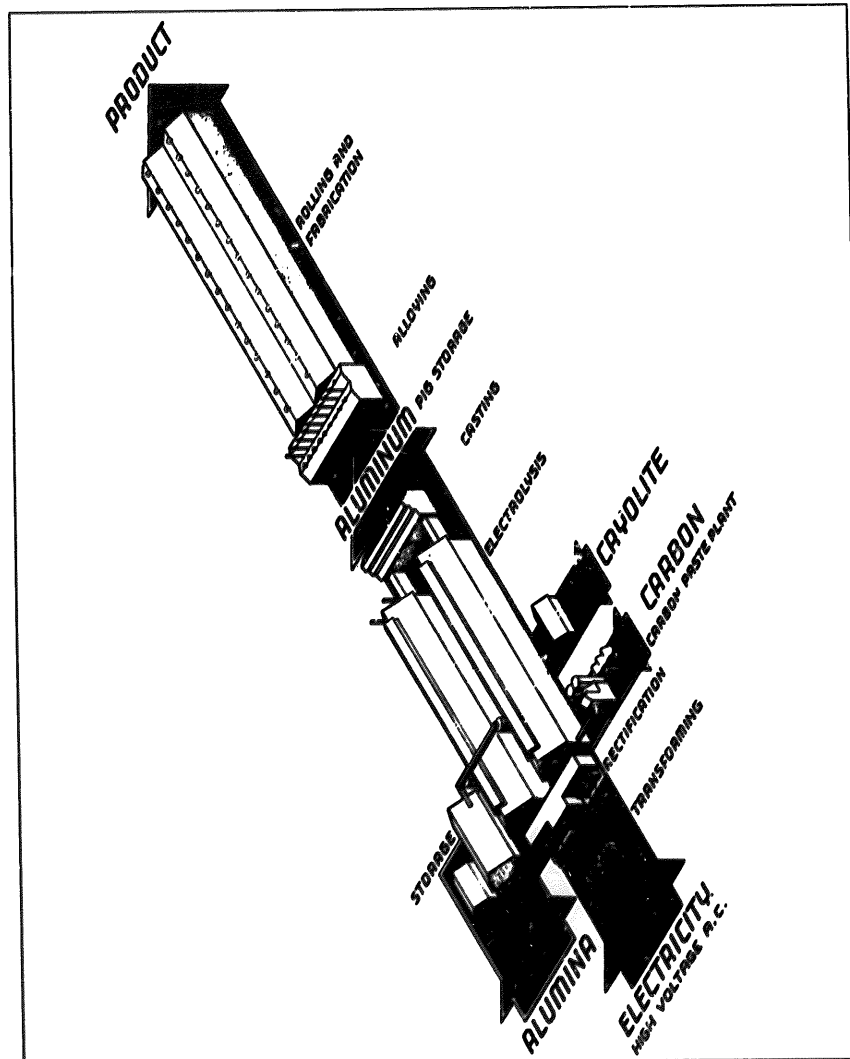


Figure 3.7: Aluminum Product Flow

cryolite, carbon (to replace electrodes), and electricity. Tall cylindrical silos store both the alumina and the cryolite. The alumina silo is the larger of the two. One silo of each type serves two potlines. Often conveyors connect the silos across the top of the potroom.

Electrolysis is the reduction process for aluminum production. Large rectangular pots (with carbon linings as electrodes) accomplish the reduction. The potrooms house one or two long lines of electrolytic cells (potlines). The potroom is a gable roof structure with monitors. A plant usually has a series of potrooms to house all the potlines. Each potroom (which may be in excess of 300 meters long) houses several hundred cells. Each cell produces around 400 kilograms (900 pounds) of aluminum in a 24 hour period.

Rectifiers, located at the end of the potroom, convert alternating current to direct current. The rectifier building can be a long low flat roofed building (with or without ventilators) across the end of the potrooms. The rectifiers and transformers may be situated along the side of the building rather than within a structure. Most plants have a substation between the rectifier building and the power transmission lines.

Carbon electrodes, lowered into the cell, provide a path for the direct current flow. This heats the cryolite in the cell. Hoppers, situated directly over the cell, dump alumina once the cryolite melts. The mixture forms a crust that must be broken to allow total melting of the alumina. The alumina and cryolite mixture melts at 960°C (1760°F) and produces molten aluminum, fluorine, and oxygen.

Processing of the collected gases recovers fluorine. The recovered fluorine produces additional cryolite after recycling. The fluorine recovery building is a small compact building, located at the end of the potroom (or between potrooms), with waste gas stacks.

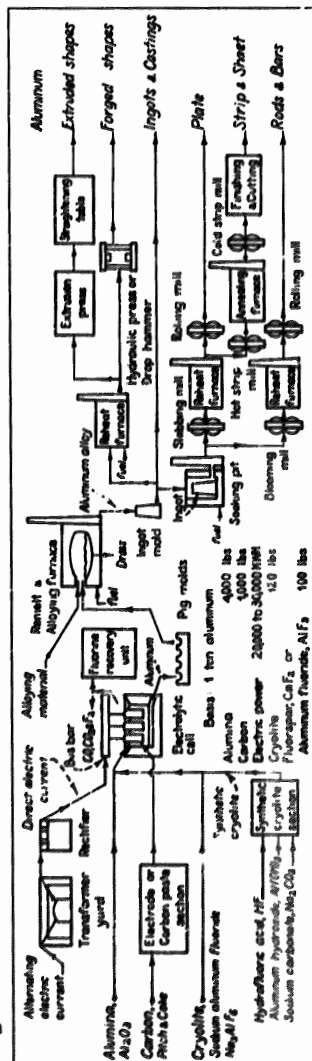


Figure 3.8: Aluminum Reactions

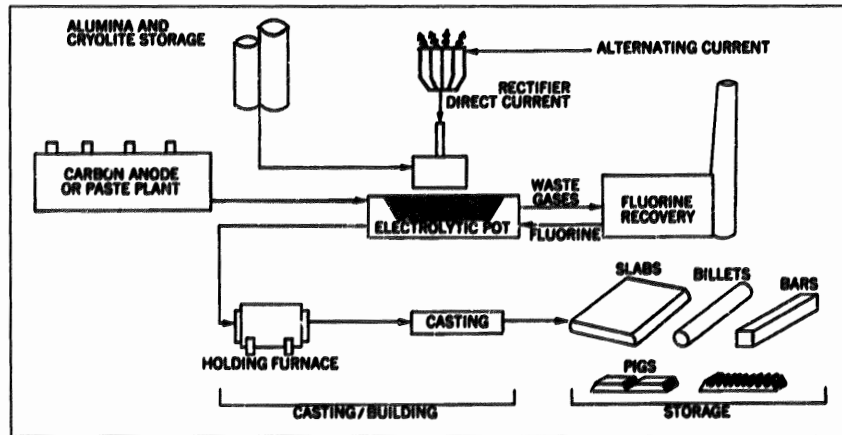


Figure 3.9: Aluminum Industry Flow Chart

Collection plates remove the molten aluminum from the melt. Crucibles transfer the aluminum to the casting building for production of foundry ingots, or, after treatment in holding furnaces, cast into ingots. The casting house is a long ventilated gable or flat roofed structure. If the casting house is a separate structure from the potrooms, a conveyor system will link the two structures. The holding furnaces, within the casting building, heat the aluminum (pure aluminum melts at 658° C), allowing dross (waste floating to the top) removal. Any alloying material

(copper, magnesium, manganese, zinc, silicon, or nickel) is added at this time. Small stacks indicate the presence of holding furnaces. The ingots are in pig, billet, or slab form. Normally, the plant uses open storage for ingots awaiting shipment. Some aluminum plants have aluminum rolling mills collocated with the complex. The rolling mill complexes are very long buildings with ventilated gable roofs.

The Hall-Heroult anode is a solid anode suspended in the electrolytic solution. The Soderberg anode is a carbon paste (coke, tar, and pitch) filled container immersed in the bath. The paste melts into the solution,

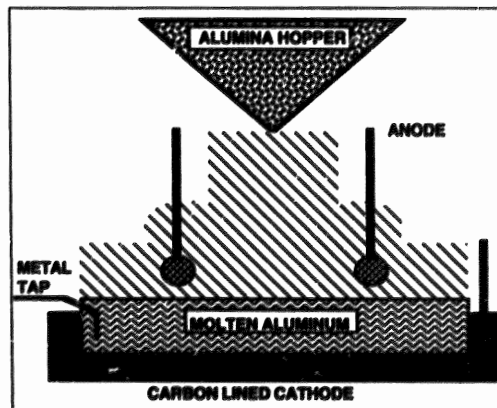


Figure 3.10: Aluminum Metal Production

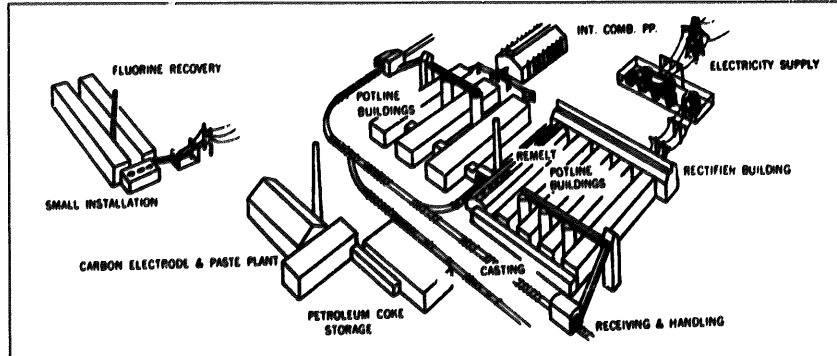


Figure 3.11: Aluminum Reduction Plant

acting as an anode for electrolysis. The electrolytic process produces .45 kilogram (1 pound) of aluminum from (2 pounds) of alumina. During this process, oxygen, liberated from the alumina, consumes .35 kilogram (.75 pound) of carbon from the electrode. Processing requires continual replacement of the carbon. Petroleum coke or anthracite coal provides a carbon source for electrode production. The carbon electrode plant producing the electrodes is a long dark toned structure with numerous ventilators. The carbon electrode plant (Hall-Heroult) configuration is several parallel buildings with a building at each end. The carbon paste plant is one building with either a waste gas stack or ventilation system. Additional equipment at the paste plant includes tanks, silos, conveyors, and a rotary kiln. This equipment can be housed within the one building (or not).

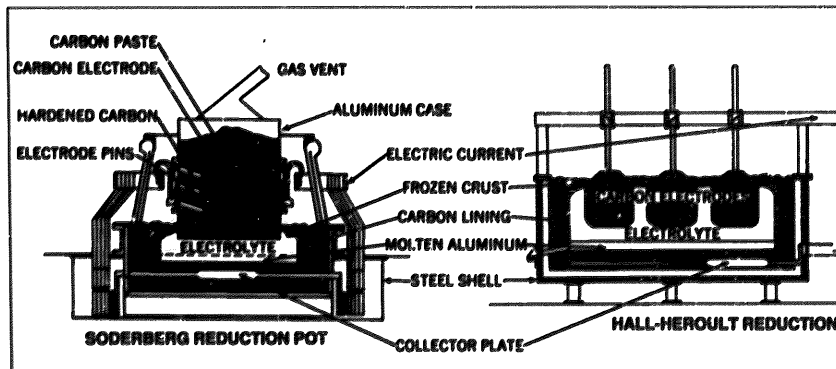


Figure 3.12: Reduction Pot Types

Copper

Copper is one of the most important nonferrous metals. The pure metal, alloying, and industrial chemical industries use large amounts of copper. Copper's electrical properties (thermal and electrical conductivity) make it invaluable in electrical industries. The processing for native copper (naturally in metal

form) involves crushing, washing, and smelting (resulting in the end product of cast ingots). The smelting (with coke) of oxide and carbonate ores yields blister copper. The processing sequence for sulfide ores first involves smelting the ore, forming sulfide matte. Converting the matte (with lime and air) yields blister copper. Electrolytic refining of blister copper yields pure copper. Slimes (the by-product of the electrolytic anodes) yield accessory gold and silver metals after additional processing.

Usually the copper mine, ore concentration plant, and the copper smelter are collocated. Local economics determine the location of the copper refinery. Copper plants are leaching type or smelting type (seven different types of smelter furnaces). Leaching is a hydrometallurgical process (using liquid solvents) and smelting is a pyrometallurgical process (using fire). Identification features of the copper plant include close association to the mine (usually a large open pit), tall stack emitting dense white smoke, slag piles, and either a waste pond or a sulfuric acid plant. Additional features include roasting and smelting buildings, casting building, a substation, and the electrolytic refinery (with tankhouses).

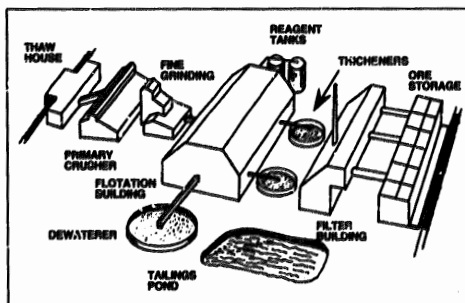


Figure 3.13: Copper Ore Concentration

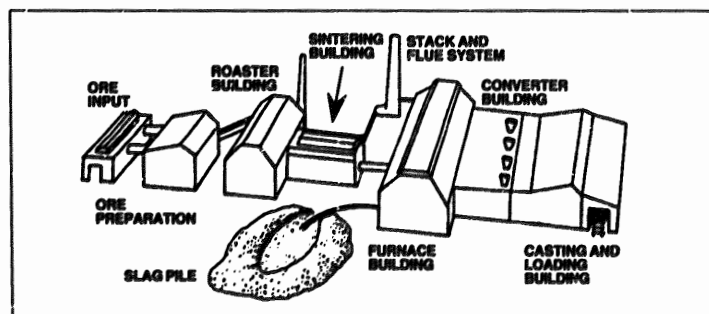


Figure 3.14: Copper Plant Components

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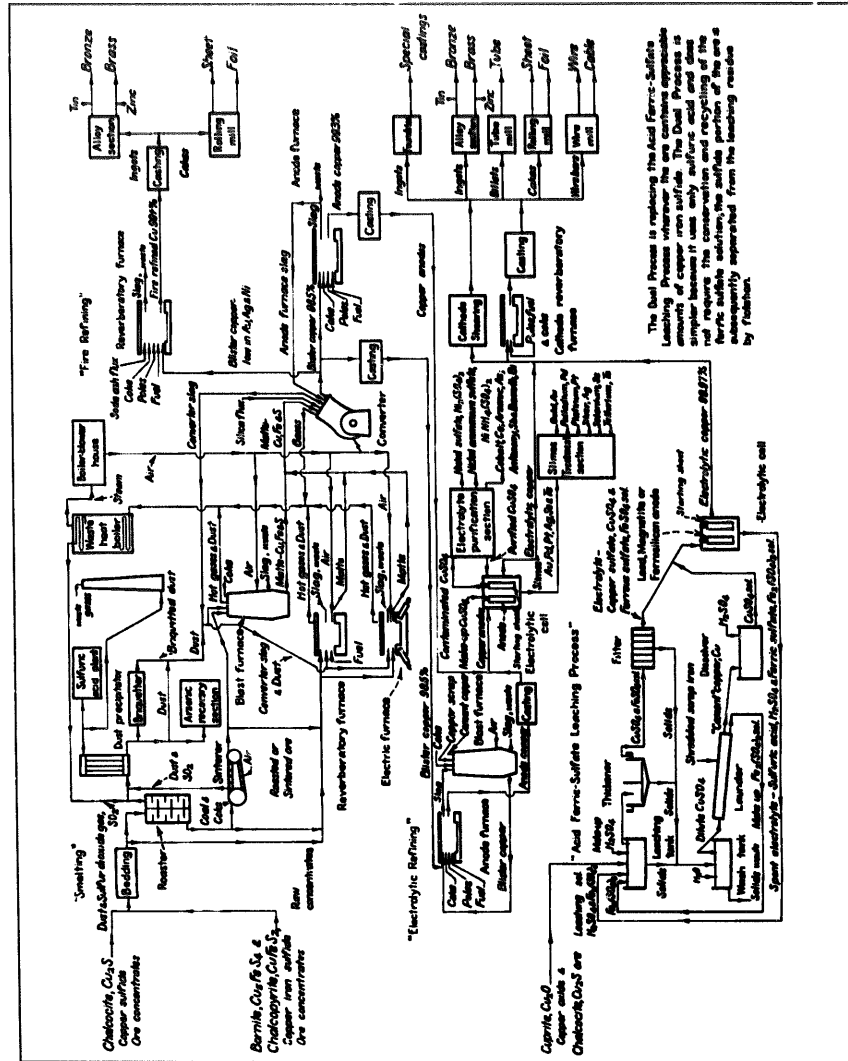


Figure 3.15: Copper Processing Flow Chart

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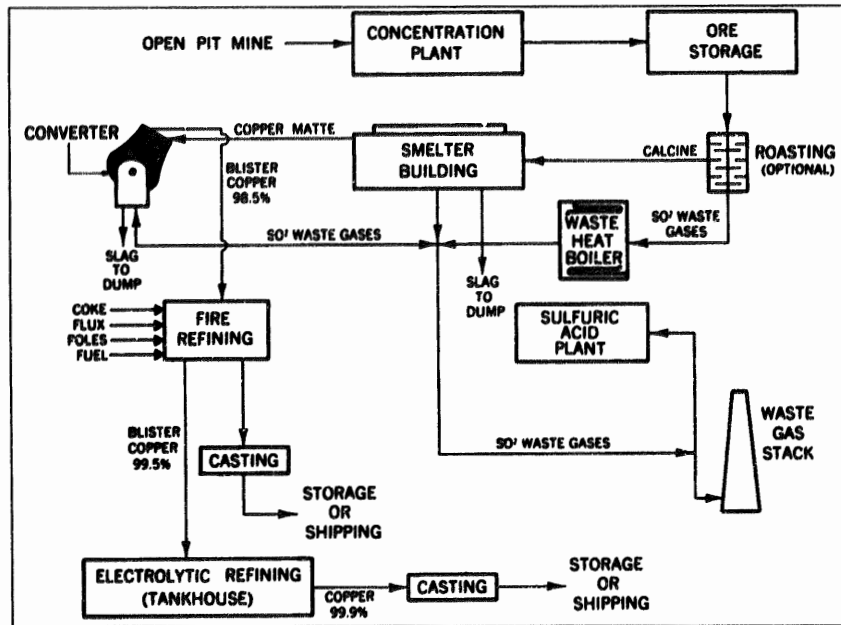


Figure 3.16: Copper Production Flow

Processing

The first step in copper ore processing is the removal of gangue at the ore concentration plant. Roasting removes sulfur dioxide ("SO₂") from the ore. Most roasters (roaster buildings) are the multiple hearth type, but newer plants use the fluid bed roaster. Removal of the sulfur dioxide reduces air pollution and provides a source for the production of sulfuric acid (acid plant is a criss-cross of piping, absorbers, converters, and tankage). Sulfuric acid is a leaching agent for copper ore processing and resale of the acid also defrays the cost of ore processing.

Roasting

The roaster building is a tall, rectangular, gable roofed, monitored structure with conveyors leading from the ore storage area. An extensive large flue system leads from the roaster building to the waste gas stack. One or two 90-180 meters (300-600 feet) tall waste gas stacks disperse gases and smoke at the plant. The flue system consists of cylindrical or rectangular ductwork connecting the buildings to the stack. Either a baghouse or a Cottrell precipitator (small building situated along the flue system) recovers copper dust from the waste gases.

The multiple hearth furnace is a tall cylindrical structure composed of several horizontal brick-lined hearths arranged vertically. Ore enters from the top, and heats, releasing sulfur fumes. Rabble arms push the ore to the outside of the hearth. Here, the ore falls down to the next level. Rabble arms push the ore to the center, where it falls down another level, and so forth. Air, blown counter to the feed, mixes with the sulfur, forming sulfur dioxide. The product of the roaster, calcine, proceeds onward to the smelter for additional processing. The waste gases pass through waste heat boilers for heat recovery. The sulfuric acid plant recovers the sulfur dioxide to produce sulfuric acid. The tall waste gas stack disposes of the rest of the gaseous material.

In the fluid bed roaster, air, blown from the bottom of the roaster (through tuyeres) suspends the ore feed (dropped through the top of the roaster). The suspended ore heats and reacts, liberating the sulfur from the ore. The greatest advantage for the fluid bed roaster is the minimal number of moving parts in the system. The greatest disadvantage is the retooling cost for older plants. The treatment for the calcine and the sulfur dioxide output from the fluid bed roaster is the same as the multiple hearth roaster.

Smelting

The next step in copper ore processing is the smelting of the calcine. Two smelter categories encompass seven types of furnaces. The first smelter category uses one of four standard furnaces (electric furnace, Momoda blast furnace, flash furnace, or reverberatory furnace) producing a copper matte. The copper matte produced from these smelters requires additional purification in converters. The second category uses a continuous furnace (Noranda, WORCRA, or Mitsubishi furnace) to produce a very high grade copper matte. This high grade matte doesn't require additional converter processing.

The smelter is the largest structure at the copper plant. The building is a long tall gable roofed structure. The smelter has the roaster building at one end and a converter and waste heat section at the other. Additionally, rail tracks lead from the smelter to the slag piles, another set of tracks provides furnace charges, and a flue system links the smelter to the waste gas stack.

Sintering fuses fine-grained ore concentrates before smelting. A mixture of fine coal or coke and the ore passes over a gas flame carried on an endless grate. Some sintering machines perform a dual function of roaster and sinterer.

The two most common smelters use the reverberatory furnace and the flash furnace. In the oil or gas fired reverberatory furnace, the calcine, mixed with silica flux, heats to 1100° C (2012° F). The ore melts, forming copper matte (copper with impurities), slag, and sulfur dioxide gas. The slag (composed of silica, iron oxide, and alumina) floats to the top. The tapped slag is disposed of on the slag pile. Sulfur dioxide gas, separated from the gaseous waste, forms sulfuric acid at the acid plant. The remaining gases vent to the atmosphere through the stack. The tapped copper matte goes to the converter for further purification (forming blister copper). Or, casting at the casting building produces low grade metal.

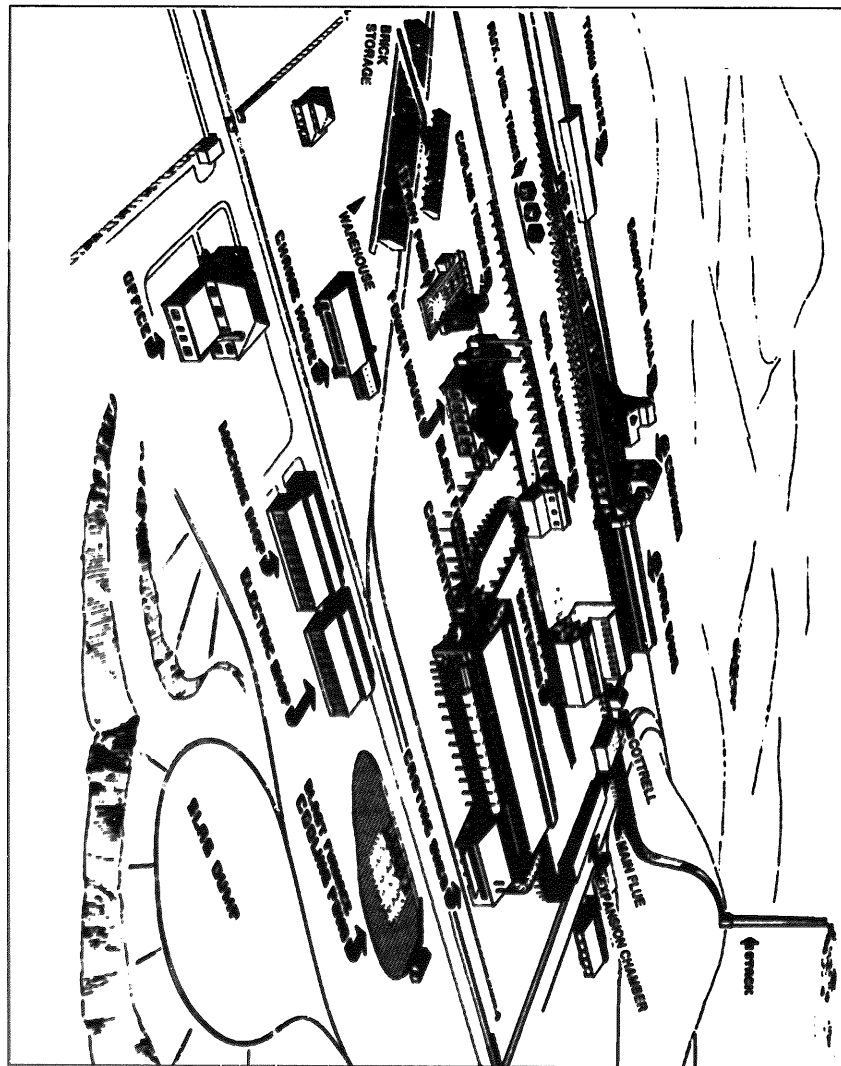


Figure 3.17: Copper Smelter

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The flash furnace smelter combines roasting and smelting in one operation. Additionally, the furnace produces a high sulfur dioxide (6-10%) content, perfect as primary acid plant feed. Fluxed ore concentrates, fuel, and oxygen or pre-heated air injected into the reaction chamber creates an exothermic oxidation reaction. The settler of the furnace collects the particulate material from the reaction. In the settler, the matte and slag separate.

The blast furnace is another method of copper smelting. The furnace charge consists of ore concentrates, coke, converter slag, and briquetted recovered dust. The ignited fuel heats and melts the charge. Air (not pre-heated) injected into the furnace both supports combustion and oxidizes iron and sulfur. Converter slag, acting as a flux, combines with impurities, forming slag, which rises to the top of the charge. The heavier matte sinks to the bottom of the furnace.

Converter

All the standard furnaces require a converter in the next stage of copper ore purification. Location of the converter building (a long rectangular gable roofed structure) is between the smelter and the electrolytic refinery. The casting building is a small building next to the converter building.

A silica flux and the ladle collected matte (at 1100° C) charge the converter. Air, blown into the matte, oxidizes the impurities (mostly iron oxides and sulfur). Tapping of the molten copper occurs when the converter is half full. This molten copper (blister copper) is of 98.5% purity. Additional refining produces copper of higher purity.

Refining

Refining the blister copper from the smelter by fire refining yields 99.5% pure copper. Electrolytic refining yields copper of 99.9% purity.

Fire refining (anode and fire refining furnaces) eliminates oxygen and sulfur impurities from the copper. An anode furnace accepts the still molten blister copper. First injected air drives off the remaining sulfur. Then a mixture of coke and either green logs (green timber) or hydrocarbon gas added to the copper removes oxygen from the copper. Blister copper, mixed with soda ash, melts in the reverberatory furnace in fire refining. The soda ash removes arsenic and antimony impurities. The refined copper is cast into ingots and shipped or cast into anodes for electrorefining. Fire refined copper is not suitable for electrical use but is suitable for structural use.

Electrolytic refining yields the highest purity copper metal. Electrolytic refining takes place in the tankhouse. This is a single story, multiple-bay structure with numerous roof vents and possibly a rectifier or substation section. Additional associations include a rail-served storage yard and the casting building.

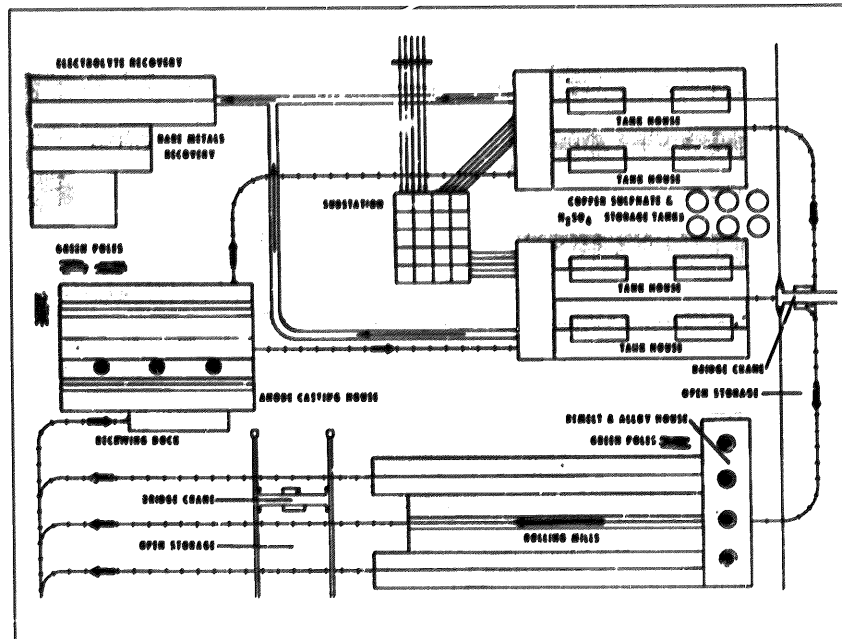


Figure 3.18: Electrolytic Refinery

Direct current flow acts on the cast anodes and thin copper sheet cathodes, placed in a sulfuric acid and copper sulfate bath (tank). The copper from the anode dissolves and re-deposits on the cathode sheet. Impurities remain in solution or drop to the bottom of the tank as slime (mud). Gold, silver, and platinum recovery plants remove accessory metals from the slimes. A reverberatory furnace melts the cathodes (poled with green logs) for casting and shipment.

Leaching

There are four leaching processes that differ only in the location of the ores (that are being leached). The chemical used is usually sulfuric acid. Dump leaching is leaching of the waste ores from a mine (acid poured on the mound of ore). Heap leaching is leaching of oxide ores on a prepared surface (so acid doesn't leak into the ground). Flotation cannot separate oxide ores of copper. In place (in situ) leaching is leaching of the ores while still in the ground, usually on very porous ores with an impervious rock layer beneath. The fourth method is vat-leaching. Agitator equipped tanks of sulfuric acid (and ferric sulfate in some cases) leach the ores.

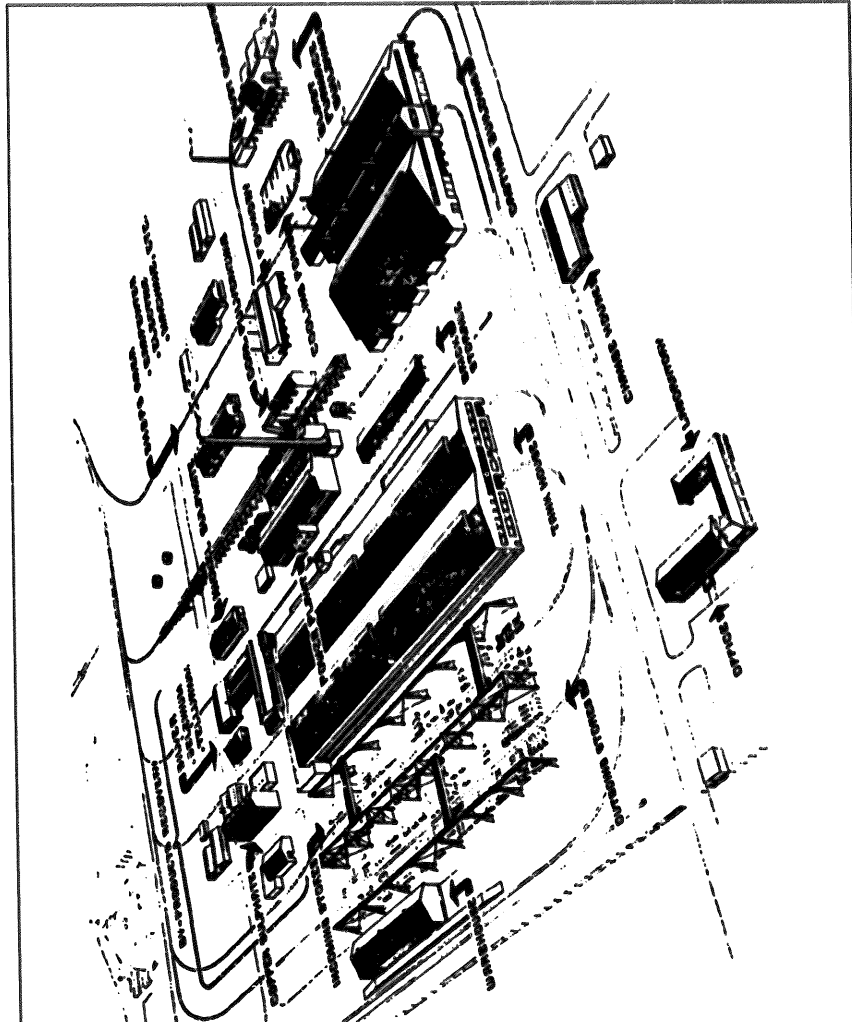


Figure 3.19: Copper Refinery

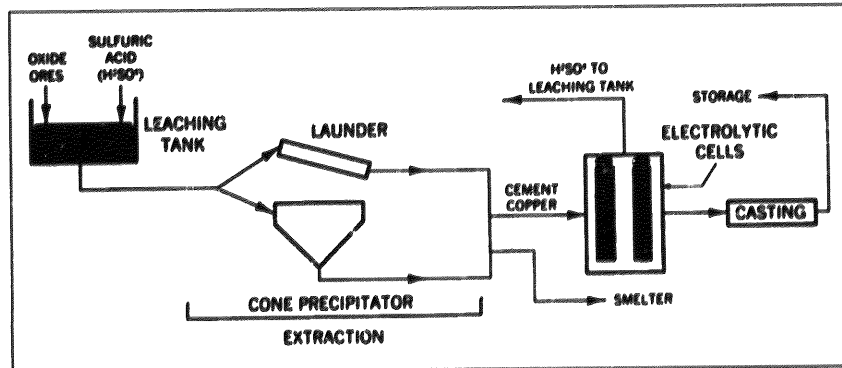


Figure 3.20: Copper Leaching Flow

Vat leaching consists of a series of large rectangular or cylindrical tanks covering a large area. Identification of dump, heap, and in-situ leaching is difficult. The only indication is a pipeline carrying sulfuric acid to the waste ore piles. Additional components include a sulfuric acid plant, substation, and tankhouses.

Two methods separate the copper from the acid solution for production of the copper metal. The first is precipitation (or cementation) of the copper from solution followed by smelting. The second is the electrowon process (recovery of metals by electrolysis). Solvents extract the copper from the leachate (identified by a series of 10-20 low rectangular buildings) and electrowinning removes the copper from the solvent-based solution. Or, electrowinning produces copper directly from the leaching solution.

Precipitation separates copper from the copper and acid solution for dump, heap, and in-situ leaching. The solution, forced upwards through scrap iron in a cone precipitator or launder, precipitates the copper (iron replaces the copper in the solution, leaving the copper free to fall out of solution). Standard smelting and refining produce copper metals from the resulting cement copper.

The product from vat-leaching goes directly to the tankhouse for electrowinning (because the solution has a very high copper concentration). The electrolytic refining process is slightly different. The anode is lead rather than copper, but the cathode is still a copper sheet. The solution provides the copper metal for the process rather than the anode. The product of this process is suitable for structural, sheeting, and alloy production (but not electrical uses). The solvent extraction process produces electrical quality copper.

By-Products Recovery

Roaster dust and gases yield arsenic and sulfuric acid after recovery operations. The sulfur dioxide gases yield sulfuric acid at the sulfuric acid plant.

Electrolytic solutions and slimes yield addition elements. Sulfuric acid leaches the dried slimes. The leached slimes, soda ash, and sodium bisulfate charge a smelter. The resulting slag carries selenium and tellurium. The remaining metal in the smelter furnace is high in silver, gold, platinum, and palladium. Electrolysis uses anodes, cast from the metal, in recovering these elements.

Electrolytic cells, equipped with insoluble anodes and copper cathodes, recover any remaining copper from the contaminated electrolytic solutions. Purification tanks (using reagents, controlled temperature, and controlled acidity) precipitate various impurities. Filtering, drying, and refining produces (from the precipitates) arsenic, antimony, bismuth, cobalt, and nickel.

Gold

Uses of gold include jewelry (75%), medium of exchange, medicine (7%—chiefly dentistry), industry (electrical conductors and electronic components such as integrated circuits and contacts), and a minor use in glass production of high grade optical components (such as IR sensitive mirrors for optical systems).

Gold occurs as native metal (free metal) in placer (gravel) or vein (as inclusions in quartz) deposits. Gold also occurs as the telluride ore sylvanite (Ag_3AuTe_2).

Gold occurs as an accessory (minor constituent) mineral in lead and copper sulfide ores. The gold ores contain little gold (in the range of 15 grams per metric ton).

Refer to the sections on copper and lead processing for a discussion of secondary metal recovery of gold from sulfide ores. The processing of gold ores involves normal ore concentration methods (refer to the section on mining), producing an impure gold metal containing copper, silver, and several other base metals.

Purification of the gold includes melting and oxidizing, removing the base metals and the silver. The Miller process purifies gold through melting and chlorination, which also removes the base metals and silver. Treatment of silver containing gold metal is through the Wohlwill process. The Wohlwill process purifies the gold by electrolysis of the gold chloride in a HCl solution (hydrochloric acid). The alloy (gold and silver cast material) forms the anode and pure gold forms the cathode. Electric current deposits the gold onto the cathode. The silver forms a silver chloride and remains as the anode.

Most gold processing plants are located near the mine. They look like a small compact ore concentration plant with additional buildings containing the casting houses, electrolytic cells, and chlorinating sections.

Lead

Lead metal usage is in the top four of all metals. Because lead is a health hazard and is very toxic, processing requires careful consideration. Uses for lead include alloying, solder, paints and coatings, and the production of printing type, batteries, and shot for ammunition.

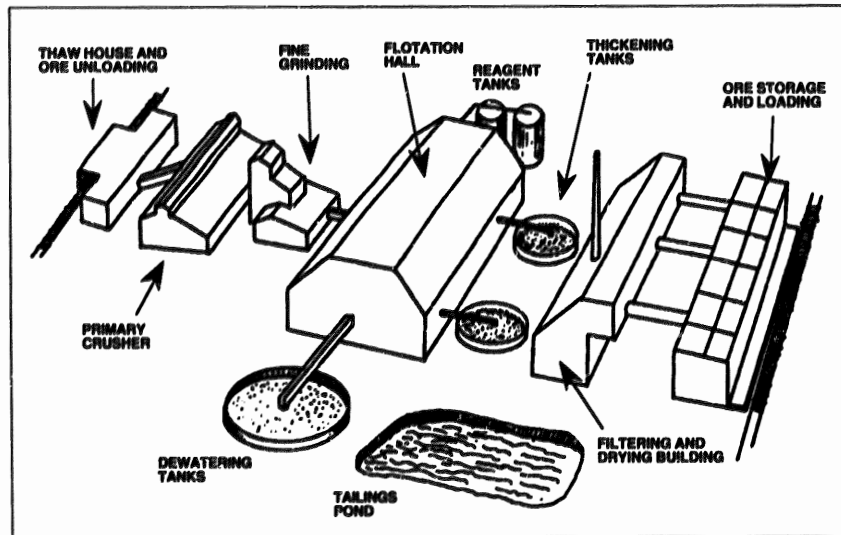


Figure 3.21: Lead Ore Concentration

Lead ore concentration includes crushing, grinding, classification, and flotation. The concentrated lead ore contains 45% to 60% lead, 0% to 15% zinc, 0% to 3% copper, and 0% to 2% antimony. The ore also contains sufficient traces of gold and silver metals to warrant recovery. A zinc plant may be collocated to the lead plant since lead and zinc ores are often found intermixed.

Roasting

The lead ore contains 10% to 30% sulfur that must be burned off before smelting. Removal of the sulfur compounds is by roasting and/or sintering depending on the concentration of the ore. High concentration lead ores require a roasting operation to remove sulfur. The roaster building is a long slender gable (or sloping) roofed structure with a continuous monitor. A conveyor transfers ore from the ore storage area and another conveyor transfers roasted ore to the sintering facility. A pipeline connects the roaster building to the sulfuric acid recovery plant (if one is present). The roaster can remove only part of the sulfur when handling highly concentrated lead ores. To prevent the concentrated lead ore from melting and clogging the roaster, the operational temperature of the roaster is maintained below 750° C (1382° F). The lowered temperature doesn't remove all the sulfur.

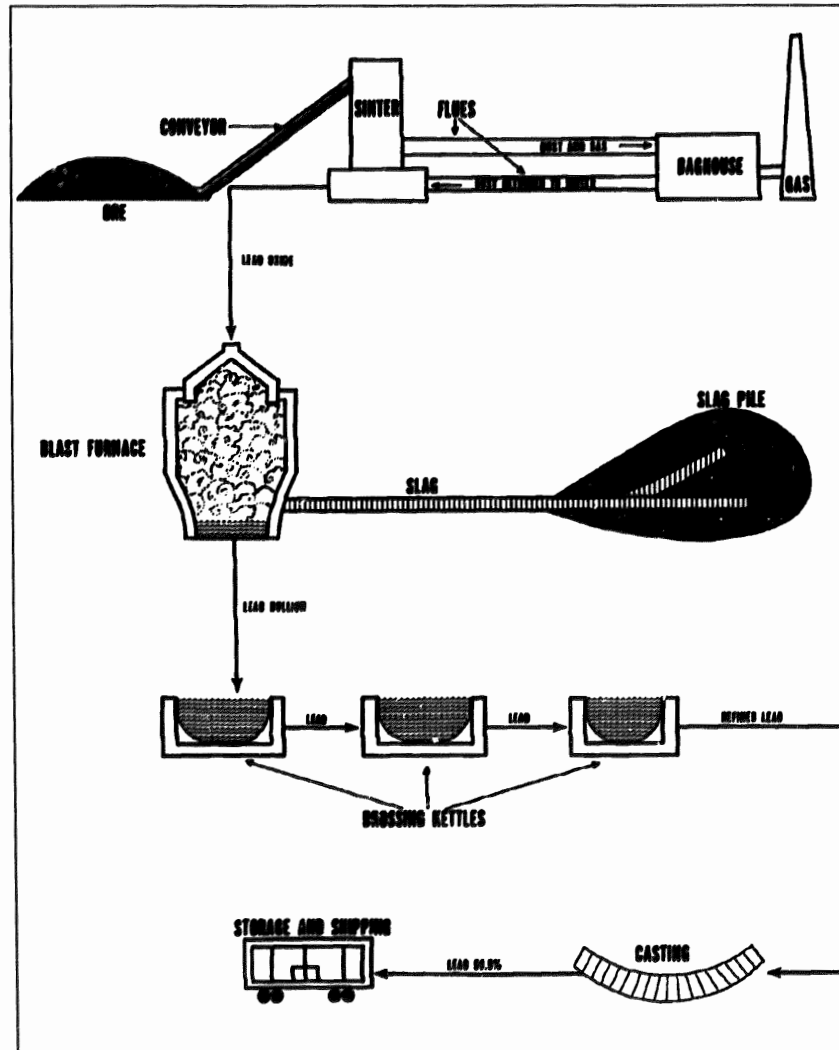


Figure 3.22: Lead Processing Flow

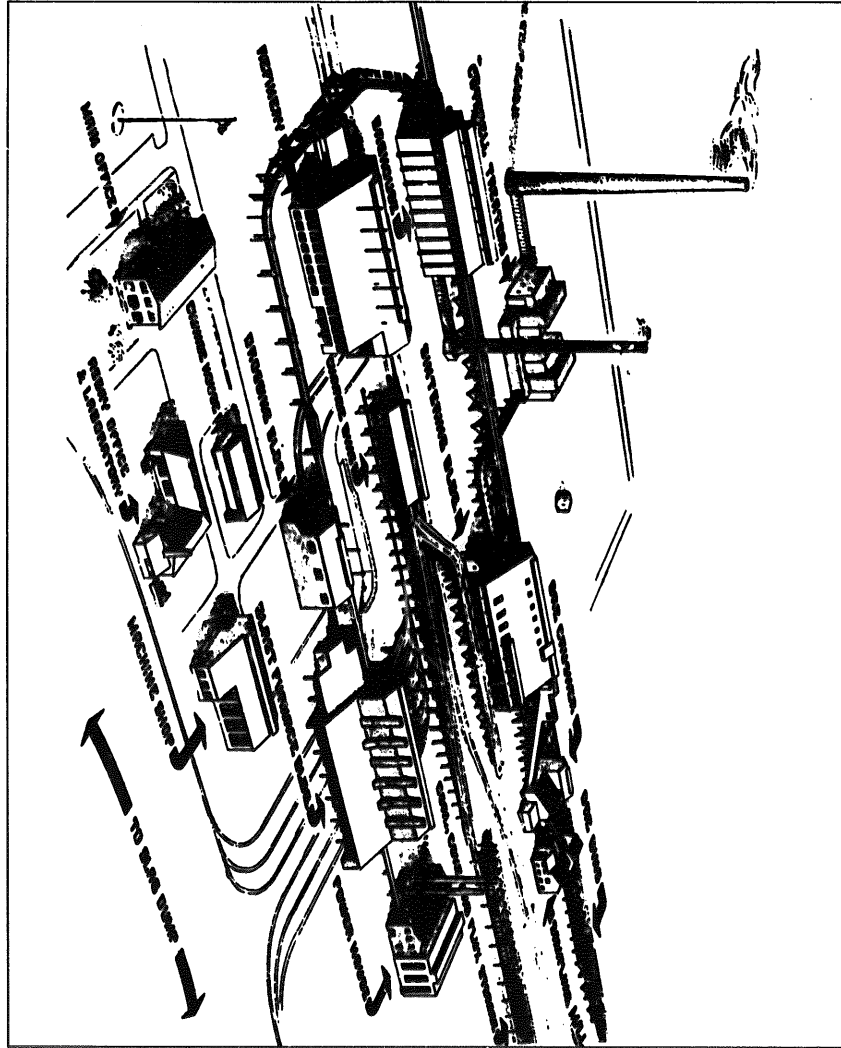


Figure 3.23: Lead Smelter and Pyrometallurgical Refining



Figure 3.24: Lead Processes

Sintering

The sintering facility removes the remaining sulfur from the lead ore concentrates (now in the form of lead sulfates). The sintering building has a similar appearance as the roaster building with the addition of several short stacks and monitors. A flue connects the large baghouse to the sintering building. The flue system consists of long cylindrical or rectangular pipes. The baghouse is a large flat roofed building. Another flue connects the sintering building to the extremely tall waste gas stack. The sintering building is normally situated next to the blast furnace. The sintering process involves placing the concentrates, mixed with fine coal or coke, on a moving grate. A gas flame ignites the mixture and drawn air oxidizes and sinters the mixture forming lead oxide. The sulfur dioxide and dust from the burning charge pass through flues to the baghouse. The baghouse recovers lead dust for return to the sinterer. The acid plant recovers the sulfur dioxide gas (or waste gas stacks vent the gas to the atmosphere).

Then the blast furnace smelts the lead oxide, freeing the lead metal and gathering the impurities in a slag. The blast furnace is the tallest structure at the lead plant. The structure is a gable or flat roof building with either 4 to 7 short waste gas stacks or a continuous monitor. Flues connect the blast furnace to the baghouse. A conveyor carries roasted and sintered ore from the roasting or the

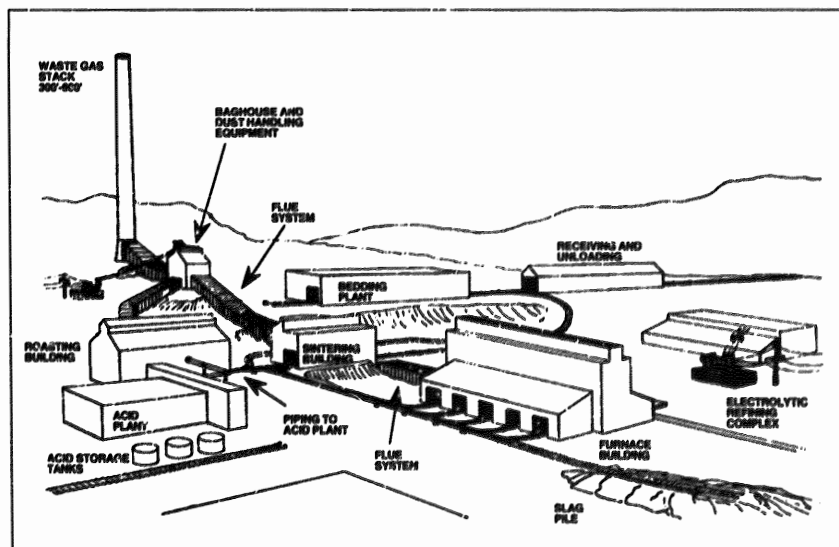


Figure 3.25: Flue System at Lead Plant

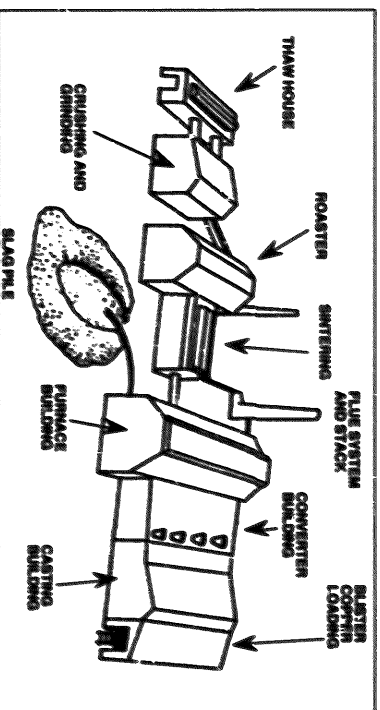


Figure 3.26: Slag Pile at Lead Plant

sintering building. The blast furnace usually has a shed extension. A compressed gas pipeline supplies air for the furnace operation (from the compressor building). The sintered ore, mixed with coke and a lime silica flux provides the charge for the blast furnace. The ignited ore, supported by a compressed air flow, burns, forming carbon monoxide. The carbon monoxide reduces the lead ore to a molten lead bullion. The molten lead settles to the bottom of the furnace and the slag rises to the surface. The slag fuming plant recovers the zinc oxide content from the slag and the remaining slag is sent to the slag pile for disposal. Railroad tracks carry the slag from the blast furnace to the slag dump (dark, toned pile).

A drossing kettle reduces impurities in the lead bullion (primarily in the form of copper) by controlled cooling to 327° C (621° F). The impurities oxidize during the cooling and rise to the surface of the lead. A perforated disc skims the impurities from which copper and other by-products are recovered.

Refining

Pyrometallurgical (fire refining) and electrolytic (Betts process) are the two methods used for refining the lead bullion after drossing. Pyrometallurgical refining involves heating the copper free lead. Zinc dust, added to the melt, causes arsenic and antimony impurities to form a dross (and softening the lead). Additional smelting produces antimonial lead (hard lead) from this dross. Furnaces heat the remaining softened lead until it reaches a molten state. Added zinc to this melt causes gold and silver impurities to separate forming a dross for removal. The drossing and refining building is a low irregular gabled roof structure of low to moderate height. The building has either continuous monitors or numerous short stacks. The structure is near (or attached to) the blast furnace

or casting building. Flues connect this building to the baghouse. The dressing and refining building contains the dressing and by-products kettles and sometime a casting wheel.

Canada and Peru are the primary users of the electrolytic process of refining. A solution of fluosilic acid and lead fluosilicate electrolyze lead bullion anodes. Direct current, passing through the solution, causes the deposition of pure lead on the cathodes. Some impurities remain on the anode and the rest enter the electrolytic solution. Reagent[®], controlling the temperature and acidity, purify the electrolytic solution. The separation of the impurities from the solution allows the production of a 99.85% purity lead product. The electrolytic refining building is a large (almost square) structure with nearby substation, rectifier buildings, and electrolytic tanks.

Casting

Casting forms lead pigs from the refined lead bullion. The casting building is a low to moderate height rectangular gable (or flat) roofed structure. The casting shed has either a continuous monitor or numerous ventilators. The casting shed is situated adjacent to the dressing and refining sections. Railroad tracks lead to the casting and storage section.

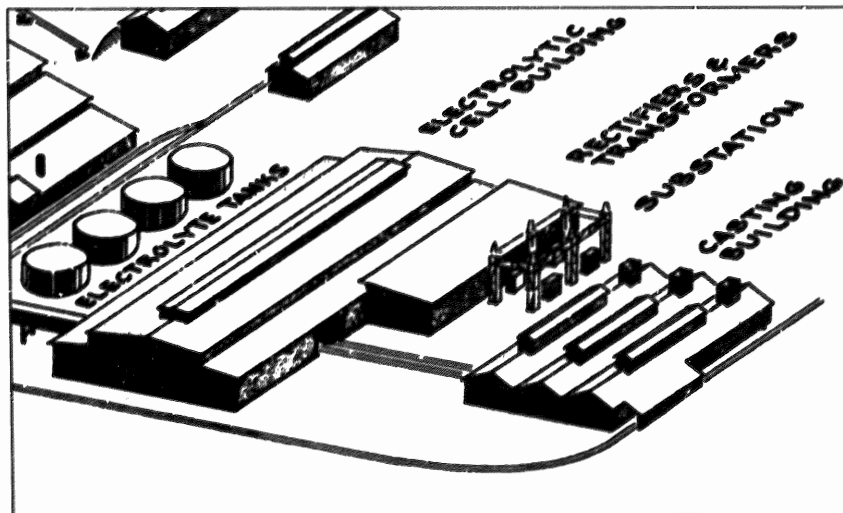


Figure 3.27: Lead Refining, Electrolytic Method

Magnesium

Magnesium and its alloys are extremely strong materials able to withstand high temperatures. The aerospace and vehicle production industries use most of the magnesium production in construction of structural members, engines, and sheets. Explosive, nuclear, and incendiary industries also use magnesium metal. The organic and in-organic chemical industries make use of magnesium in chemical processes.

Magnesium metals have a high affinity with oxygen. The ores of this metal require reducing (of their chlorides) at high temperature in a vacuum (or an inert atmosphere).

Dolomite, magnesite, and carnallite ores contain magnesium. Seawater, natural brines, and salt deposits also contain magnesium. Sea water extraction is the source for half of metallic magnesium, dolomite is the source for almost all the rest.

The two main processing methods are electrolytic (chemical processing) and electrothermic (mechanical processing) processing. Electrolytic processing accounts for 80% of magnesium production. The Dow and the Farben electrolytic processes differ only in the electrolytic cell configuration. The Dow and Farben electrolytic processes produce magnesium from magnesium chloride. Sea water and lime (oyster shells if available) mixed in large settling tanks precipitate insoluble magnesium hydroxide. The filtered hydroxide treated with hydrochloric acid forms magnesium chloride. Electrolysis converts the fused material into chlorine gas and molten magnesium. Scrubbing towers recover the gas and the magnesium is cast into ingots.

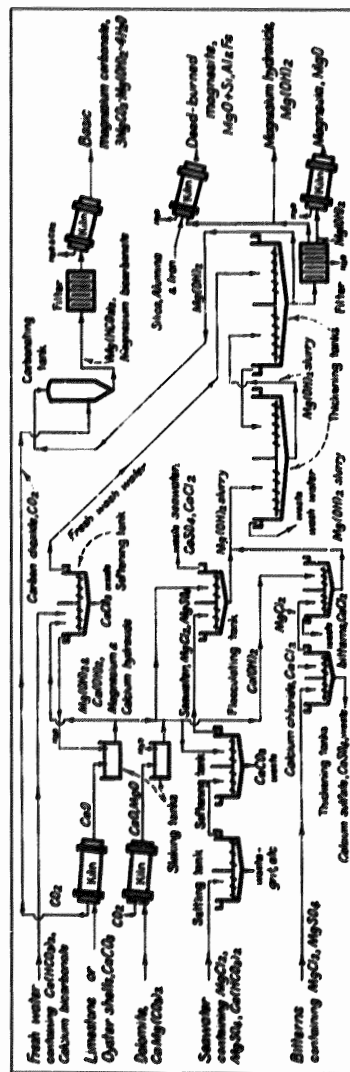


Figure 3.28: Magnesia Flow Chart

The carbothermic and ferrosilicon processes are electrothermic processes. Magnesium oxide and carbon reduce to carbon monoxide and magnesium vapor in the carbothermic process. The vapor condenses to an impure magnesium dust. The reheated briquetted magnesium dust vaporizes and condensers produce pure magnesium metal. In another process, the ferrosilicon process, the magnesium oxide (dolomite), mixed with ferrosilicon, heats in a vacuum. The condensed magnesium gas yields metallic magnesium ready for casting.

Magnesia Production

Magnesium oxide (magnesia) for magnesium metal production comes from magnesia plants. The location of the magnesia (from brine) plant is usually along the coastline. Well brine and salt deposits (bitterns) also provide a magnesium source. A refractory brick plant, using magnesia, may be located near the magnesia plant. Processing 712,000 liters (188,000 gallons) of seawater yields 900 kilograms (1 ton) of magnesia.

Slaked lime (calcium hydroxide) is the reagent used in extracting magnesia from brines. Mixing crushed calcined (roasted) seashells (light-toned stockpile),

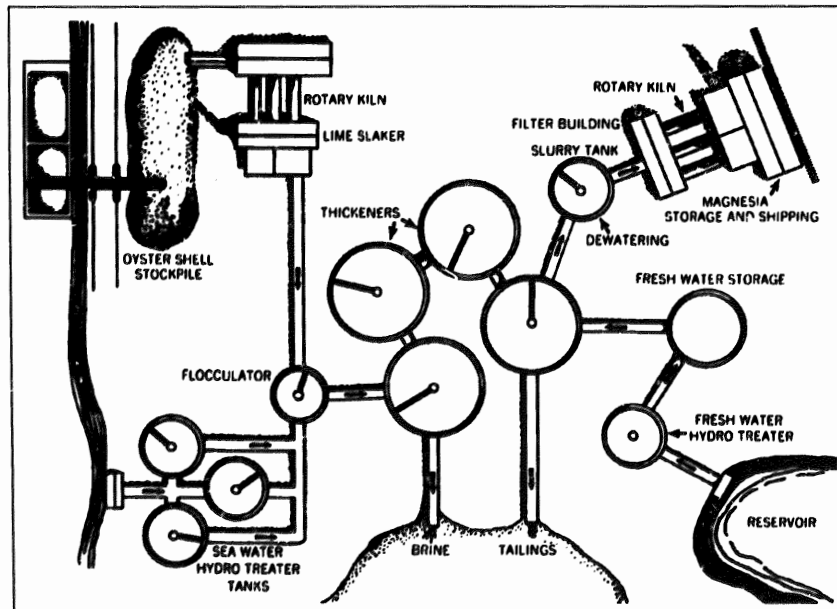


Figure 3.29: Magnesia From Brine Plant

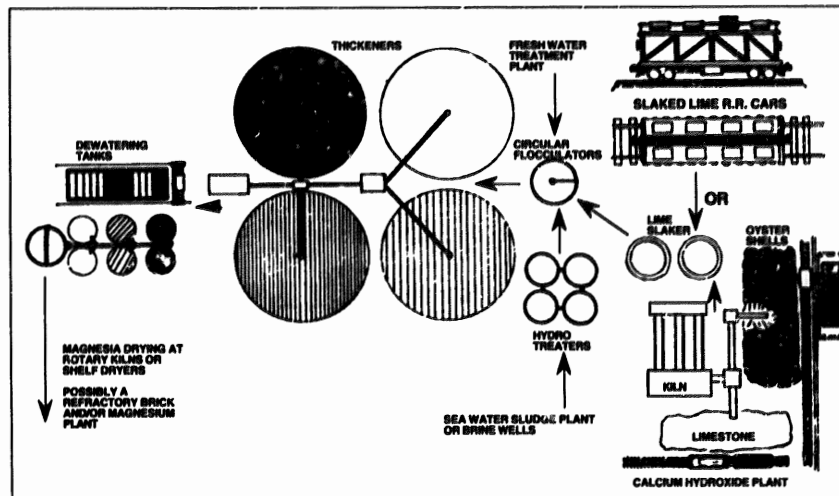


Figure 3.30: Magnesia From Brine Plant Components

limestone, or dolomite and water produce the slaked lime. If dolomite supplies the slaked lime, 356,000 liters (94,000 gallons) of seawater yields 900 kilograms (1 ton) of magnesia, because the dolomite supplies both calcium hydroxide and magnesium hydroxide. Most plants have a separate rotary kiln for roasting the lime. The kiln is a set of long parallel tubes with hoppers at one end and a filter building on the other. Storage of the slaked lime is in a small tank (slaker) located near the raw material storage silos or bins (i.e., raw material storage for slaked lime production).

Large tanks (hydro treaters) hold the brine, pumped from their source (seawater). When the slaked lime and the brine mix, the soluble bicarbonates and impurities precipitate. Rakes and pumps remove the by-products from the center of the tank. The clarified brines, containing magnesium hydroxide, flow over the edge of the tank and on to the flocculator tank.

The addition of calcium hydroxide causes the settlement of the magnesium hydroxide in the flocculator tank. The flocculator is a small cylindrical or rectangular tank. Pumps send the settled magnesium hydroxide to the thickening tanks and the remaining brines to the waste pond (for disposal). The waste pond is a large, light-toned area.

Fresh water washes the magnesium hydroxide in the thickening tanks. The large thickening tanks are typically in groups of four. Each tank has an arm (or rack) extending to the center (central discharge point). The treatment of the fresh water (before use in the thickening tanks) removes bicarbonates by the applica-

tion of slaked lime. A single fresh water hydro treater tank performs the treatment and a single fresh water storage tank stores the treated water. The fresh water hydro treater is a small dark-toned tank. A counterwashing system separates the magnesium hydroxide from the impurities. The fresh water moves in a direction of flow opposite to the flow of the magnesium hydroxide. At the end of the treatment process pumps send the wash water to the waste pond for disposal. The dewatering tank (or alternatively the filtering section of the rotary kiln) removes the excess water from the magnesium hydroxide slurry (from the last tank in the series).

Calcining of the magnesium hydroxide is the last stage in the magnesia process. Rotary kilns dry the magnesium hydroxide (water escapes as steam). Large bins or silos store the finished magnesium oxide (magnesia) prior to shipment or further processing at the magnesium plant.

Magnesia obtained by calcining magnesite (magnesium carbonate) yields a material suitable for refractory and insulating materials (without additional purification or processing).

Magnesium

Magnesium chemical processing (electrolytic) produces most magnesium metal. Magnesia, carbon, and chlorine produce magnesium metal in the Farben electrolytic process. Magnesia combined with peat moss and carbon (in the form of petroleum coke or anthracite coal) produces a porous pellet. The pellets, mixed with magnesium chloride, forms a paste. Tunnel kilns (rotary kilns) dry the pelletized paste.

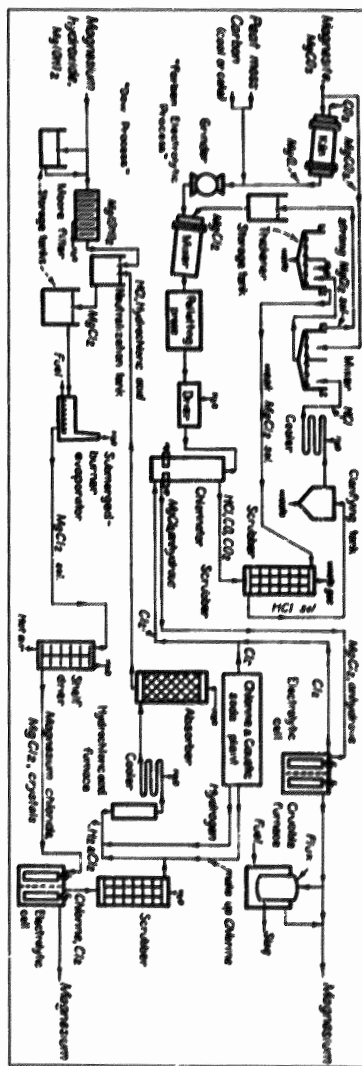


Figure 3.31: Electrolytic Process Flow

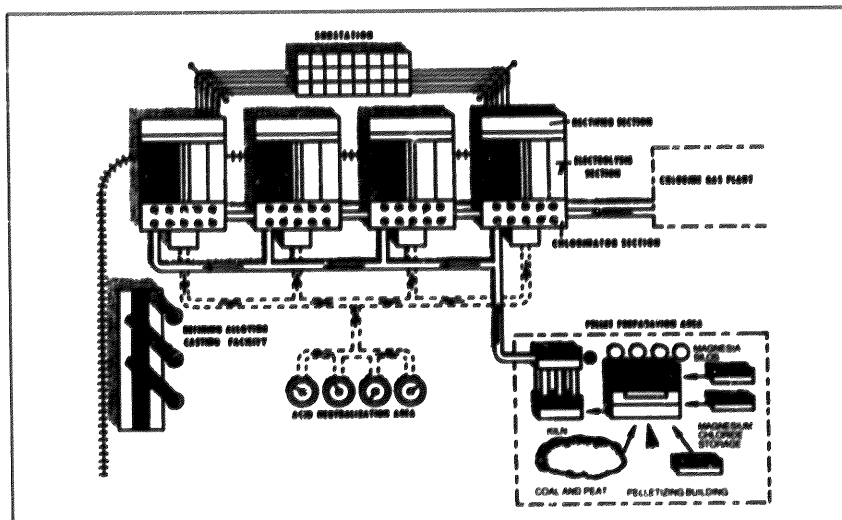


Figure 3.32: Pellet Preparation Area

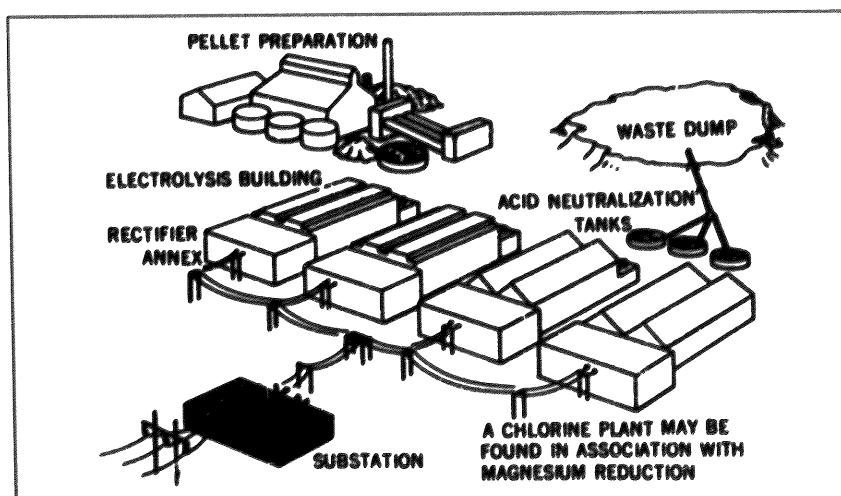


Figure 3.33: Farben Electrolytic Cell Magnesium Plant

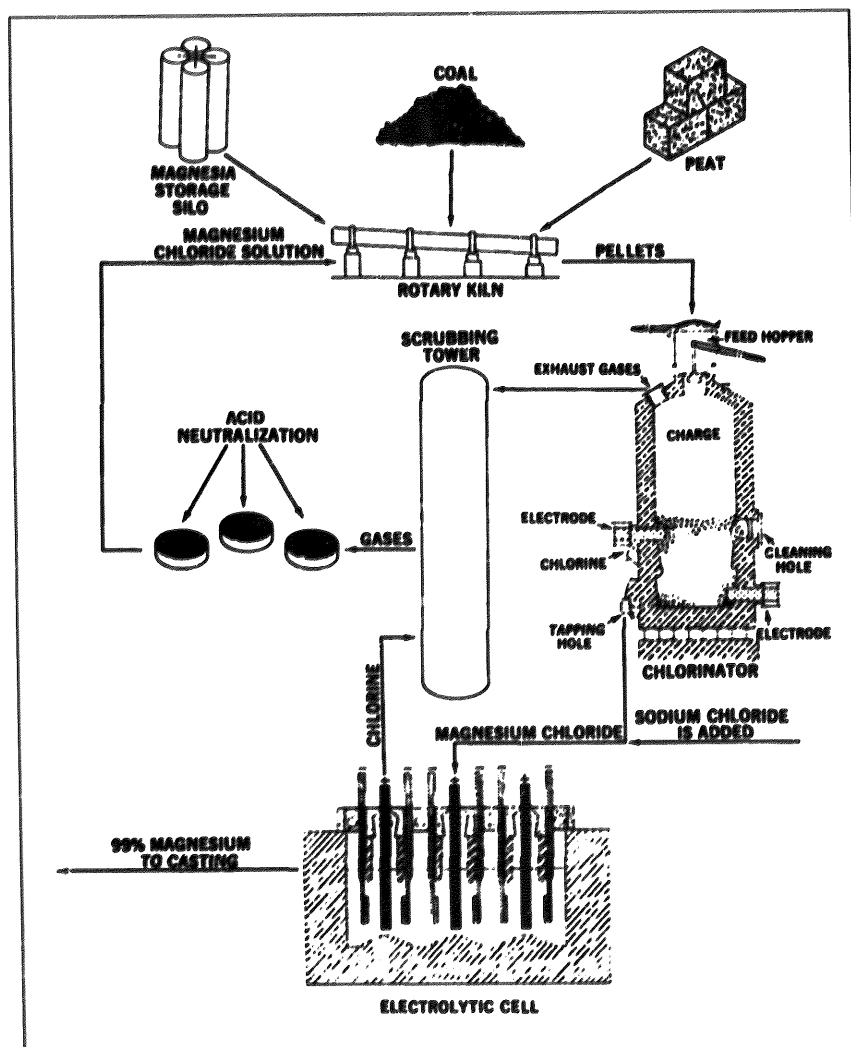


Figure 3.34: Electrolytic Cell For Magnesium Metal Production

Chlorinators (tall, cylindrical, electrically heated furnaces) heat the pellets and a chlorine atmosphere to 900°C (1652°F). An associated chlorine and caustic soda plant supply the chlorine gas. The magnesium reacts with the chlorine, forming molten anhydrous magnesium chloride. Once an hour the tapped magnesium chloride charges the electrolytic cells. Scrubbing towers, clarification tanks, and coolers recover hydrochloric acid and anhydrous magnesium chloride from the exhaust gases (consisting of hydrochloric acid, anhydrous magnesium chloride, carbon monoxide, and carbon dioxide) of the chlorinator. The acid neutralization plant produces magnesium chloride from the recovered materials.

Gas-fired furnaces heat the mixture and the cells operate at 670°C to 730°C (1238°F to 1350°F). Direct current flow in the electrolytic cell produces molten magnesium and chlorine gas from the anhydrous magnesium chloride electrolyte (added sodium chloride increases conductivity and lowers the melting point of the solution). The scrubber recycles the released chlorine gas from the cell.

Modern plants produce 99% pure magnesium, suitable for immediate casting. Older plants produce 85% pure magnesium and additional refining in crucible furnaces produces higher purity magnesium metal. The crucible furnace heats the magnesium and flux charge to 1100°C (2012°F), the impurities sink and the pure magnesium rises to the top of the melt. The pure metal is then ready for casting into billets, slabs, or ingots.

Chlorinating magnesium hydroxide with hydrochloric acid produces the magnesium chloride used in Dow electrolytic cells. Magnesium hydroxide slurry and a dilute hydrochloric acid react, forming magnesium chloride. Submerged-burner evaporators remove excess water from this mixture, increasing the magnesium chloride concentration. Shelf dryers crystallize (with hot air) the concentrated

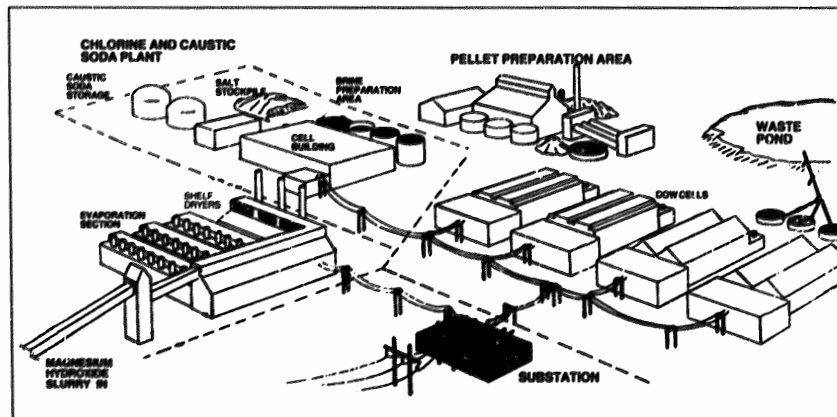


Figure 3.35: Dow Electrolytic Cell Magnesium Production

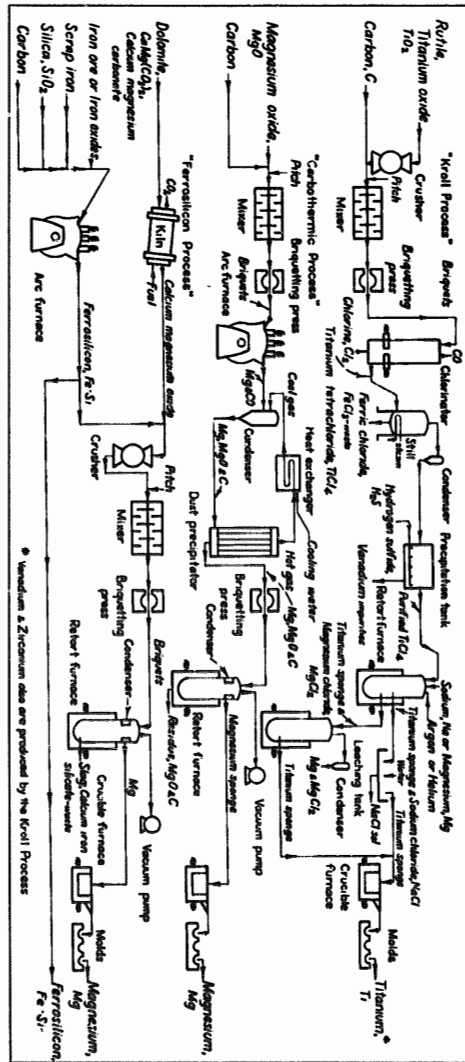


Figure 3.36: Electrothermic Process Flow

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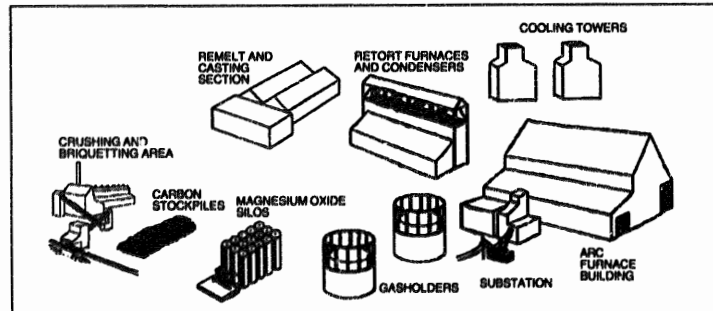


Figure 3.37: Carbothermic Magnesium Plant

magnesium chloride before charging into the Dow electrolytic cells. Associated hydrochloric acid and chlorine and caustic soda plants recover the by-products and produce the raw material necessary for this process.

Briquetted magnesium oxide, mixed with carbon and pitch, produce magnesium metal in the carbothermic (electrothermic) process. Electric arc furnaces reduce the briquettes to metallic magnesium vapor and carbon monoxide. Hydrogen or natural gas rapidly chills the evacuated gases (from the arc furnace). The chilling reduces the amount of magnesium oxide produced in the process by dropping the gases below the critical reaction temperature. Electrostatic precipitators collect the magnesium dust, magnesium oxide, and carbon particles from the condenser. Briquettes (60% to 65% pure magnesium), made from the collected dust, charge a cylindrical retort (equipped with a water-cooled condenser). An electric resistance furnace heats the retort to 750° C (1380° F) under a constant vacuum. The magnesium

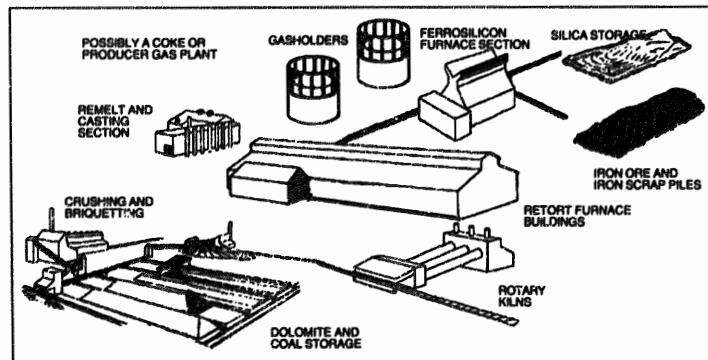


Figure 3.38: Ferrosilicon Magnesium Plant

sublimes and condenses in the top of the retort. After 72 hours the retort is cooled and the magnesium is recovered. Crucibles re-melt the magnesium for casting.

Another electrothermic process, the ferrosilicon process (virtually obsolete) uses calcined crushed dolomite (calcium magnesium carbonate) mixed with ferrosilicon to produce magnesium metal. Electric resistance furnaces (or gas-heated furnaces) heat the dolomite and ferrosilicon mixture (in a retort) to 1150° C (2100° F) under a vacuum. The calcium magnesium oxide combines with the ferrosilicon, forming waste calcium iron silicate and magnesium metal vapor. A condenser at the end of the retort cools the vapor and differential contraction separates the metal from the waste.

Electric arc furnaces at ferrosilicon plants supply the ferrosilicon. A mixture of carbon and siliceous iron ore or scrap iron and silica sand charge the furnace. The furnace reduces the mixture to metallic silicon and iron, which combine to form ferrosilicon. Similar plants using electric arc furnaces produce ferrochrome, ferromanganese, ferrovanadium, and ferromolybdenum.

There are few magnesium plants in the world. Most use the electrolytic process and are difficult to identify. Identifiable components are the chlorinating section, the rectifier annex, and the electrolytic cell building. The chlorinator section is a (40-50 feet) tall building housing the scrubbing towers and chlorinators. Unhoused chlorinator sections look like silos with pipes leading into the tops. The electrolytic cell section is a long narrow rectangular building with numerous roof vents. The rectifier section is a small flat roofed building with or without vents. Normally, a substation is nearby.

These components will be near to, or adjoined, each other. The typical arrangement is the electrolytic cell building in the center with the chlorinator section and the rectifier annex on opposing ends. A titanium plant may be collocated with the magnesium plant (magnesium used in titanium production).

Manganese

Manganese uses include alloying applications in non-ferrous metals such as copper and nickel, in the production of manganese alloy steel, and applications as a deoxidizing agent. Principle manganese ores are pyrolusite, braunite, hausmannite, and rhodochrosite.

Manganese processing methods include reduction or electrolysis of the oxide ore.

Reduction of the Oxide Ore

Ferromanganese (a mixture of 80% manganese and 20% iron) is the result of reduction of oxide ores. A blast furnace or electric arc furnace produces the reduced ore. The charge for the blast furnace includes manganese ore, carbon, and aluminum, magnesium, or sodium. The electric arc furnace charge is manganese ore, limestone, and coke. Both of these processes recover around 85% of the metal.

Electrolysis

Electrolysis yields high purity manganese metal. A roasted ore converts the manganese ore to its oxide (MnO). Leaching the MnO with sulfuric acid (H_2SO_4) yields a sulfate. Neutralization of the solution removes the iron and aluminum by precipitation. Electrolysis of the remaining sulfate solution yields 99.94% pure manganese metal.

Mercury

Mercury ranks in 10th in non-ferrous metal production. Uses for mercury include manufacture of electrical apparatus, use in mercury cells in the processing of chlorine and caustic soda, and paint manufacture. Additional uses are in pharmaceutical and agricultural chemical production.

The main mercury ore is cinnabar. Cinnabar contains 86.2% mercury. Flotation of the cinnabar ore raises the mercury concentration of the rock to 25-50%. Roasting the concentrate releases mercury in the form of gas. A distillation process recovers a condensate with a purity of 95% (for furnace plants) to 98% (for retort plants).

A refining process of distillation or filtering, oxidation, and acid leaching yields mercury of 99.9% purity. Triple distillation yields nearly pure metal for those applications with exacting purity requirements. Secondary recovery of mercury metals, mercury-bearing equipment, and amalgams yield around 20% of the domestic mercury production.

Nickel

Primary uses for nickel are in the production of stainless steel and high-nickel alloys (in the aerospace and steel industries). Additional uses are in nickel plating, castings, coinage, copper or brass product applications, chemical and petroleum industries. High grade nickel sulfide ores (especially pentlandite) are the major source of nickel. Low grade nickel ores occur in lateritic deposits. The nickel sulfide ores commonly occur with copper and iron ores.

Refining for nickel ores consist of pyrometallurgical or hydrometallurgical methods. A separate pyrometallurgical and hydrometallurgical method exist for each type (lateritic and sulfide deposits) of ore. The most common method of refining is the pyrometallurgical method, however, the most efficient method is hydrometallurgical refining. Products include nickel cathodes, pellets, powder, briquettes, ferronickel, nickel oxide, and nickel salts.

Nickel refining methods vary world-wide. In general the production flow for processing involves the following steps. Roasting partially removes sulfides from the ore. Smelting removes rock, leaving a copper-nickel-iron matte. The Bessemer converter removes the iron and sulfur. After magnetic separation and flotation, sintering the remaining nickel sulfide forms an oxide. The oxide is cast as anodes for electrolytic processing to form nearly pure nickel. Also the electrolytic process recovers accessory gold, silver, platinum, and several other metals.

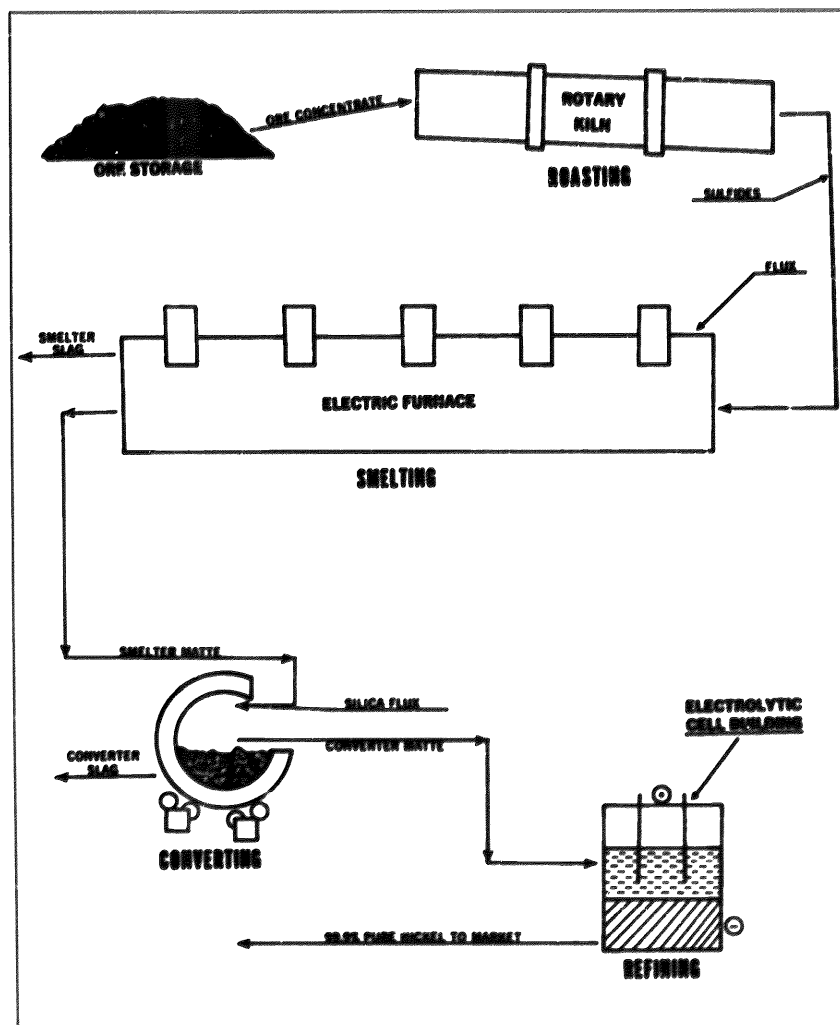


Figure 3.39: Nickel Process Flow

Identification of the Nickel Refinery

Most nickel refineries consist of one or more tall waste gas stacks, an air separation plant, and electrolytic refining buildings. Both types of plants also have smelters and converter buildings. The lateritic ore nickel smelter has, in addition, one or more rotary kilns.

The rotary kilns used in lateritic ore smelting remove sulfur and oxidize the ore. The kilns consist of one or more long parallel tubes with buildings at either end. One building is the charge building, the other building houses the smelter and converter. The kilns slope gently downward in the direction of the process flow.

Roasting and sintering buildings smelt sulfide ores. The tall rectangular gable or flat roofed building has a conveyor leading from the ore storage area.

Smelting and converting buildings are used for all nickel ore processing. This is the tallest and largest building at the refinery. This is an irregularly shaped flat roofed structure with numerous vents or a continuous monitor. Railroad tracks lead from the building to the slag dump. Common smelter types for nickel ores are the electric furnace and the blast furnace. Rotary kilns lead to this building when processing lateritic ores.

Both the sulfide and lateritic ore processing plants use electrolytic refining. The electrolytic refining building is more common at sulfide ore plants. The long rectangular flat roofed building has numerous roof vents or monitors. A substation and rectifier building are located nearby.

An air separation plant is a common support facility. The plant produces nitrogen, oxygen, and argon from the atmosphere. The plant consists of a long rectangular flat roofed compressor building, a tall square (stepped appearance if collocated with the compressor building) cold box, and wet or dry gasometers for gas storage.

Pyrometallurgical Processing of Nickel Sulfide Ores

A multihearth furnace, fluid bed roaster, sintering machine, or rotary kiln partially roasts the sulfide concentrates. Roasting reduces the sulfur content by 50% and produces a mixture of copper-nickel-iron sulfides. Next, a reverberatory furnace, blast furnace, flash smelter, or electric furnace smelt the sulfide and flux mixture, forming an impure copper-nickel-iron matte.

In the converter, the matte and silica flux is blown with air, the silica flux removes most of the iron and some sulfur (as sulfur dioxide), yielding a sulfur deficient copper-nickel matte. After several days of controlled cooling, a grinding and flotation process separate the nickel sulfides from the copper sulfides (allowing separate processing of copper and nickel). Roasting the nickel sulfide yields a nickel oxide sinter for use in the steel industry. Or further reduction by an electrolytic (most common) or carbonyl method yields a purer product.

The electrolytic method involves immersing a crude metal (or nickel sulfides) anode and a thin starter sheet (of pure nickel metal) cathode in the electrolyte. Through electrolytic action the anode dissolves into the electrolyte solution. A purification train removes impurities after the solution are pumped from the cell. The re-introduced purified solution takes ten days to form 99.9% pure nickel metal on the cathode.

The carbonyl (Mond process) process refines the nickel by reacting the crude nickel and carbon monoxide at 100° C (212° F) forming nickel carbonyl. A decomposition tower heats the nickel carbonyl to 200°-300° C (392°-572° F). The decomposed nickel carbonyl deposits as 99.9% pure metal pellets on nickel shot.

Hydrometallurgical Processing of Nickel Sulfide Ores

An ammoniacal solution dissolves the nickel sulfide ores, forming nickel, copper, and cobalt amines. Heating the resulting solution precipitates the copper amines. Oxidation of the cobalt and nickel amines forms sulfates. The sulfate, combined with hydrogen, at high temperature and pressure forms 99% pure nickel metal powder.

Pyrometallurgical Processing of Nickel Laterites

The pyrometallurgical method of processing nickel laterites requires an enormous amount of fuel or electrical energy. Smelting the ore and flux (gypsum) produces an iron-nickel matte. Processing the iron-nickel matte is the same as for the nickel sulfide ores. The converter removes the iron impurities and electrolytic cells refine the nickel.

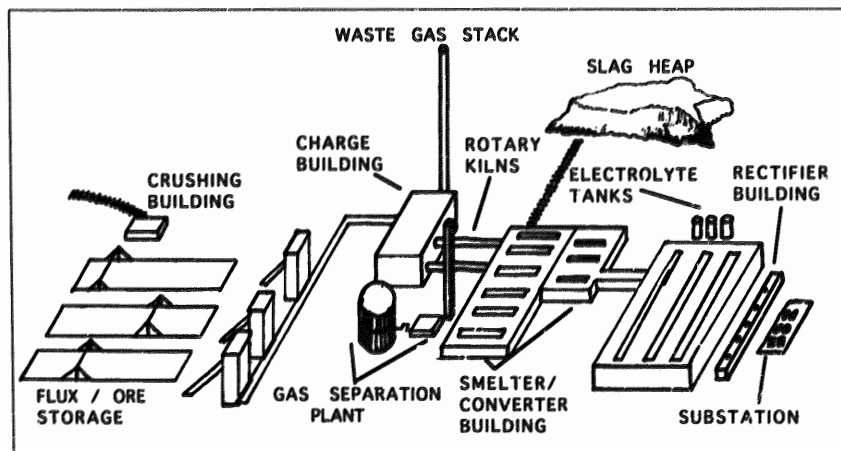


Figure 3.40: Pyrometallurgical Process Nickel Refinery

The production of nickel rondelles is by a roasting process. The roaster produces a nickel oxide from the iron-nickel matte. Grinding, compacting, and reducing (using charcoal in a muffle furnace) the nickel oxide yields 99% pure nickel rondelles. The muffle furnace typically is a long rectangular gable roofed structure with numerous short stacks. The rotary kilns lead into the side of the structure. The production of ferronickel involves smelting the nickel laterite without a flux and reducing the smelt with coke in electric furnaces. The resulting ferronickel has a 20%-50% purity.

Hydrometallurgical Processing of Nickel Laterites

Ammonia or sulfuric acid leaching is the process for hydrometallurgical refining of nickel laterites. The first step in the ammonia process is the reduction of the nickel oxide. Next, ammonia leaches the nickel and dissolves the nickel. Heating the solution precipitates nickel carbonate. Roasting converts the nickel carbonate into a nickel oxide product for use in the steel industry.

In the acid process sulfuric acid leaches the ore at high temperature and pressure. The temperature and pressure differential cause the nickel and sulfur to enter solution but prevents iron from entering the solution. Mixing with hydrogen sulfide precipitates nickel and cobalt sulfides from the purified solution. Refining the resultant nickel sulfide by a conversion process yields nickel sulfate. Reduction of the nickel sulfate with hydrogen produces a high purity nickel powder.

Platinum

Platinum occurs as native metal or more commonly as an accessory ore in nickel-copper sulfide ores. Uses for platinum include alloys for jewelry, scientific apparatus, and electrical contacts. A major use is as a catalyst in industrial applications.

Processing facilities for native metal deposits are basically an ore concentration plant. Refer to the sections on copper and nickel refining for a discussion of secondary metal recovery. The basic process involves smelting the copper-nickel ores, containing the secondary platinum metal. Anodes formed from the smelted material are electrically dissolved. Copper deposits on the cathode, nickel enters solution, and the platinum remains as a slime attached to the anode. Roasting the platinum slime removes the sulfides. Leaching removes any residual copper and nickel and the platinum precipitates from solution. Washing and drying the precipitate allows the material to be calcined to form nearly pure platinum metal.

Silver

Silver occurs as native metal, silver chloride ores, and simple or complex silver sulfide ores (as associated minerals with lead, copper, and zinc ores). Principle industrial uses for silver include photographic film, electrical contact, alloys, chemical, and battery manufacturing. Additionally silver finds uses in jewelry, sterling silver, mintage, and art.

Historically, silver processing included simple ore concentration of native metal, and amalgamation and cyanidation ore concentration and recovery. Modern silver processing is by secondary recovery from copper, zinc, and lead ores.

A typical process for silver recovery involves separating the copper, zinc, and lead ores. The silver ore is also separated if the silver grade is high enough. Otherwise, smelting of the lead and copper ores produces mattes, from which through electrolytic refining, the silver is recovered. When associated with copper and lead refining, look for an area containing electrolytic vats and refinery. This area may not be separate from the rest of the refinery but may be incorporated in the rest of the complex.

Leaching and electrolytic processes are used for the zinc ores. Processing of the residues of the electrolytic plant produces silver metal. When associated with zinc refining, look for a leaching area and an electrolytic vat building.

Refer to the sections on refining of copper, lead, and zinc for a more detailed explanation of these processes and components.

Tin

Tin ores occur as tin oxides and tin sulfides. The main uses for tin are in tin plating, alloys, solders, and chemical production.

Secondary tin recovery is much more extensive than the primary metal production. Tin recovery (from recycled materials) is through electrolytic or chemical methods.

Primary metal production of oxide ores is through ore concentration, roasting (forming oxides), and crude metal recovery from a blast furnace. Additional refining occurs in electrolytic furnaces.

Titanium and Associated Electrothermic Metals

Titanium, vanadium, zirconium, and their alloys are extremely strong materials able to withstand high temperatures. Steel production (ferroalloys) uses most of the titanium, vanadium, and zirconium production. The aerospace, military, chemical, and tool industries use these alloys in equipment production. The paint and pigment industries use titanium dioxide. The primary titanium ores are rutile and ilmenite. Almost all commercial deposits (at least at present) occur as rutile bearing sands. Dredges mine the sands; then gravity, magnetic, and electrostatic concentration methods yield a 95% purity titanium dioxide for additional processing.

Titanium, vanadium, zirconium, and magnesium collectively are referred to as electrothermic metals, due to the method used in processing the ores. Titanium, vanadium, and zirconium metals have a high affinity with oxygen. The ores of these metals require reducing (of their chlorides) at high temperature in a vacuum (or an inert atmosphere). The Kroll process produces titanium, vanadium, and zirconium. Titanium oxide, carbon, and chlorine react in a chlorinator, forming titanium tetrachloride in an exothermic reaction. Titanium tetrachloride and

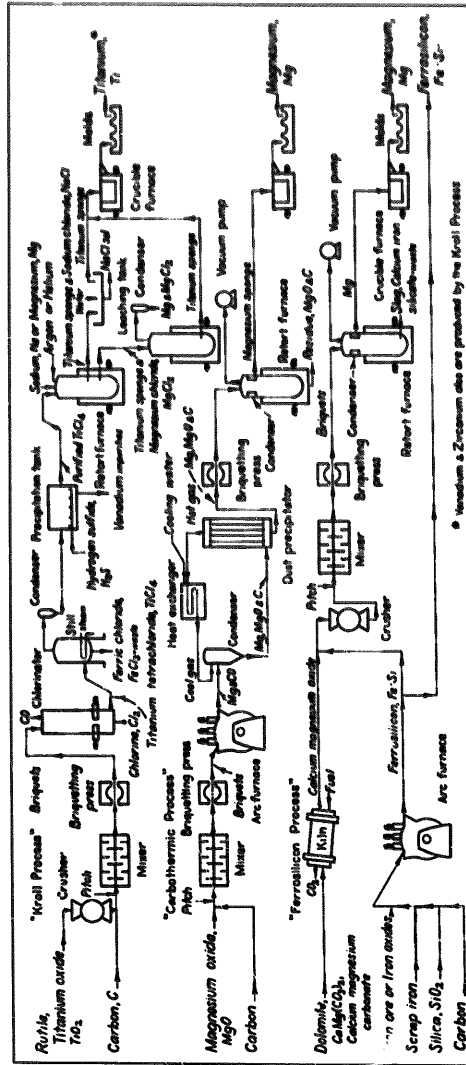


Figure 3.41: Electrothermic Metal Production

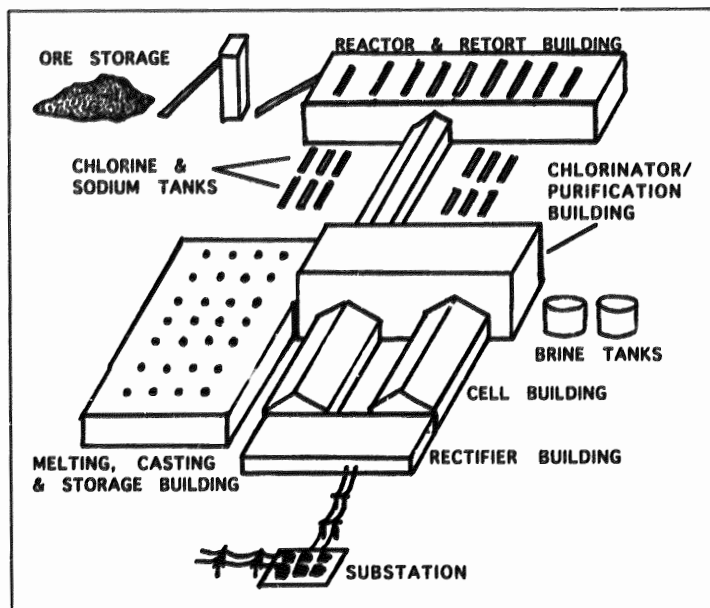


Figure 3.42: Titanium Production

metallic sodium (or magnesium) reduce at 50°C (122° F), producing titanium metal sponge and sodium chloride (or magnesium chloride). When magnesium is used, the resulting magnesium chloride by-product is recycled through electrolysis for re-use in processing. A third method of titanium production is the direct electrolysis of titanium tetrachloride.

Zinc

Zinc metal is fourth in annual consumption and use. Major uses of zinc are in zinc metals and alloys, protective coatings, and chemical compounds. Zinc oxide uses include applications in chemical, rubber, and paint production. Zinc usually occurs in conjunction with lead ores as lead and zinc sulfides (sphalerite and galena). Secondary recoverable minerals to the lead-zinc ores include copper, silver, antimony, and bismuth. Zinc ore is separated from lead ore at the concentration plant located at the mine. The ores are finely ground and the ores separate by froth flotation. Whichever ore is not separated first is separated from the gangue by a second froth flotation pass. Two smelting methods of processing zinc are the oxide reduction and the combined lead-zinc processes.

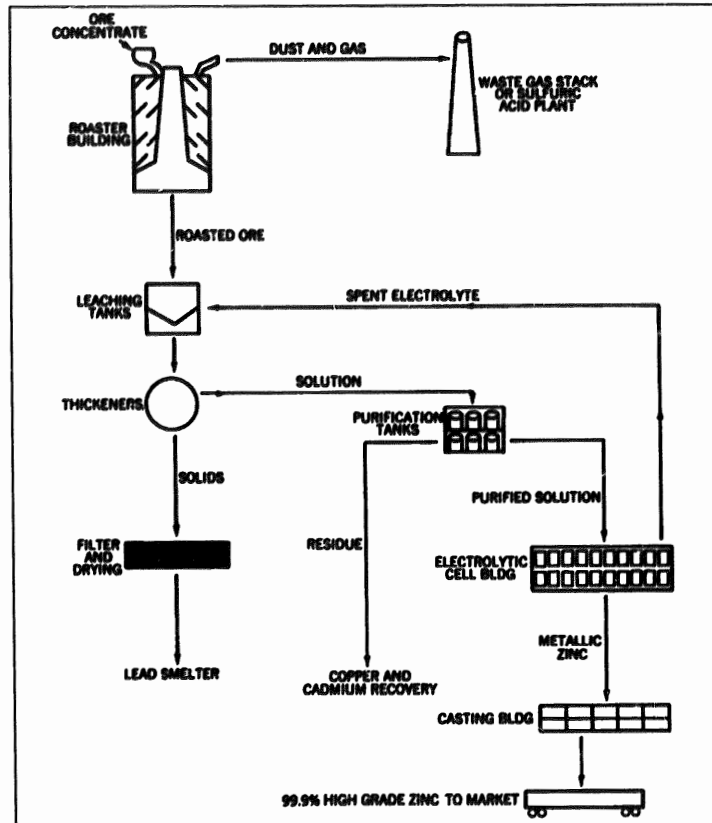


Figure 3.43: Electrolytic Zinc Flow

The horizontal retort process is the oldest zinc smelting method, still accounting for 10% of world production. Small horizontal retorts roast the zinc ore. Coal is mixed with the concentrate and the mix is heated for 1-2 days. The zinc, in the form of vapor, is condensed and recovered. Several hundred retorts will be required in the process. A newer horizontal retort process uses fluid-bed roasters or sintering furnaces in place of the hundreds of smaller retorts. The vertical retort process is much less labor intensive than the horizontal retort method. In the vertical retort process, zinc sulfide ores mixed with coal are briquetted and charged into the vertical retort furnace. The continuous process is heated by gas,

driving off zinc vapors for condensation. A newer process uses an electric shaft furnace. Here, the roasted and sintered zinc ore is mixed with coke and fed to the furnace. The electric arcs melt the ore, freeing zinc vapor.

The two methods for simultaneously processing zinc and lead ores are the Imperial Smelting Process (ISP) and the Kivcet Process. The ISP uses a blast furnace to produce the zinc vapor and the lead is reduced at the same time. The Kivcet Process has finely ground lead, copper and zinc sulfides heated in a cyclone furnace by burning the ore with a stream of oxygen. The lead is reduced and collected. The zinc, mixed with slag, is reduced to zinc oxide vapor in an electric furnace. The oxide is reduced by carbon and the zinc vapor is condensed. The copper is recovered as a matte formed with the sulfur in the reactions, and is then reduced.

Plant Identification

Most zinc metal reduction occurs at an electrolytic plant. Key identifiers are the Cottrell precipitator building and stack, a stepped leaching and purification building, electrolyte tanks, and the electrolytic cell building with associated rectifiers and substations. The roaster building is a tall gable roofed structure with a continuous monitor. The roaster has conveyors leading from the ore storage and handling areas and flues leading to the sulfuric acid plant or waste gas stack. Often the plant is located on a hillside to take advantage of gravity during the production process. Associated with the plant may be a sulfuric acid production plant.

The leaching and purification section is a large stepped roof structure located below the roaster. The upper sections contain the leaching tanks and the lower sections contain the purification tanks. The upper section has numerous short stacks or vents. The structure also houses the thickeners and filters.

The electrolytic cell is a very large low building with vents or continuous monitors. Pipelines connect the leaching and purification building and the electrolytic cell building. Also present are substations, rectifier annexes, and electrolyte tanks (open or closed).

The casting building is a moderate sized gable or flat roofed structure with numerous vents or monitors. It is found adjacent to or near the electrolytic cell building. If the plant is on a hillside, the casting building will be the lowest structure. Storage and loading facilities are nearby.

Reduction can occur also at horizontal or vertical retort smelters. A pottery plant will be nearby for the horizontal retort smelter. Look for baghouses, waste gas stack with flue system, sulfuric acid plant, and slag piles. Zinc oxide may be produced by several processes. Look for buildings with rotary kilns, flue complexes, baghouses, and cooling columns. Zinc refining is accomplished using a reverberatory furnace (probably an additional building in the plant) or in distillation columns.

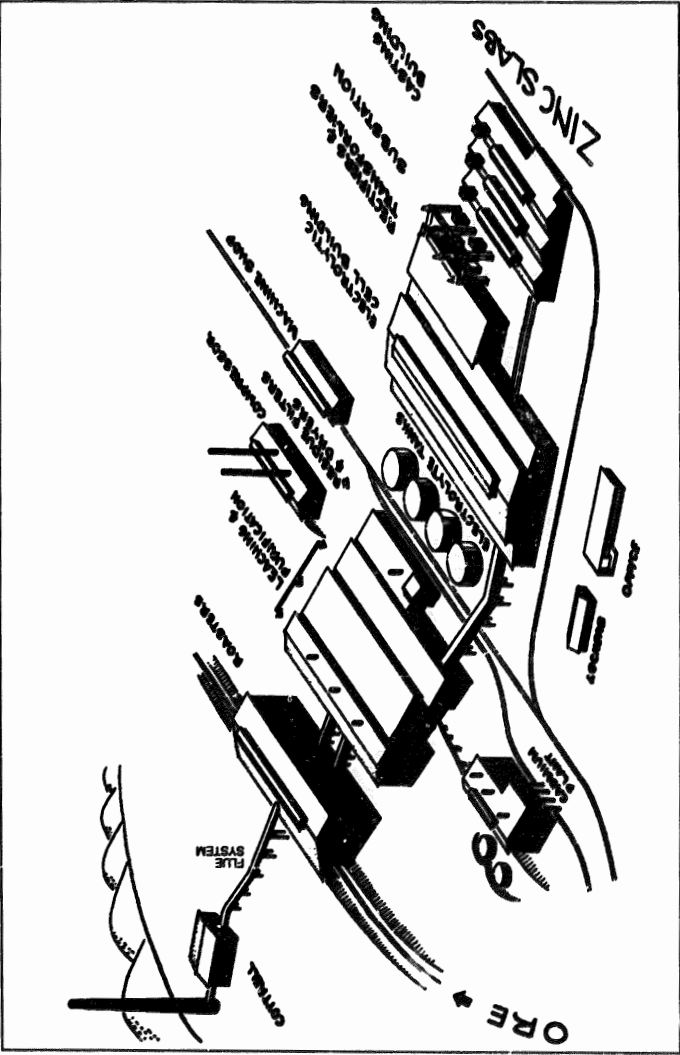


Figure 3.44: Electrolytic Zinc Plant



The Electrolytic Process of Zinc Production

Several processes can be used to convert the concentrated zinc ore into metallic zinc. Among the processes are electrolytic, horizontal retort, vertical retort, sterling, electrothermic, blast furnaces, and the American process. The most common process is electrolytic process which produces 75% of the world's zinc metal.

The first step is roasting, converting the zinc sulfide into zinc oxide, and ridding the ore of its sulfur content. The three roasting methods are the multiple hearth furnace, the fluid bed roaster, and the least common, the flash furnace. Refer to the section on copper roasting for a furnace operation description for the fluid bed and multiple hearth roaster. The flash roaster consists of two top hearths, two bottom hearths, and an open combustion chamber between the hearths. The concentrated ore passes through the feeder and dryer hearths to a ball mill where the ore is ground to a fine dust. The dust is returned to the combustion chamber, through burners situated below the drying hearths. The zinc ores burn to zinc oxide and waste sulfur dioxide gases. The zinc oxide exhausts through the bottom hearths. The sulfur dioxide can be wasted to the atmosphere or recovered at a sulfuric acid plant. Dust, associated with the waste gases, is high in cadmium (recovery at an associated processing section). Three methods can remove the cadmium dust from the gases. They are an electrostatic precipitator (Cottrell or other type), a bag house, or an expansion chamber built into the flue system. The most common and most efficient method is the precipitator.

Next the zinc oxide is mixed with 10%-25% sulfuric acid in leaching (and agitating) tanks. The piped slurry separates by gravity in thickening tanks. The solids are removed, filtered, dried, and sent to a lead smelter. The settled solids contain recoverable lead, gold, and silver. Purification tanks process the zinc sulfate solution. Added zinc dust and aluminum cause the precipitation of impurities such as cadmium, copper, cobalt, ammonia, and arsenic.

The refinery section consists of electrolytic cells. The cells use lead anodes and aluminum cathodes. Metallic zinc deposits on the cathodes as direct current passes through the zinc sulfate solution. The casting section of the plant strips the cathodes and casts the 99.9% pure zinc metal.

Zinc Smelting Processes

Several smelting processes also produce zinc metal from concentrated zinc ores. The three common zinc smelters are the horizontal retort, the vertical retort, and the electrothermic furnaces. The typical smelter uses roasters and sintering machines to prepare the ore for the smelter. The basic process for smelting is the same. The charge for the smelter, prepared in the charge mixing building, heats above 907° C (1665 F) in the smelter. Carbon from the coke in the charge burns, forming carbon monoxide. The carbon monoxide combines with the liberated oxygen from the zinc oxide, yielding carbon dioxide. The reduced metallic state zinc vaporizes and after cooling, forms molten zinc for casting or further refining.

Horizontal Retort Zinc Furnace

The horizontal furnace is a batch operation smelter. The retorts are cylindrical clay retorts which have open-ended conical clay condensers. A nearby pottery plant produces the retorts and condensers. The retorts, suspended in rows in gas-fired furnaces, heat for several hours. Blue dust (cadmium) collects in the condensers during the first few hours. The cadmium recovery section processes the recovered cadmium dust. As the zinc reduces, it vaporizes and passes into the condensers. The condensers collect the molten zinc. During the 24 hours required to fully process the charge, the molten zinc is typically collected 3 times. After processing the charge, the removed retorts yield slag for disposal or further processing.

Vertical Retort Zinc

The vertical retort furnace is a continuous operation. Baked briquettes composed of zinc, water, and a suitable binder form the charge for the gas-fired furnace. The reduced zinc collects in condensers and sumps as molten metal.

Electrothermic Furnace Zinc

The electrothermic furnace is also a continuous operation. A special sintering for the roasted ore concentrates provides an extremely pure charge for the furnace. The sintering involves drawing air down through the sinter cake mixture of ore and coke. The process frees any remaining sulfur. Lead and cadmium concentrate in the lower half of the sinter cake. Repeated sintering of the lower half yields pure zinc.

The sintered concentrates, silica flux, and coke form the charge for the continuous operation furnace. Electrical resistance heats the charge to the required temperature for reduction and vaporization. Cooled and condensed vapor yields the molten zinc metal for casting.

Zinc Refining

Electrothermic and electrolytic zinc do not require additional refining prior to use. The output from horizontal and vertical retort zinc requires refining prior to some uses.

Reverberatory Furnace

The reverberatory furnace maintains the temperature of the molten zinc above the melting point for one to three days. During this time zinc oxide and other impurities rise to the surface as dross for removal and recycling in the retort furnaces. Iron and lead impurities sink to the bottom for removal and recovery. Refined zinc is tapped and cast.

Distillation Columns

Distillation columns are sets of stills for refining the zinc. In the first column (kept above the boiling point of zinc) zinc oxide, iron, and lead remain in the liquid and solid phase. These impurities collect in the bottom of the column and are removed for recovery. The volatilized zinc passes into a second column

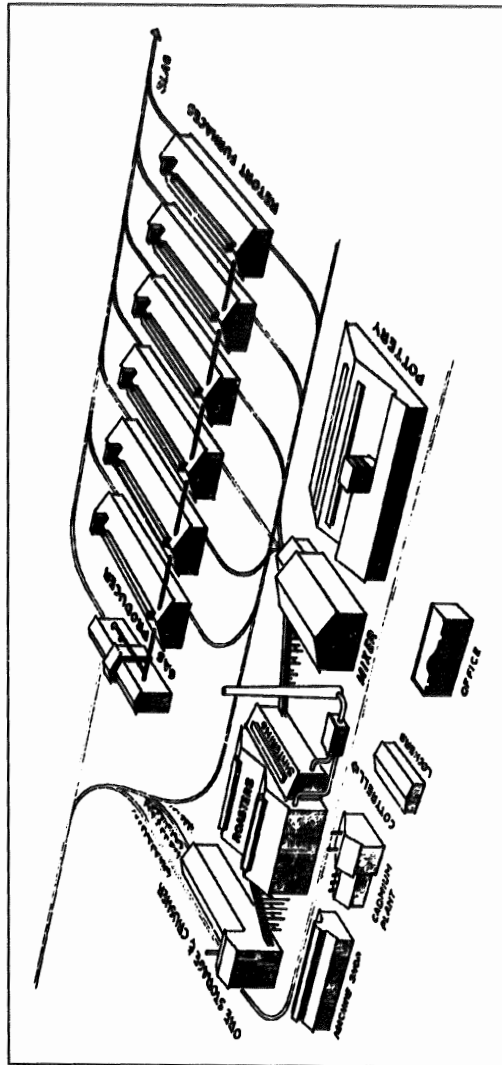


Figure 3.46: Horizontal Retort Zinc Plant

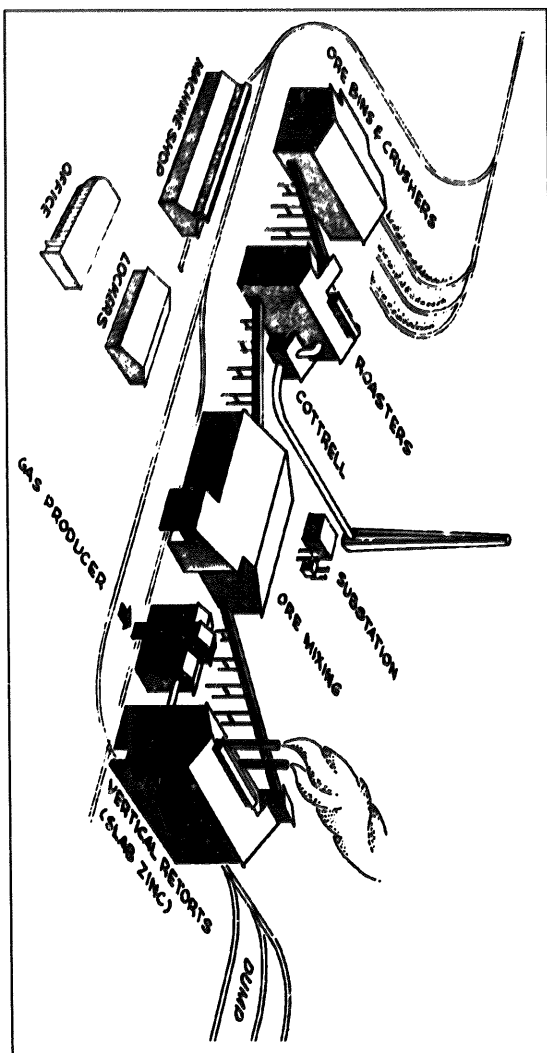


Figure 3.47: Vertical Retort Zinc Plant

maintained above the boiling point of cadmium. The cadmium passes into condensers for recovery. The zinc condenses in the column as molten zinc metal for removal and casting.

Zinc Oxide Production

Roasted and sintered zinc concentrates are the primary source of zinc oxide. Metallic zinc, lead smelter slag, and retort furnace slag also are a source for zinc oxide. Several methods produce zinc oxide but the basic process is the same.

Raw material, mixed with coke, charges the furnace. Vaporized heated zinc burns in the furnace and oxidizes. The oxidation forms small aerosol particles of the white zinc oxide. The zinc oxide particles, drawn through cooling flues into baghouses or electrostatic precipitators, can then be recovered. Baghouses are buildings containing numerous cloth bags suspended over hoppers. The zinc oxide particles adhere to the cloth material and, after shaking, fall into the hopper for recovery.

American (Wetherhill) Process

The American process uses roasted and sintered zinc concentrates in the production of zinc oxide. The American process has two operational types, a batch and a continuous process. The batch furnace (heated from the base and charged from the top) heats and vaporizes the charge. The zinc oxidizes in the upper portion of the furnace. Withdrawn zinc oxide particles are recovered.

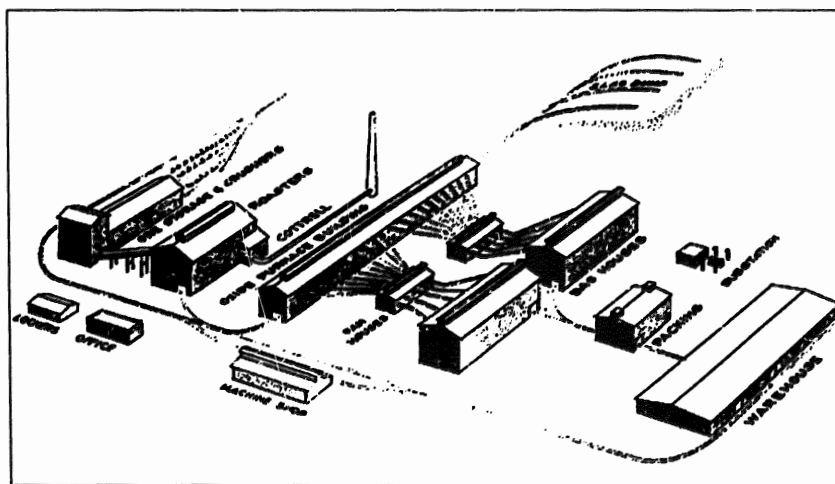


Figure 3.48: American Process Zinc Oxide Production

The continuous process furnace is essentially a moving grate sintering furnace. The charge passes through the combustion chamber and the vaporized zinc oxidizes. Collected zinc oxide is graded and bagged.

Electrothermic Oxide Furnace

The electrothermic oxide furnace operates in the same manner as the electrothermic zinc furnace. The electric current reduces and vaporizes the charge. The vaporized zinc burns in the air.

Waelz Process

Low grade oxide ore, slag from zinc retorts, and slag from lead smelters provide the charge for the rotary kilns in the Waelz process. The kiln processes the charge, producing zinc oxide for collection from the lower end. By controlling the temperature, pairs of kilns can produce both zinc and lead oxides. Keeping the temperature of the first kiln above the boiling point of zinc but below the boiling point of lead produces zinc oxide only. The second kiln, kept above the boiling point of lead, accepts the discharge of the first kiln and yields lead oxides. Operating kilns above the boiling point of both lead and zinc produces leaded zinc oxide.

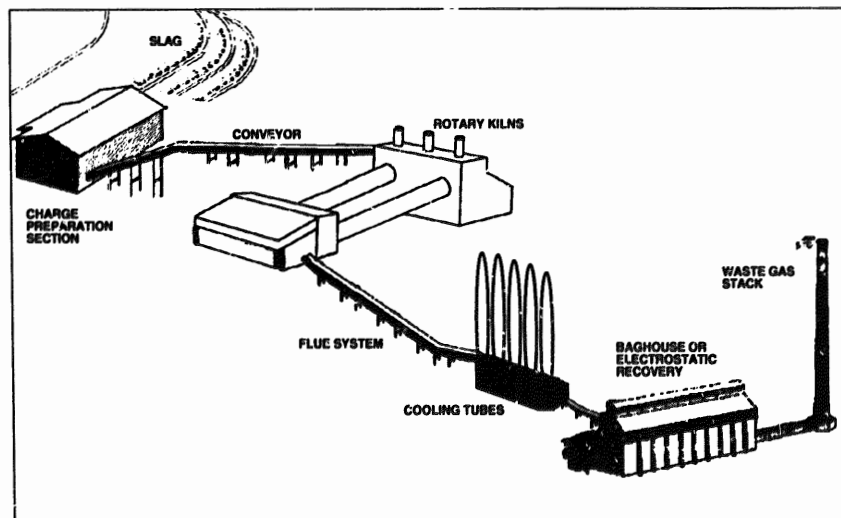


Figure 3.49: Waelz Zinc Oxide Plant

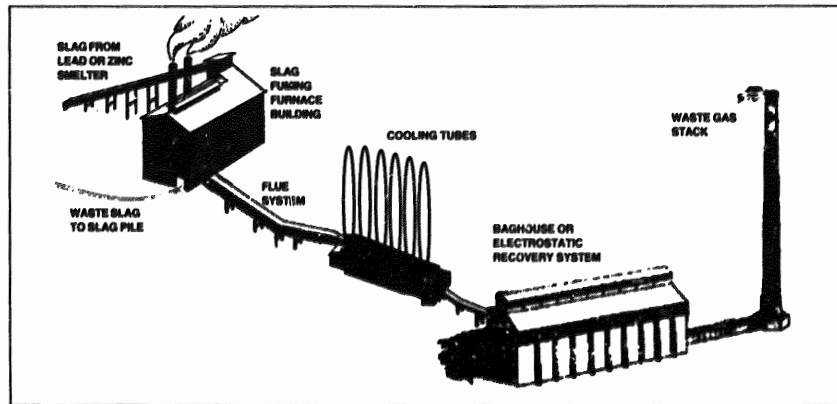


Figure 3.50: Slag Fuming Plant

Slag Fuming Furnace

Slag from lead smelters provides the raw material for the production of leaded zinc oxides in slag fuming furnaces. The slag fuming furnace is similar to the vertical retort furnace. Heating above the boiling point of lead yields zinc and lead vapors. The oxidized vapor produces leaded zinc oxide.

French Process

Broken slabs of metallic zinc are the charge for the French process. Closed retorts heat the zinc in an atmosphere of carbon monoxide. The vapor burns in the air at the open end of the retort and forms zinc oxide.

By-Products Recovery

Cadmium is the chief accessory metal recovered at zinc plant. Other accessory elements are indium, gallium, and germanium. Sources of the cadmium are roaster and sinterer dust, condenser residue, purification tank precipitates, and zinc sulfate sludge. Three methods recover cadmium, depending upon the source. They are the wet method, the retort method, and the electrolytic method.

The wet method recovers cadmium from roaster and sinterer dust. Leaching and agitating the dust with sulfuric acid forms a slurry. Filtering removes solids leaving a clear electrolytic composed of sulfuric acid and cadmium sulfate. Zinc dust, added to the slurry in lead-lined tanks, precipitates the cadmium. Retorts heat the dried briquetted cadmium past the vapor point of cadmium. Condensers recover the molten cadmium.

The retort method uses cadmium containing material mixed with coke. Heating the retort yields vaporized cadmium for condenser recovery.

The electrolytic method of cadmium recovery is similar to electrolytic zinc processing. Electrolysis recovers metallic cadmium from a cadmium sulfate solution.

Zinc slag and spent electrolytic solution contains recoverable amounts of lead, silver, and gold. Lead smelters recover these metals. A sulfuric acid plant recovers sulfur compounds.

Radioactive Materials

The use of radioactive materials is widespread. Medicine, industry, fabrication, power, and weapon industries use radioactive materials. Radioactive elements (isotopes) exist both naturally and artificially. Examples of naturally radioactive materials are barium, uranium, thorium, radium, bismuth cobalt, cesium, and polonium. The production of artificially radioactive isotopes is by the bombardment of the parent isotope by alpha particles, deuterons, or neutrons (using a chemical or mechanical particle source). Examples of artificial isotopes are iodine, iridium, bismuth, plutonium, xenon, strontium, phosphorus, potassium, gold, cesium, californium, sodium, and yttrium.

The use of radioisotopes in medicine includes diagnosis and treatment of disease, radioactivation and tracer usage, radionuclide imaging, and radiopharmaceutical production. Some industrial uses are in food preservation, polymerization of plastics, analytical testing and measurement, as tracer materials, and the process instrumentation measurements of mass, density, thickness, and moisture content.

The production of radioactive isotopes (with the exception of uranium and plutonium) has no definitive signature. Isotope production occurs by irradiating the parent material in a small non-power production reactor. The neutron flux from the reactor transmutes the parent material into a radioactive daughter. Standard chemical and physical techniques separate the isotopes. These facilities look like any other plant using chemical processing methods. The associated buildings have sophisticated dust and air handling equipment.

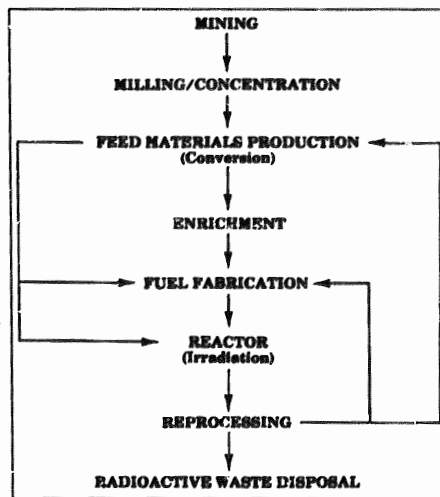


Figure 4.1: Uranium Flow Cycle

Uranium Production

The main use for uranium is in power generation. Uranium has limited use in construction of nuclear weapons (nuclear weapon tamping material and as a secondary in H-bombs). Depleted uranium (low in ^{235}U , therefore lower in radioactivity) finds use as weights in industrial applications, armor for military uses, and as solid penetrator elements in conventional weapon design (mostly anti-armor rounds). The three natural isotopes of uranium are ^{238}U (9.28%), ^{235}U (0.71%), and ^{234}U (0.006%). The isotope ^{235}U forms the basis (slow neutron fission) for gun-type atomic weapons (of historical importance only, modern weaponry uses implosion). Modern fission weapons do not require ^{235}U as the primary element. Uranium can form the basis for the secondary fission element in fission-fusion-fission (H-Bomb) devices.

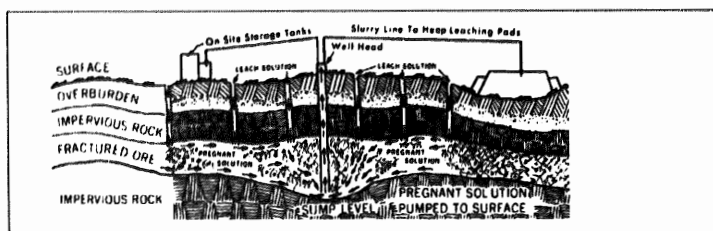


Figure 4.2: In Situ Mining

Natural uranium occurs as oxides (U_3O_8) in association with gold, copper, and phosphate ores. Uranium ores are classified as primary (un-oxidized) and secondary (oxidized) ores. Important primary ores include Uraninite and Coffinite. Important secondary ores include Carnotite and Autunite. Some secondary ores contain phosphates. Traditional mining methods are used to extract most uranium and thorium ores. The most common methods are surface mining through open pit or strip mining or underground mining through vertical shaft or adit.

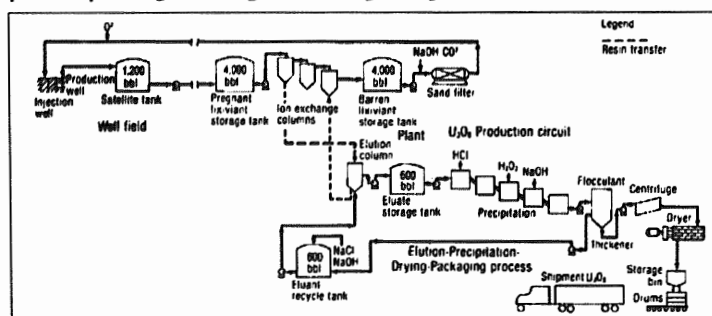


Figure 4.3: In Situ Leachate Recovery Process

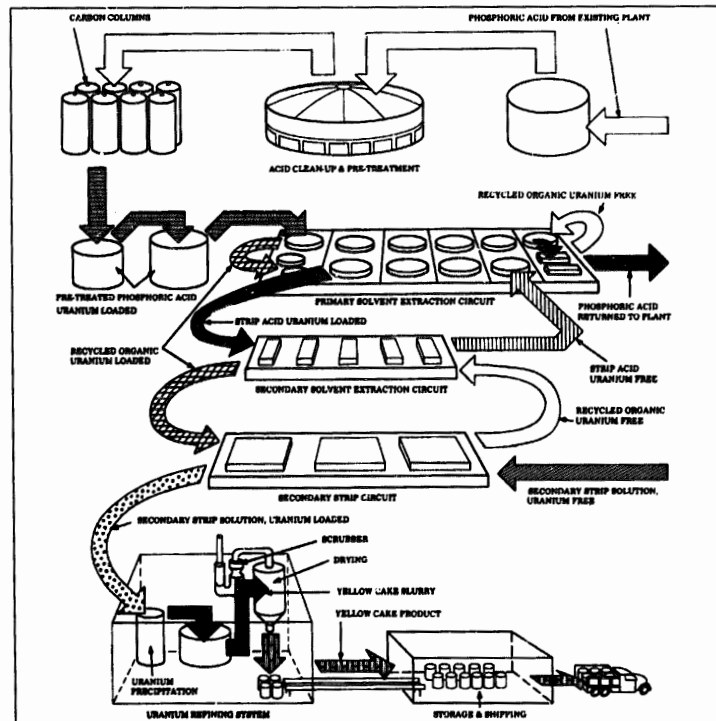


Figure 4.4: Uranium Recovery from Phosphoric Acid (Phosphate Ores)

In situ mining methods can be used in some cases. In situ mining involves blasting the ore into fragments followed by injection by sulfuric acid. The sulfuric acid leaches the uranium, collects in a sump, and is pumped back to the surface. The slurry collects in the shallow rectangular leaching pads. A processing plant then recovers the uranium from the sulfuric acid slurry. One advantage of this method is the prevention of radon gas exposure to the miners. Some mines use leaching methods to recover additional uranium from mine tailings. In addition to uranium mining as the primary ores, some mines producing gold or phosphate ores produce uranium ores as an accessory mineral. In these cases the uranium recovery will occupy only a small portion of the ore processing plant.

The production of uranium metal from oxide ores is an intensive and expensive process. The component plants of the processing chain (for fissionable materials) are geographically dispersed. This prevents the loss of more than one segment in the chain due to catastrophic accident.

Ore Concentration and Treatment

The uranium concentration in the ore is extremely small and large amounts of ore must be processed during recovery operations. Because of the large amounts of ore, the preliminary processing plants are located near the uranium mine. Normal ore concentration methods will not work with uranium ores because of insufficient difference in the physical properties of the constituents. Essentially the entire ore is treated by extraction methods, recovering the uranium. Preliminary treatment of the uranium ore is crushing, grinding, leaching (acid or alkaline leaching), separation, precipitation, thickening, and filtration.

The ore concentration process varies on the type of ore, concentration of the ore, and the age (or sophistication) of the facility. The first step in ore treatment is through primary (jaw or gyratory), secondary (cone), and possibly tertiary (cone) crushers. Next the crushed material is further reduced through grinding (rod and ball mills). The crushed ore can be separated using several methods.

Primary uranium ores are usually separated using leaching, flotation, or a combination of both. Of course, uranium slurry produced from in situ mines will not have associated crushing and grinding sections. The ores will be leached in large open leaching tanks or in pachucas (pressurized vessels) in the concentration building. The ore is treated by an acid or alkaline leach solution. The pachucas treatment is indicated by the lack of roof vents and stains on the concentration

roof. Open tanks will stain the roof through the required roof vents.

Flotation separation occurs in flotation cells located in the concentration building. The flotation cells treat the ore sequentially until no recoverable ore is left. These buildings usually have a stepped appearance. Settling tanks and thickeners remove the concentrates. Next, either solvent extraction or an ion exchange process recovers the uranium from the chemicals used during either of the concentration processes.

An ion exchange method can also be used to purify the uranium slurry. The slurry is neutralized and the solids removed for disposal. The enriched liquid passes through ion exchange units. The ion exchange units consist of an absorption column, a measuring chamber, a rinse chamber, and an elution column. After passing through the ion exchange unit, mixing with lime

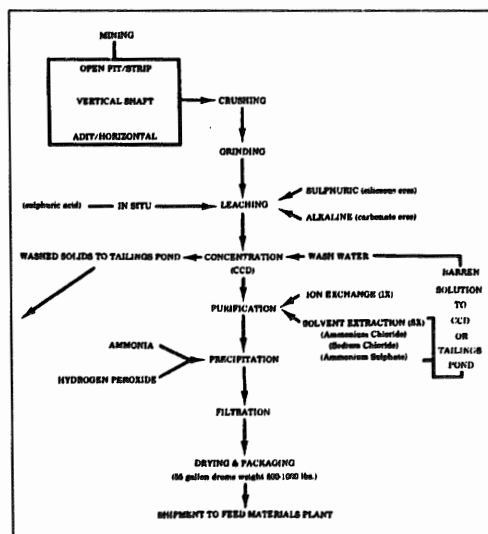


Figure 4.5: Uranium Concentration Flow

precipitates iron hydroxide from the liquor. The uranium, mixed with ammonia in thickeners, forms uranium yellow cake, which is then filtered and dried before further processing. Handling of the uranium yellowcake is usually performed by remote control in a separate building. The packaging building is an enclosed isolated structure usually under negative air pressure to maintain adequate control of uranium dust. The material typically is handled under a vacuum to prevent oxidation.

The concentration plant consists of multiple extensive tall single story structures. The storage yard (usually) is stockpiles of metal drums containing both the ore and the finished yellowcake. Uranium storage is in 800-1100 lbs drums. Ore crushing facilities are typical, with the addition of extensive dust handling equipment. Chemical storage tanks, thickeners, separators, and vats are visible. Since the tailings are a health hazard, extra care will be taken in disposal. The tailings are usually disposed into lined pits (ponds) and the filled ponds will be covered with impervious material and fill. Often the concentration plant tailings are re-deposited back into the mine for disposal (when the mine and plant are collocated).

Solvent extraction can be used to recover the concentrated uranium from the reagents used during separation. Sodium chloride, ammonium chloride, or ammonium sulfate are added to the solvent depending upon the impurities co-extracted during the solvent extraction.

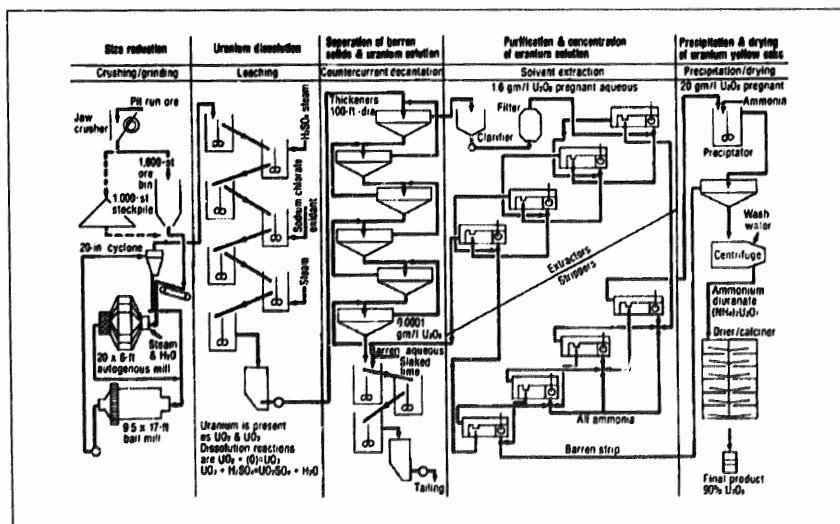


Figure 4.6: Basic Concentration Processes

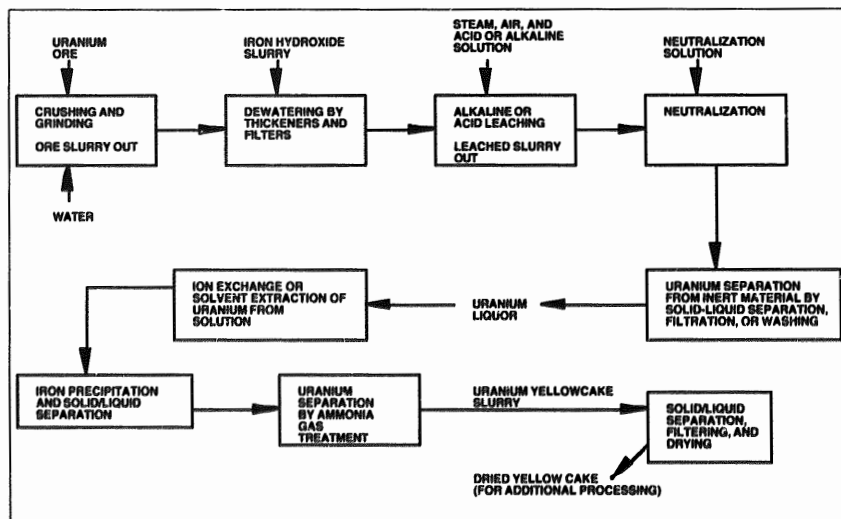


Figure 4.7: Uranium Ore Concentration By Ion Exchange

Feed Materials Plant

Uranium yellowcake (intended for nuclear fuel) undergoes additional processing at the feed materials plant. The feed materials plant converts the yellowcake into metallic or gaseous uranium. Uranium in gaseous state can be sent to enrichment facilities for processing. Metallic uranium can be used in the fabrication of reactor fuel, weapon use, or industrial non-nuclear applications. Reactor fuel material can be in the form of natural (non-enriched) uranium, enriched uranium, or even depleted uranium. Some reactors use a fuel composed of a mixture of uranium and plutonium (breeder reactors that produce additional plutonium).

Wet solvent extraction using ether or fluoride volatility processes are used to refine the yellowcake. In the wet solvent method (conventional processing), uranium yellowcake, mixed with nitric acid and filtered, forms uranyl nitrate. Heating uranyl nitrate (diluted with 50% nitric acid) to 100° C (212° F) in the presence of manganese yields a solid precipitate. Solvent extraction (by ether) produces a pure uranium metal (containing all the isotopes of uranium). At intermediate stages in the processing, the UO_2 may be diverted to produce reactor fuel.

The fluoride volatility process (dry hydrofluor process) produces extremely pure UF_6 . The feed is treated in fluid bed reactors with hydrogen or ammonia to form uranium dioxide (UO_2). The UO_2 is processed in fluidized bed reactors with anhydrous hydrogen fluoride to produce UF_4 . Fluidized bed fluorinators and

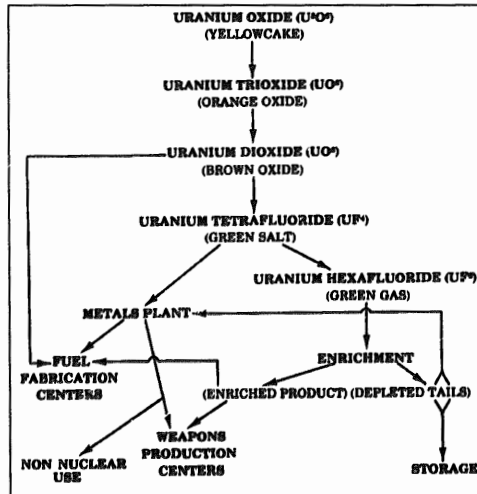


Figure 4.8: Feed Materials Production Flow

contact with elemental fluorine and calcium fluoride process the UF_4 into UF_6 . Distillation columns purify the UF_6 . After the fluorination process, the UF_6 is filtered and desublimed in heat exchangers. This causes the formation of solid UF_6 at room temperature and pressure (below 56.5°C [133.7°F]) for temporary storage in large cylinders or tanks. The solid UF_6 is sent to vaporizers and on to distillation columns to allow the production of highly pure UF_6 . The purified UF_6 is stored indefinitely in storage containers (holding around 14 tons) before shipment to the uranium enrichment facilities. The containers are stored in open outside yards and are a critical identification feature of uranium hexafluoride production facilities. The containers are overpacked within a second container for safety during shipment.

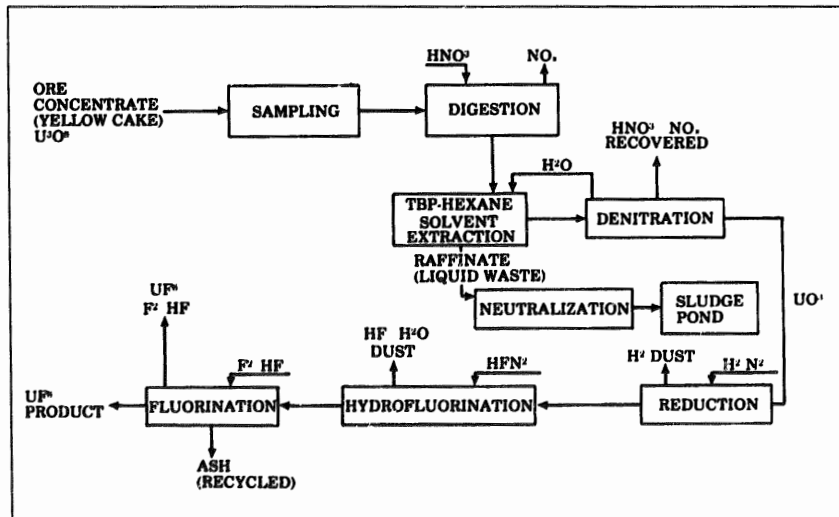


Figure 4.9: Wet Solvent Extraction

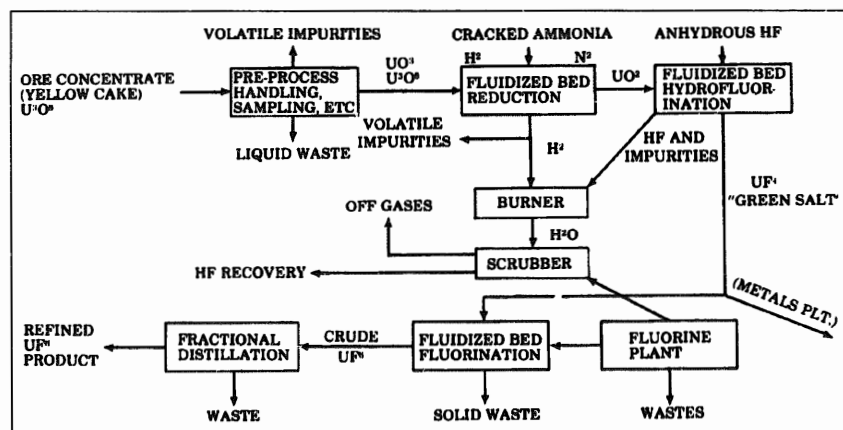


Figure 4.10: Fluoride Volatility Extraction

Metals Production

Metallic uranium can be produced using fused-salt electrolysis or reactive metals reduction. Natural uranium can be converted directly to the metallic form after shipment from the feed materials plant. Production from enriched or depleted uranium starts with the UF_6 from the enrichment (isotope separation) plant. The gaseous UF_6 is converted to the solid UF_4 by hydrogen contact. This results in the conversion of UF_6 to UF_4 and HF.

The electrolysis process produces a high purity metal. The electrolysis bath is a solution of fused-salt sodium and calcium chloride using a molybdenum cathode. The electric current causes metallic granules of uranium to collect on the cathode. The granules are stripped off, pressed and sintered, or melted into solid metallic uranium.

Most of uranium metal is produced from UF_4 by the reduction process. The refractory charge is UF_4 (green salt) with a calcium or magnesium reducing agent. The dolomitic refractory vessel is heated until an exothermic reaction occurs, melting the charge. The molten uranium metal collects below the slag until solidification and removal. A calcium reducer reacts at room temperature while a magnesium reducer requires preheating. Magnesium and uranium are heated in a "bomb" until the charge ignites. The magnesium method produces higher quality "biscuits" (also called "derby" or "dingot") or uranium masses.

Uranium ingots are commonly prepared from the biscuits by vacuum induction melting. The ingots are machined and handled using conventional metal fabrication methods. The fabrication plants, unless collocated within the nuclear industry, have no particular signature.

Processing facilities for the metal (especially if producing fuel elements) are electric furnaces (housed in tall single story buildings) and nitric acid storage. The finished fissionable uranium metal must be handled carefully to prevent the formation of a critical mass. Critical mass is the amount of material required for fission to occur. For uranium (^{235}U), 8 kg (18 lb) is near critical mass for untamped material, 4.5 kg (9-10 lb) for uranium tamped (surrounded) by a suitable neutron reflector. Critical mass for plutonium (^{239}Pu) is much smaller, around 4.5 kg (10 lbs).

Separation of Uranium Isotopes (Enrichment Processes)

Uranium in the natural state primarily consists of two isotopes. The isotopes are U-238 at 99.3% and U-235 at .7% occurrence. In order to use uranium as a reactor fuel or in weapons applications, the U-235 content must be increased. However, breeder reactors using plutonium and uranium oxide fuels do not require enrichment. The enrichment process is by isotope separation. For example, reactor fuel requires a minimum of 3% U-235 and weapons use requires more than 90% U-235. Uranium greater than 3% U-235 is referred to as SNR (special nuclear material) and that greater than 90% as HEU (highly enriched uranium). Isotopes are chemically identical with only slightly different molecular weights. This makes physical separation a difficult and expensive process.

Gaseous diffusion, centrifugation (including aerodynamic methods), electromagnetic methods, thermal diffusion, electrolytic methods, distillation, chemical-exchange and ion exchange, and laser diffusion can separate the isotopes of uranium. Gaseous diffusion and gaseous centrifuge processes are used in most separation plants. Most enrichment methods require extensive physical plants to operate. Enrichment plants are very large in extent; using enormous amounts of electric power, large amounts of water, cooling facilities, and extensive air purification systems. Most plants are clusters of very large single story buildings connected by a spider-web pattern of insulated pipelines (usually elevated 8 to 10 feet by stanchions).

Gaseous Diffusion

Gaseous diffusion (barrier diffusion) theory is based on the rate of diffusion for elements of different densities (gases). The diffusion rate is inversely proportional to the square root of the density of the material. Lighter gases diffuse faster than heavier gases. By allowing gases to pass through porous membrane barriers (filters) with extremely small holes (1×10^{-5} cm in diameter), successive stages enrich the gas in the amount of the lighter material. The plant is a continuous interconnected cascade (series) of 1000 gallon tanks (with teflon seals) linked by nickel-plated piping. The barrier is a thin metal sheet of electro-deposited nickel, rolled into a tube and placed in the diffusion tank.

Uranium hexafluoride is nearly an ideal gas and is the best compound for separation of the isotopes. Producing the UF_6 gas begins with uranium dioxide (UO_2) metal. Heating the UO_2 to 500°C (932°F) in the presence of hydrofluoric acid

yields UF_4 (uranium tetrafluoride). Uranium tetrachloride and uranium tetrabromide are other, less volatile reaction series for isotope separation. Reacting the UF_4 with fluorine gas at 350°C (662°F) yields the UF_6 (uranium hexafluoride) gas. The UF_6 is a white solid below 60°C (140°F) but in gaseous form is highly corrosive. Alternately, the reaction of UF_4 with oxygen gas at 900°C (1652°F) produces UF_6 .

Calculations for enriching uranium hexafluoride (UF_6) show a maximum enrichment (theoretical) of 1.0043 per stage. Approximately 4000 barrier stages (cascades) are necessary to enrich the uranium.

The continuous process of successive stages requires miles (more than 5 miles) of piping connecting the stages. Separate compressors and coolers are required for each stage, requiring an enormous amount of electric power supplied through numerous electrical substations. Also the diffusion operation requires a vacuum to operate.

The diffusion plant is an extremely large (in area) structure, usually a tall multiple-story steel-frame building. The plant requires a large amount of water and electric power (e.g., electrical requirements are more than 2×10^9 watts/day). There will be numerous substations, possibly a power plant, and a water treatment plant, and dozens of ancillary buildings for laboratories, boiler houses, workshops, security functions, and fire stations. Numerous insulated pipelines are visible as are chemical storage tanks, uranium storage drums, and gas storage

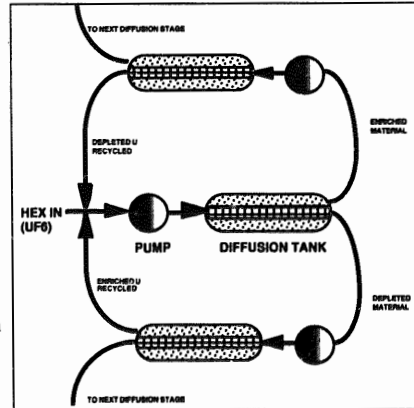


Figure 4.11: Gaseous Diffusion

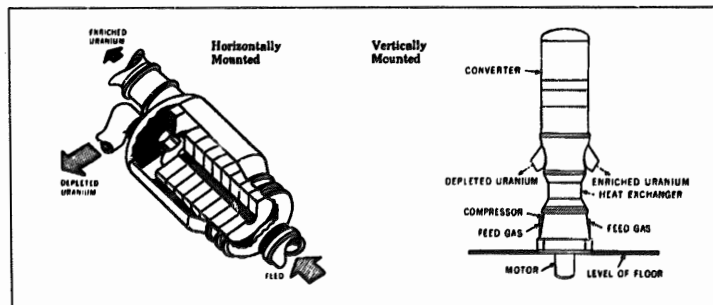


Figure 4.12: Diffusion Tank Types

cylinders. Exhaust vents and intakes for the processing buildings will have sophisticated filtering systems.

The original K-25 facility is a U-shaped 4 story building with its own thermal power plant and over 100 support buildings. The main structure containing the barriers is 805 m long by 322 m wide (2640 feet long by 1056 feet wide) and has an interior area of $6.1 \times 10^5 \text{ m}^2$ ($2 \times 10^6 \text{ ft}^2$).

Centrifugal Separation

Centrifugal separation consists of introducing the UF_6 gas into a centrifuge. The lighter fluid ($^{235}\text{UF}_6$) accumulates near the axis and the heavier ($^{238}\text{UF}_6$) near the outside edge. Numerous successive series of extremely fast rotation centrifuges (30,000–40,000 rpm) are necessary to produce the required concentration of isotope.

Large scale separation of isotopes requires thousands of centrifuges to process the uranium (40,000–50,000 to produce 1 kg/day) since the centrifuge process is not as efficient as diffusion plants. The original centrifuge chambers are 1.5 meters (4.9 feet) long by .25 meters (.8 foot) in diameter. Newer centrifuges are up to 12 m (40 feet) high. The plant containing the centrifuges is very large with the centrifuge section noticeably taller. Large amounts of electrical power and cooling are necessary to support the operation.

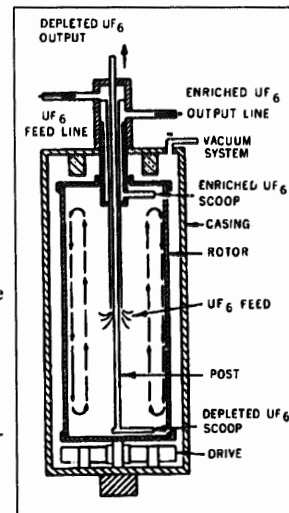


Figure 4.13: Gas Centrifuge

Aerodynamic processes use centrifugal forces delivered at high velocities to effect isotope separation. The UF_6 moves at high speed along a curved surface. The curved deflection surface moves the lighter U-235 easier than the heavier U-238. The U-238 deflects to the outside of the chamber. Again multiple passes through numerous chambers are required to enrich the material. Advantages of these systems are high efficiency and cheaper construction. The disadvantage is the extremely large amounts of electricity required.

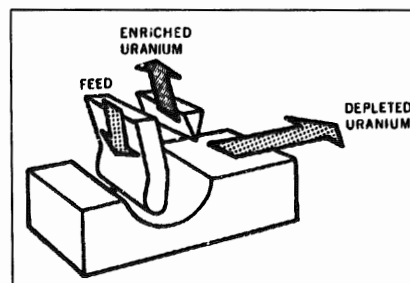


Figure 4.14: Becker Nozzle for Aerodynamic Separation

Electromagnetic Separation

Ionized gases (containing isotopes of the same element with identical electric charge) passing through magnetic and electric fields deflect according to their masses. Again a series of successive passes through numerous electromagnets (calutrons) is required to produce the required concentration of UF_6 . The first calutron enriches the isotope by 15%, the second by 90%, and so forth. Several sets of electromagnets, encased in mass spectrometer tanks, are arranged in oval configurations (called racetracks) of 50 feet by 100 feet.

The first electromagnetic separation facility, Y-12, consists of 268 buildings. The calutron building is a tall two-story structure of steel frame, brick, and tile. The racetracks are on the second floor with the first floor housing the vacuum pumps. The plant has numerous labs, shops, warehouses, change buildings, and other support buildings. In addition, the plant has a distilled water plant, a thermal power plant, a sewage treatment plant, pumphouses, a foundry, 8 substations, and 20 large cooling towers.

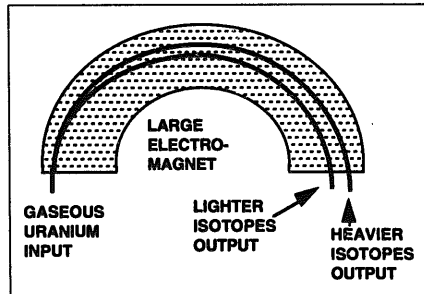


Figure 4.15: Calutron

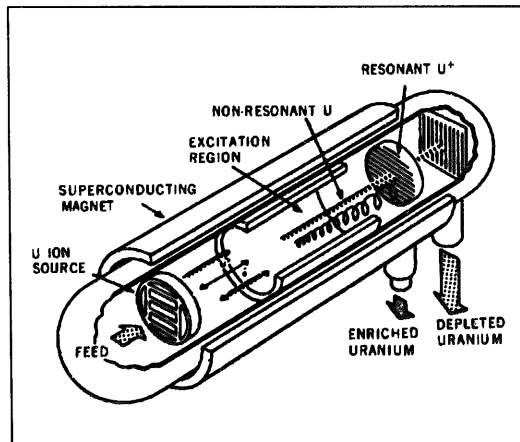


Figure 4.16: Plasma Separation

Plasma Separation

A newer process, the Plasma Separation Process, uses a metallic uranium vapor feed of plasma. A solenoid and magnets provide a RF tuned field (to the resonance frequency of U-235) which increase the energy of the U-235. The U-235 moves in a wider spiral orbit that intersects a charged collector plate for recovery. The low energy U-238 passes through the collector plates.

Laser Based Processes

Laser based systems have been developed for smaller, less expensive separation plants. The tuned

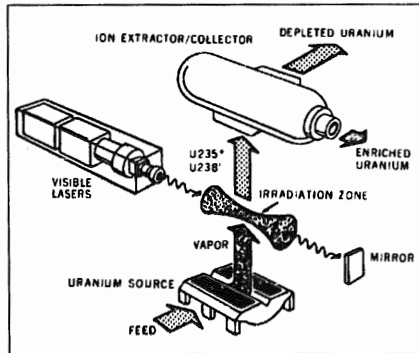


Figure 4.17: AVLIS

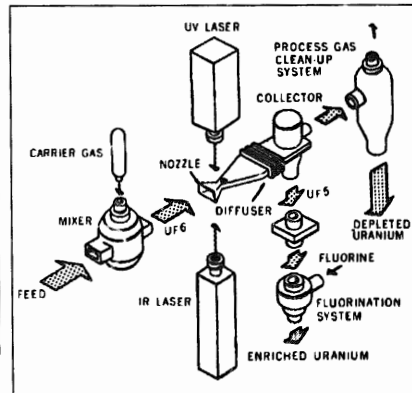


Figure 4.18: MLIS

lasers selectively ionize U-235 atoms. The laser is tuned to a wavelength that doesn't ionize the U-238 atoms. The U-235 atom absorbs energy, stripping an electron and becoming a positively charged ion of uranium pentafluoride (UF_5). The ions can be attracted to a negatively charged plate for recovery.

The AVLIS (Atomic Vapor Laser Isotope Separation) process uses a feed of vaporized uranium metal and a series of three laser beams for ionization. The MLIS (Molecular Laser Isotope Separation) process uses a feed of UF_6 and helium

gases at 50° K (-223° C [-369° F]). An IR (infra-red) laser provides preliminary excitation and a UV (ultra-violet) laser separates the enriched molecules of UF_5 .

Thermal Diffusion

Introducing a suitable fluid (gas or liquid) into a vertical column equipped with a heating element in the center causes the separation of the isotopes. The heavier isotope concentrates in the cooler outer region of the column while the lighter isotope concentrates in the warmer central area. Then the heavier isotope sinks (due to convection) in the column and the lighter isotope rises.

The original plant is housed in 155 meter (500 foot) long buildings containing the 1 meter to 1.25 meter (3 feet to 4 feet) long

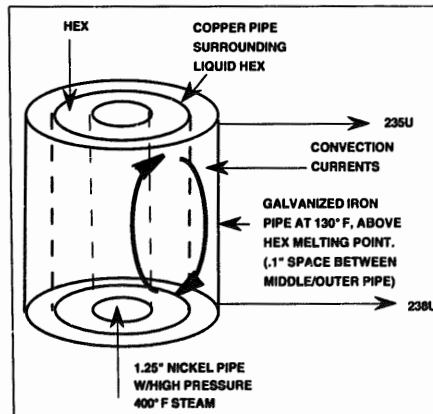


Figure 4.19: Thermal Diffusion

thermal diffusion columns. A cascade of 2,000 thermal diffusion units yields 1 kg/day of 90% uranium isotope. Thermal diffusion plants feed slightly enriched uranium to the calutron plants.

Other

Other chemical and ion exchange methods use ion transfer in aqueous, organic, or resin systems. At present these systems operate at 1/4 the efficiency of other methods and are not viable at large scale.

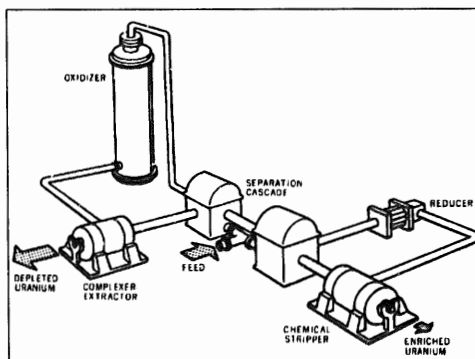


Figure 4.20: Chemical Exchange Process

Uranium Metal Forming

The isotope separation yields an enriched uranium gas. Once the desired level of enrichment occurs (the typical reactor runs on 93% and naval reactors run on 97% enriched material), a chemical process converts the UF_6 gas to its "green salt" of uranium tetrafluoride (UF_4). Reduction of the UF_4 occurs in a crucible. The UF_4 salt, mixed with biscuits of lithium metal, a reducing agent (calcium or magnesium), briquettes of ^{235}U scrap, and a thermite igniter, burns forming metallic uranium.

Most applications for the uranium metal require the uranium metal foil (.005 inch) layered with graphite moderator. The rolling and stamping mills machining the uranium graphite foils require special vacuum and adhesive techniques.

Plutonium

Plutonium does not occur in nature except in rare minute quantities associated with radioactive decay in uranium. Plutonium forms due to thermal neutron bombardment of ^{238}U and its subsequent beta decay, resulting in the formation of plutonium. Plutonium poses health hazards both because of its radioactivity (all its isotopes are radioactive) and because of its general toxicity (carcinogenic). Plutonium (in the form of ^{239}Pu) is used for nuclear power generation and as the primary explosive constituent in nuclear weapons (fissionable by both slow and fast neutrons). Plutonium (^{238}Pu) also forms the basis for small portable power sources, notably in spacecraft and satellites.

Typical production is by fast breeder reactors. Here ^{238}U fuel (91%) and 9% other isotopes (of ^{239}Pu and ^{241}Pu) transmutes to ^{239}Pu . The neutrons from fission bombard the uranium for 100 days. After a sufficient amount of plutonium is made, the fuel rods are removed from the reactor and allowed to cool (short-lived fission radiation) in cooling ponds at the reactor, this stage requires 60 days. The cooling pond is a bridge crane served lined pool of water. A reprocessing plant recovers the plutonium produced by the reactor.

Typically the reprocessing plant is not collocated with the production reactor. The irradiated fuel rods (slugs) are shipped from the reactor to the plant in heavily shielded and guarded transportation flasks. Storage awaiting reprocessing is in cooling ponds. When ready for processing, the skips containing the slugs are moved into a preparation building where the elements are removed from the rods. The first step occurs in the primary separation plant where the plutonium, uranium, and other elements are separated by chemical processing. The fuel rod material is dissolved in hot nitric acid. The solution is oxidized using cerium or lanthanum fluoride as a carrier. Adding bismuth phosphate as a carrier removes the uranium and other contaminants from the solution. The uranium is recovered as uranyl nitrate hexahydrate.

Evaporation precipitates the plutonium as a fluoride. The plutonium fluoride is re-dissolved in sulfuric acid, re-oxidized and re-precipitated, leaving plutonium. The sequence is repeated numerous times (40-80) before yielding 90% pure plutonium nitrate.

The process is highly radioactive so the structure has heavy shielding and air purification equipment. The recovered uranium is recycled through the uranium isotope separation plant requiring transportation to that facility (if not collocated with the plutonium processing plant). The plutonium purification plant extracts the plutonium and reduces it to metal. Each 907 kg (1 ton) of fuel rods produces 4 kg (1 lb) of plutonium, 862 kg (1900 lbs) of depleted ^{235}U , and 45 kg (100 lbs) of fission by-products (1 kg uranium processing yields 6.0×10^{-7} gram of ^{239}Pu).

The solvents used for the extract process are recycled. The radioactive by-products are graded into highly, medium, or slightly radioactive waste. The low level and medium level waste are stored until the radiation level drops low enough, then the waste is sent to a disposal site. The high level waste requires long term secure storage, usually underground, for thousands of years before disposal.

The original 100B facility plutonium separation plant (canyon building) is a structure approximately 250 meters long by 20 meters wide by 25 meters high (800 feet long by 65 feet wide by 80 feet tall) with 1.8 m (6 feet) thick walls and roof. The building houses 40 sections. Each area has two cells, catch tanks, precipitator, solution tank, and a centrifuge. All the processing is by remote control due to both the toxicity and the radiation danger from the plutonium.

Nuclear Weapons and Fabrication

Fission weapons consist of a plutonium core surrounded by a tamping material such as U-238. Explosive lenses of fast and slow high explosives surround the core. A series of high voltage capacitors (thyristors) provides the split-second timing and charges to detonate the explosives at the critical moment. Upon detonation, the lenses compress the fissionable material to a supercritical stage. Next a (obsolete) chemical initiator such as beryllium-polonium (placed in the center of the core), or a mechanical initiator (such as a minitron high voltage vacuum tube) provides the necessary neutrons to cause a high level nuclear explosion.

An H-bomb uses a fission device as a trigger to initiate fusion in an additional element containing lithium-6 deuteride surrounding more plutonium (another fission chain). The level of the yield (dial-a-yield) may be controlled by injecting

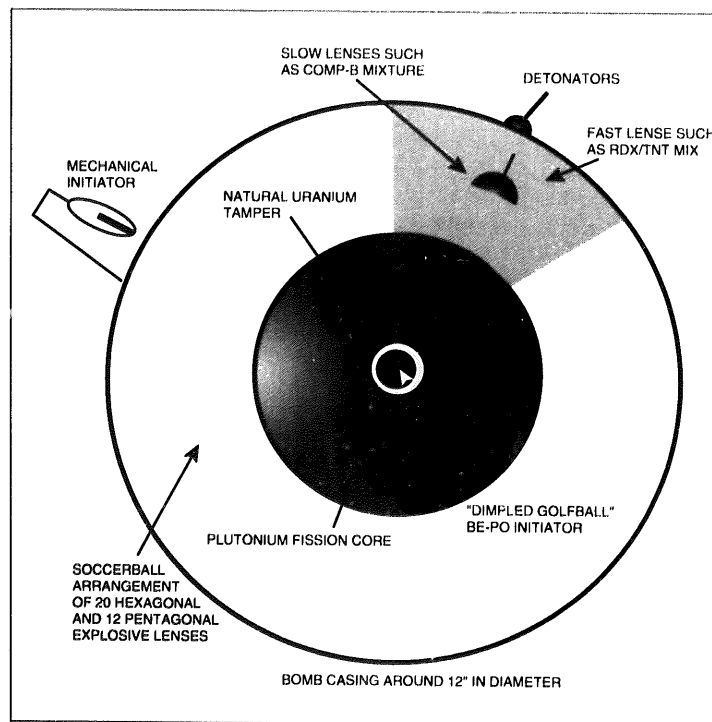


Figure 4.21: Fission Bomb (A-Bomb)

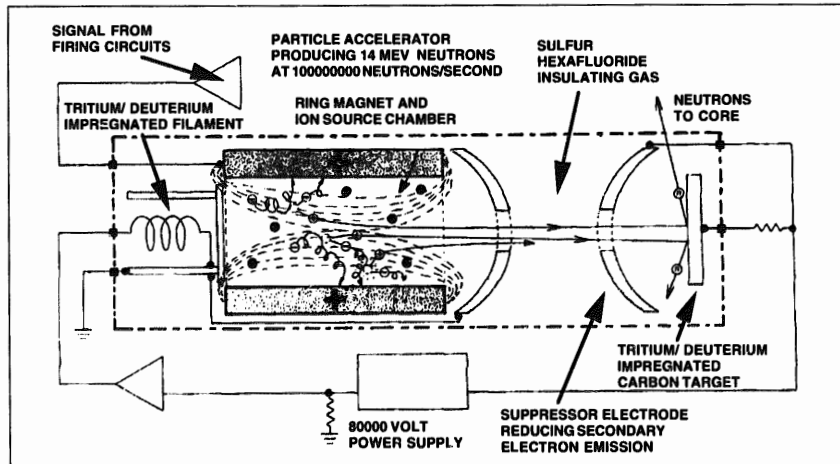


Figure 4.22: Mechanical Initiator

varying amounts of tritium and deuterium gas into the primary before detonation. The neutron bomb is a variation using a casing of tungsten alloy (primarily) with nickel, iron, and rhenium to produce larger amounts of radiation with smaller yield weapons.

The assembly of a nuclear weapon is simple once the fissionable material is processed. However, to protect the considerable investment in physical plants required to produce the components, the processes for fabrication and assembly of nuclear weapons are geographically dispersed. Each step of the process and each component is produced in separate locations throughout the nation. All the components meet at a final assembly plant for final fabrication. This plant will have heavy security, extremely large bunkers for the actual assembly work, and limited completed weapons storage. Typically the same facility handles disassembly of the weapon when its usable life is reached.

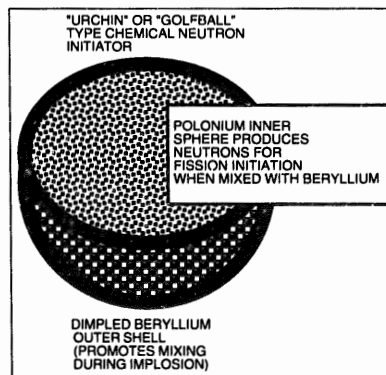


Figure 4.23: Chemical Initiator

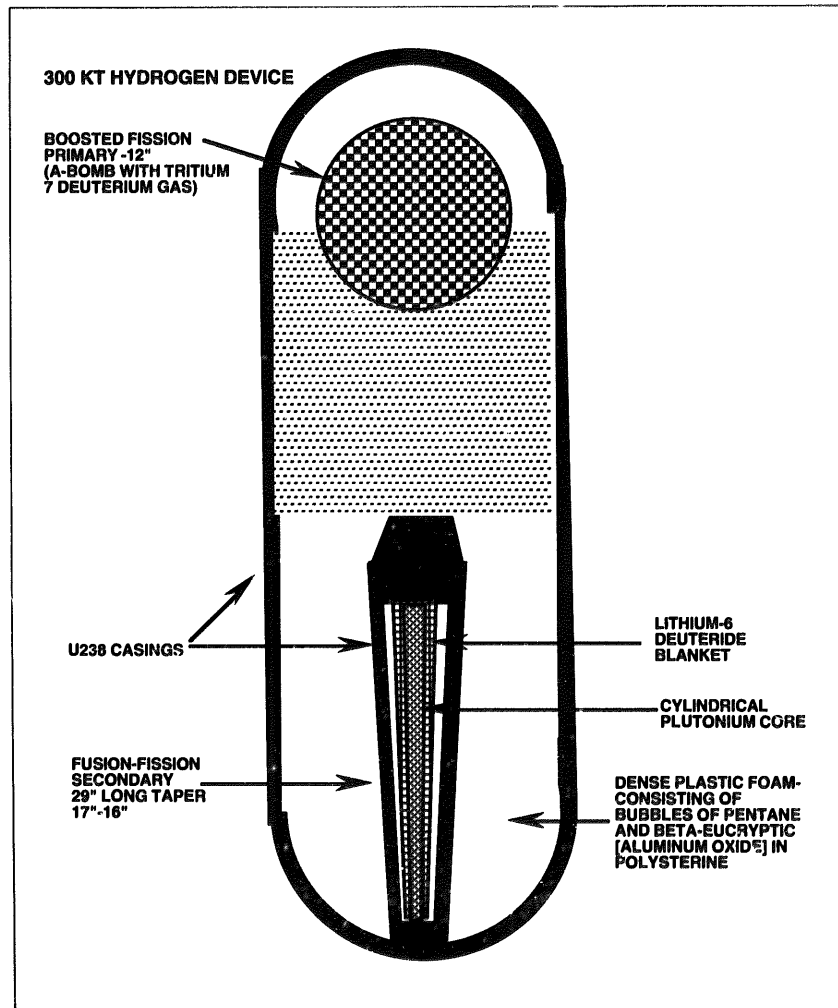


Figure 4.24: Fusion Bomb (H-Bomb)

Chemicals

Introduction

Chemical industries use chemicals and chemical processes in rearranging raw materials in the production of material. Pressure, heat, other chemicals, and catalysts form the basis of the chemical processing. The general classification of a chemical plant divides plant type into primary chemical production and secondary chemical production. Primary (basic) chemical plants produce a chemical from a basic raw material. A secondary chemical plant produces a finished product from primary chemicals. The third classification, petroleum, produces both primary and secondary chemicals from natural gas and crude oil. Petroleum chemical production is covered under the petroleum and refining section of this book.

Identification of a chemical plant is not difficult, but identification of the actual process may be very difficult. This is especially true in many modern chemical plants where several processes are layered. The size and complexity of plants range from a single small process to very large, multi-process chemical complexes. The components of the plant may be under weather protection, further

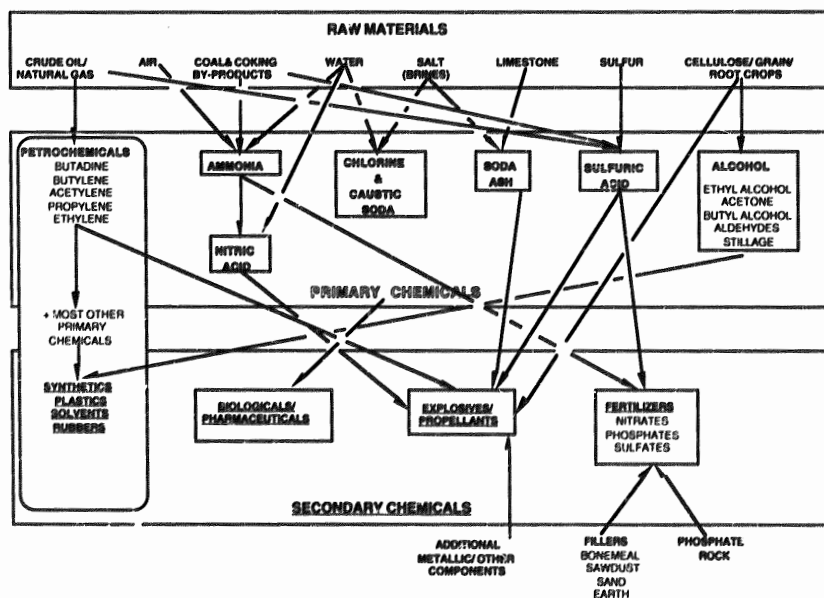


Figure 5.1: Chemical Industries Overview

Primary (Basic) Chemical Production

Air Separation

Air separation plants produce the raw materials of nitrogen, oxygen, and argon from the atmosphere. These elements (in liquid or gaseous forms) form the basis for steel, refrigerants, chemical, and missile propellant production.

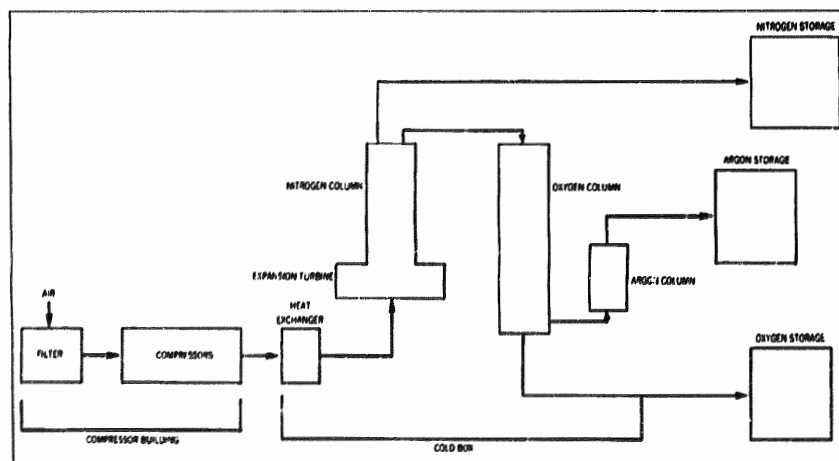


Figure 5.2: Air Separation Plant Flow Chart

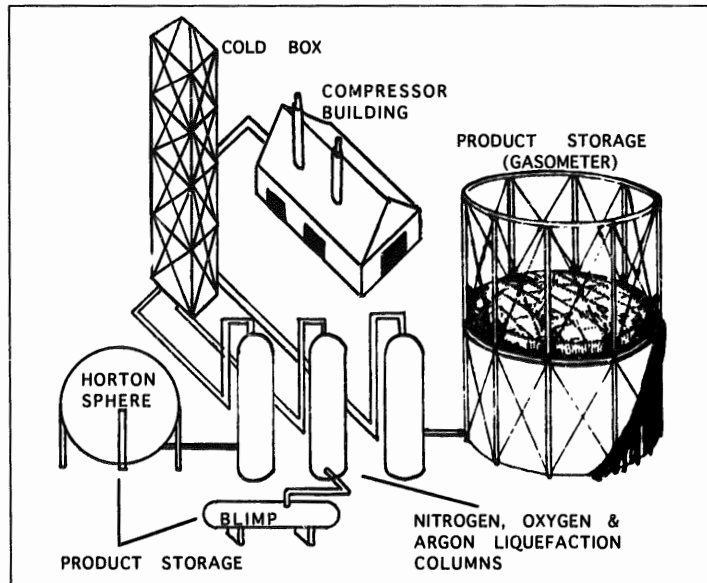


Figure 5.3: Air Separation Plant

The most economical method of producing gases involves compressing atmospheric air using an air compressor after filters remove any impurities. The compressor building is a long, rectangular, flat-roofed structure (one or two story). Gasometers or cold boxes are situated nearby.

Piping transfers the compressed air to a cold box building. Here, heat exchangers cool the air and remove carbon dioxide and water vapor. The processed air goes into an expansion turbine, the air expands, forming nitrogen vapor. A nitrogen column removes the product nitrogen. Compressors re-condense the remaining air into the oxygen column. In the oxygen column, the air moves downward, it becomes richer in oxygen and argon content. At the highest concentration of argon, the argon element is sent to the argon column for impurity removal. The remaining oxygen passes through the oxygen column as the final product. A single cold box is a square structure, taller than the compressor building. Several cold boxes can be located next to the compressor building with all the structures covered by a single long, rectangular, stepped building.

Storage facilities, if any, consist of closed tanks. Wet or dry gasometers are the most common type of tank. When only one tank is present, it serves as a surge tank for excess gas.

Alcohol

An offshoot of the alcoholic beverage industry is the industrial alcohol industry. Medicines, flavoring, and beverages use pure ethyl alcohol (edible alcohol). Additives denature alcohol for industrial use, rendering it in-edible. Uses for denatured ethyl alcohol include the production of acetaldehyde, ethyl acetate, ether, medicinal products, and antifreeze. Butyl alcohol is used in the production of lacquer solvents and esters. The co-products of alcohol production include acetone (solvent) and glycerine (organic chemical synthesis), butylene glycol (butadiene and synthetic rubber production), citric acid (food industry), lactic acid, starches and wheys, and acetic acid (vinegar). Fermentation methods form the basis of the antibiotic and pharmaceutical industry.

Alcohols are produced by fermentation methods or by the petroleum industry (synthetic alcohols). Historically methyl alcohol (methanol) was obtained from the distillation of wood pulp but now is produced by petrochemical rather than fermentation processes. Fermentation processes remain competitive due to the value of the byproducts. In fermentation, microorganisms ferment the starch and sugar in a mash, converting it to alcohol. Distillation purifies and concentrates the solution. Yeast fermentation of an acid mash yields ethyl alcohol (ethanol) and glycerine. Bacteria fermentation of an acid mash yields butyl alcohol (butanol) and the byproduct of acetone and ethyl alcohol.

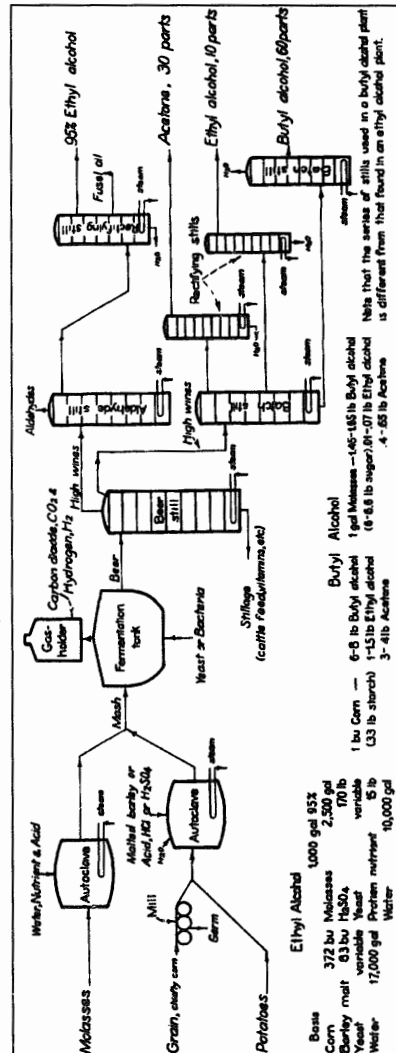


Figure 5.4: Alcohol Flow Chart

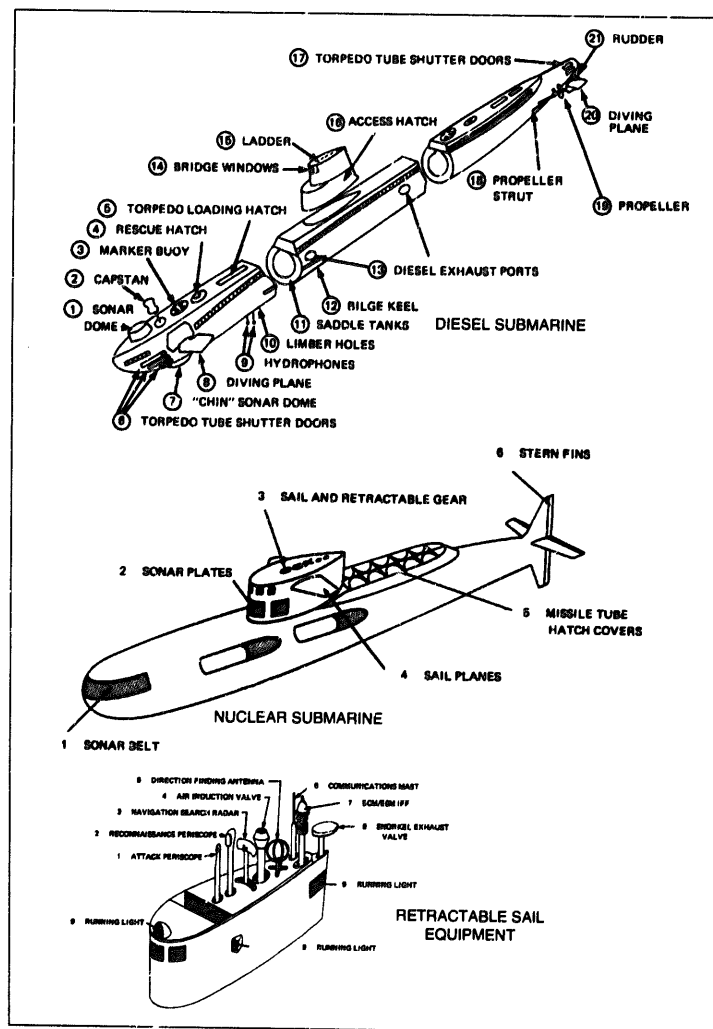


Figure 15c: Naval Vessel Types

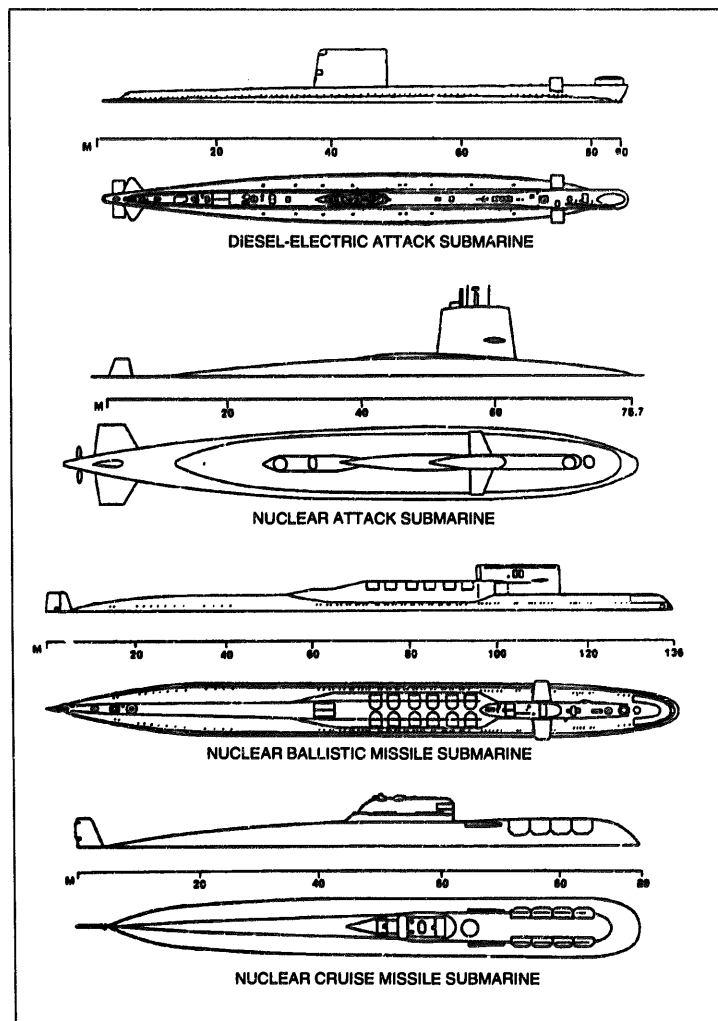


Figure 15d: Naval Vessel Types

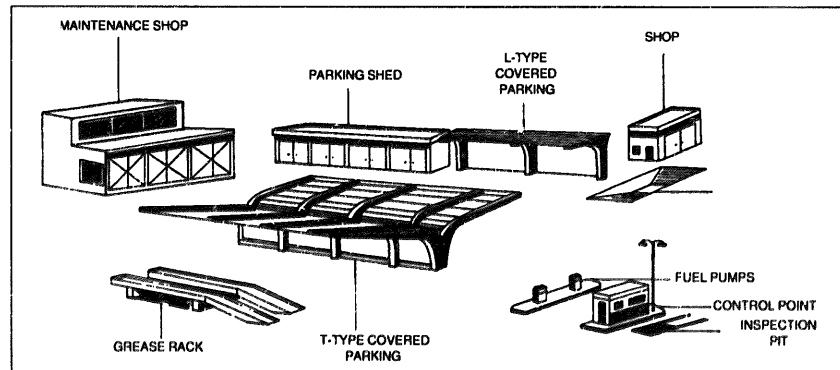


Figure 37: Military Motor Pool Shop Area

Sometimes vehicles are parked under cover of long, low, open sided parking garages or sheds. Sometimes these sheds are arranged along the sides of the motor pool.

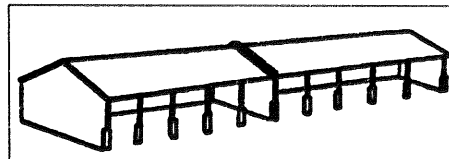
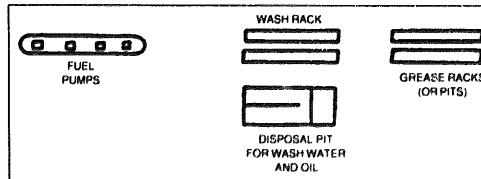


Figure 38: Parking Shed

The motor pool also provides for maintenance and repair of vehicles.

An area will be devoted to this function. This area contains fuel pumps and tanks, wash stands, grease racks and pits, hydraulic lifts, parking garages, and repair shops and garages. Maintenance

Figure 39: Vehicle Checkout and Fueling Area



garages can be identified by a taller roofed structure flanked by smaller structures. The taller structure is a high bay garage, designed to allow the entry of trucks and other tall vehicles.

Missiles

In the simplest definition, rockets are unguided munitions and missiles are guided or steered. Once a rocket motor burns out, the device continues on a course determined by its final velocity. A missile, on the other hand, has at least a minimal guidance system and a method to steer the device. One classification divides missiles into two types. Ballistic missiles, such as ICBMs or SAMs, are

guided by their motors. Non-ballistic missiles, such as cruise missiles, are steered by activating wing surfaces or guidance vanes on the craft.

Strategic rocket forces typically use surface-to-surface ballistic missiles as delivery systems for nuclear, chemical, or biological weapons. Ballistic missiles are classified by their range capability. Intercontinental ballistic missiles (ICBM) have ranges more than 4800 km (3000 mi). Intermediate range ballistic missiles (IRBM) have a range of 1800 – 4800 km (1100 – 3000 mi). Medium range ballistic missiles (MRBM) have a range 1125 – 1800 km (700 – 1100 mi). Short range ballistic missiles (SRBM) are tactical missiles with a range under 1125 km (700 mi). Strategic rockets can be designed for launching from either a fixed site, typically a hardened silo, or from a mobile, usually canister type, launcher.

Cruise missiles are also used for strategic or tactical delivery systems. As with the ballistic missile, the cruise missile can be launched from a fixed site, typically a pad, or from mobile rail launchers.

A variety of tactical support systems have been developed to for use on the tactical battlefield. Some of these systems are missiles and some are rockets. Tactical systems are classified into light-support with a range of 40 km (25 mi), medium-support with a range of 325 km (200 mi), and heavy-support with a range of 800 km (500 mi).

For a fixed launch site, the missile and all its support equipment is always maintained in an operational readiness state. The launch sites are usually hardened silos designed to withstand all but direct hits. As a further precaution, the launch sites are dispersed throughout the area to minimize the damage one enemy warhead could inflict. Most of these silos consist of a small fenced cleared area and concrete silo doors.

Mobile sites typically consist of a pre-surveyed point with geodetic control. In some cases, some site preparation, which may include construction of concrete pads, is done before moving missiles into launch position. Mobile ballistic missiles are not kept in a state of constant readiness. The missile is only fully operational once the missile is erected at the site.

Before continuing with this section, a note about systems and site nomenclature is necessary. A site consists of the missile, the erector-launchers, and all its support equipment. A single missile site, especially when referring to SAMs, may contain several missile launch positions or pads. These launch positions function as a single operational unit. For example, depending on the operational requirements of the system design, a single operational unit SAM site could consist of 8 missiles and eight launch pads. When referring to military missiles, the term multiple refers to the presence of more than one operational unit.

Launch Pad

The large fixed gantry served launch pads are used for the launch of research, intelligence gathering, communications, or surveillance satellites. In other words, these facilities are used for space launch vehicles. These pads are part of large

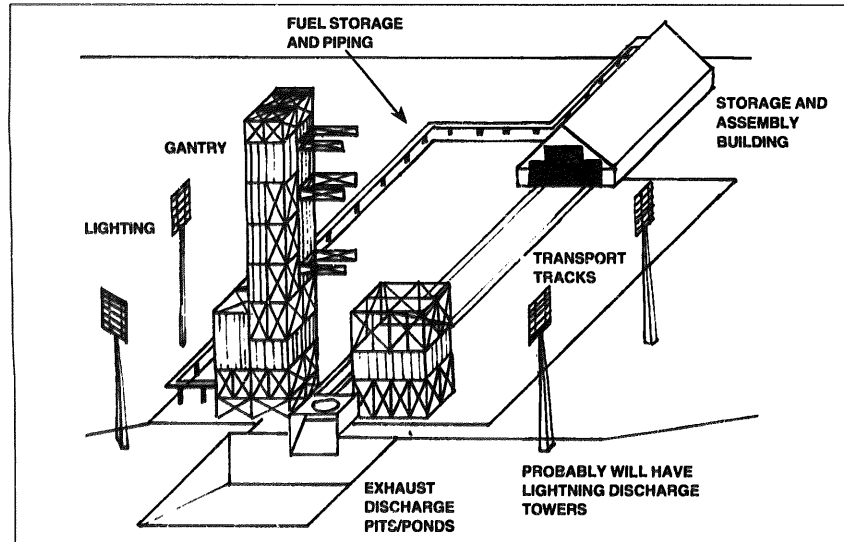


Figure 40: Launch Pad

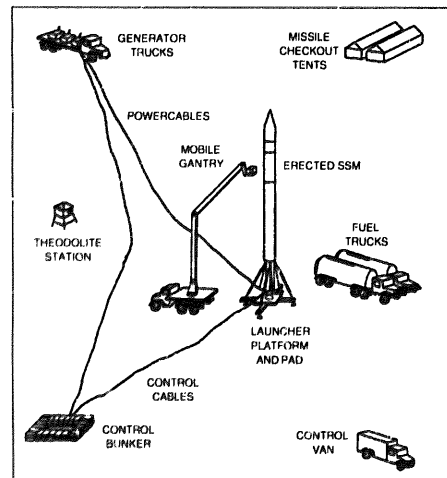


Figure 41: Launcher with Mobile Support Vehicles

complexes dedicated to the launch of these devices. The complex is located in a remote area. The complex consists of administration, supply, and control buildings. Numerous checkout, assembly (very large structures), and fuel storage areas serve several launch pads. In addition there will be several electronic areas devoted to communications and guidance functions.

The launch pads are usually surfaced with cement, sand, or earth, since grass and asphalt would be damaged due to the intense heat generated at the time of launch. Around the tall lattice gantry towers will be smaller towers for lights and towers serving as lightning arresters. The simplest launch pad is a round or rectangular surface without any fixed structures. In this case, all the support equipment, the transporter, missile erector, and launcher are mobile.

Surface-to-Surface Ballistic Missiles

Since the size and capabilities of ballistic missiles vary, it is very difficult to determine what missile a particular site supports. Usually larger missiles have longer ranges, carry a larger payload, and can be positioned farther from the perceived threat. Identification of the exact missile relies on ancillary source and the close examination of the missile silo, associated equipment, and deployment characteristics. Refer to the supplemental handbook for additional information on both defensive and offensive missile systems.

There are some general rules for identification of missiles and missile sites. Fixed missile sites are normally located in undeveloped areas, usually close to military bases. The military base provides supply, maintenance, and administrative support for the missile detachments. The necessary elements forming a missile launch facility include missile storage and assembly, launch points, support equipment, propellant and warheads, quarters, security facilities, and transportation.

Missile storage and assembly are performed in one large structure. Typically this structure is an underground or partially buried (bermed) bunker facility. The missile fuselage, motors, and warhead are mated and checked before transport to the silo or launch site.

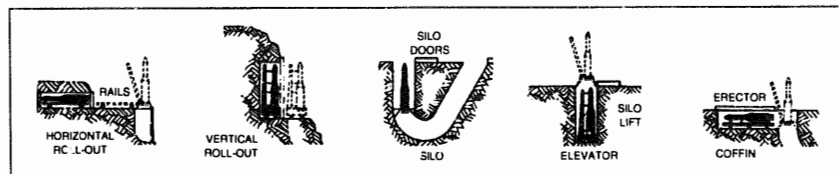


Figure 42: Types of Silos

The launch points (or firing points) can be pads or silos. The pads can be as simple as 30 – 100 m (100 – 300 ft) diameter round or square concrete paving. Pads will be linked by road or rail to the missile storage area. The launchers (or rails) can be permanently mounted on the pad, or may be part of a mobile system. The missile can also be fired from a silo, an underground facility. The silo remains closed until immediately before missile launch, then blast doors are mechanically opened or blown clear of the tube. There are several silo configurations. Some require the missile to be moved by elevator or track to the firing position. Some execute a "cold launch" of the missile. That is, a steam generator or gas producer exerts sudden pressure against the bottom of the missile, catapulting it into the air for motor ignition. Missile silos are usually fenced with additional electronic detection systems deployed around the area. The silo doors will be visible and in some cases a personnel access door. Most silos maintain a control and launch facility at some distance from a group of silos. The actual silo is un-manned except for security troops.

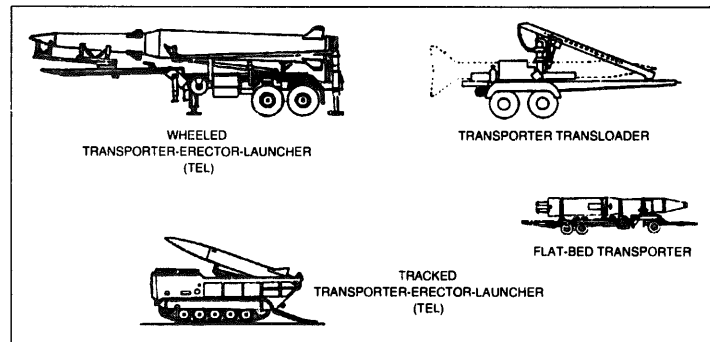


Figure 43: *Missile Support Equipment*

A variety of support equipment is required for missile launch facilities. Prime movers, transporters, erectors, launchers, and missile silo reload equipment are necessary. Each missile system requires an array of specialized equipment designed for that one missile type.

Most missiles have solid-propellant motors and the propellant is mated to the motor when built. Liquid propellant is rarely used for strategic rocket forces but is still used extensively for space launch rockets and missiles. Liquid propellant requires either a network of pipelines to the launch point or a series of transporters to carry fuel from the storage area to the pad. Rocket fuel is stored like any other explosive material, in widely spaced and bermed tanks or underground facilities. The warheads are stored in distinctive areas with heavy security that includes fencing, towers, patrol roads or paths, and extensive cleared zones around the complex.

Fixed Ballistic Missile Systems

Most are small compact single silos dispersed over wide areas. Individual silos are identified primarily by differences in tone due to access roads, cleared areas for silo doors and access portals, and fence lines.

Major silo based (1991) ICBM systems include Minuteman II/III, Peacekeeper, SS-11 mod 2, & 3, SS-17 mod 3, SS-18 mod 4/5 and 1/3/6, SS-19 mod 3, and SS-24 (rail mobile or silo based).

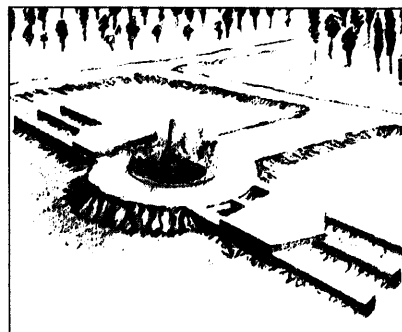


Figure 44: *Russian ICBM Silo (SS-11, SS-17, SS-18, SS-19 & SS-24)*

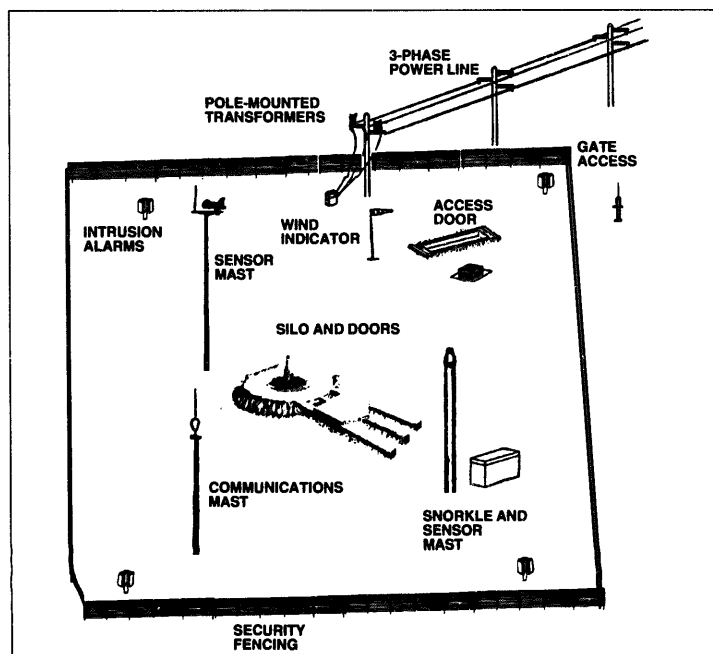


Figure 45: Improved Minuteman II/III Silo

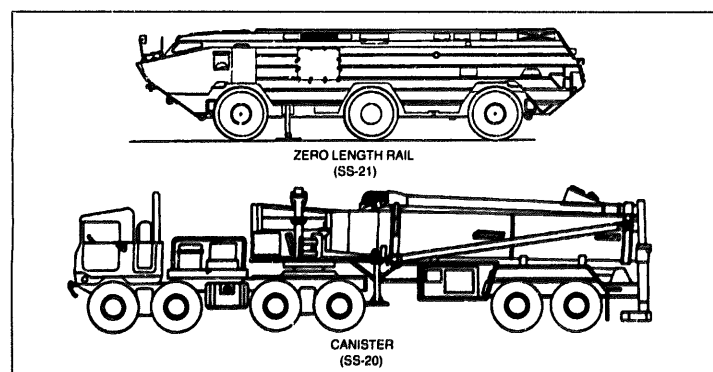


Figure 46: Mobile Launcher Types

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Mobile Systems

ICBM

Present (1991) mobile ICBM systems consist of the Russian SS-24 and SS-25, mod 1/2. The SS-24 is a rail mobile (also silo-based) system. The SS-25 is launched from a wheeled transporter-erector-launcher (TEL). The requirements for firing a mobile missile include a geodetically controlled and surveyed site.

Mobile systems may be launched from pre-surveyed and prepared positions. Typically the systems are maintained in vehicle (both rail and road) storage sheds until deployment. Then the missile is moved to one of several possible launch sites. In the case of rail mobile systems, the site is a rail siding connected to the main line.

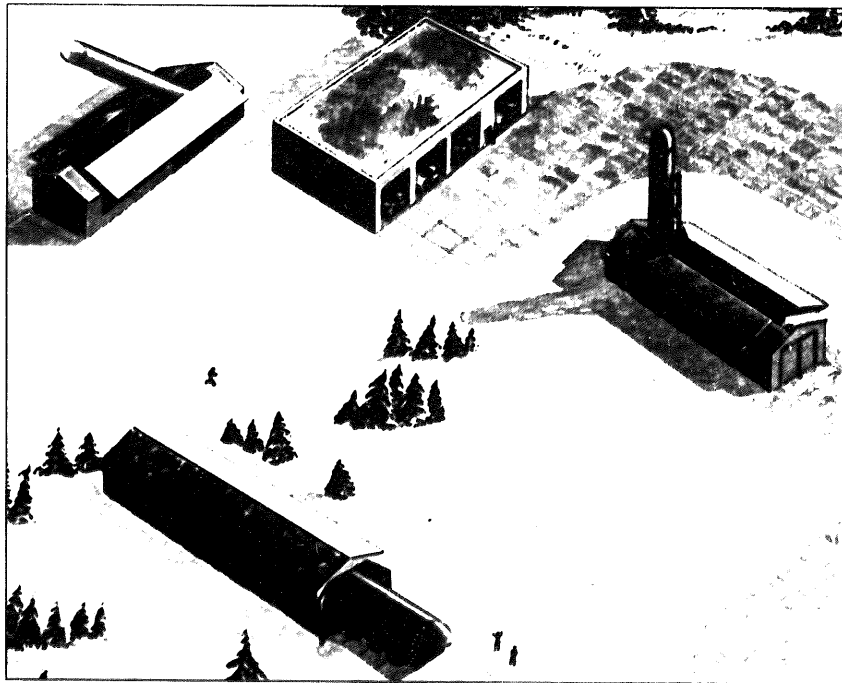


Figure 47: SS-25 ICBM Soft Silo and Mobile TEL

IRBM

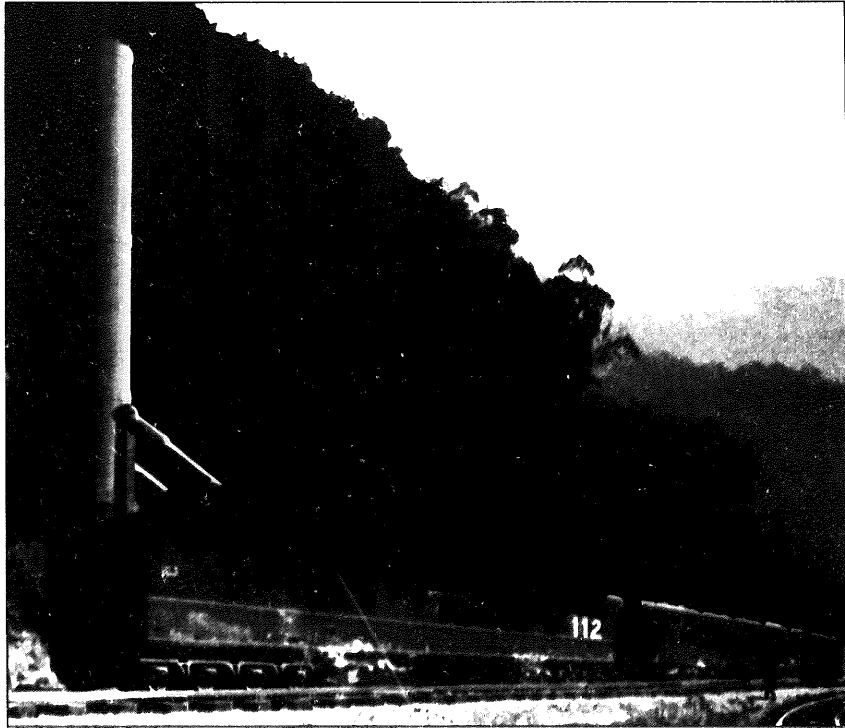


Figure 48: SS-24 Rail Mobile Launcher

The major Intermediate Range Ballistic Missile system currently in use is the SS-20 (SABER), which is deployed in soft silos or as fully mobile 12x12 wheeled TEL. The SS-20 is intended for critical theater targets but is slated for destruction under the INF and START reduction treaties. Effective 1991, all SS-20 missiles were to be destroyed. SS-20 bases are presently being re-configured as SS-25 bases.

MRBM

The Pershing 1A (MGM-31) is a SRBM, being replaced by the Pershing II. The Pershing 1 missile is 10.4 m (34.5 ft) long and 1.2 m (3.25 ft) diameter. The system is a fully mobile articulated 8x8 truck and trailer combination TEL that is deployed with a transporter (for generators and testing equipment), a battery control vehicle, and a communications vehicle.

The Pershing II is a MRBM. The missile is 10.5 m (34.5 ft) in length and 1.02 m

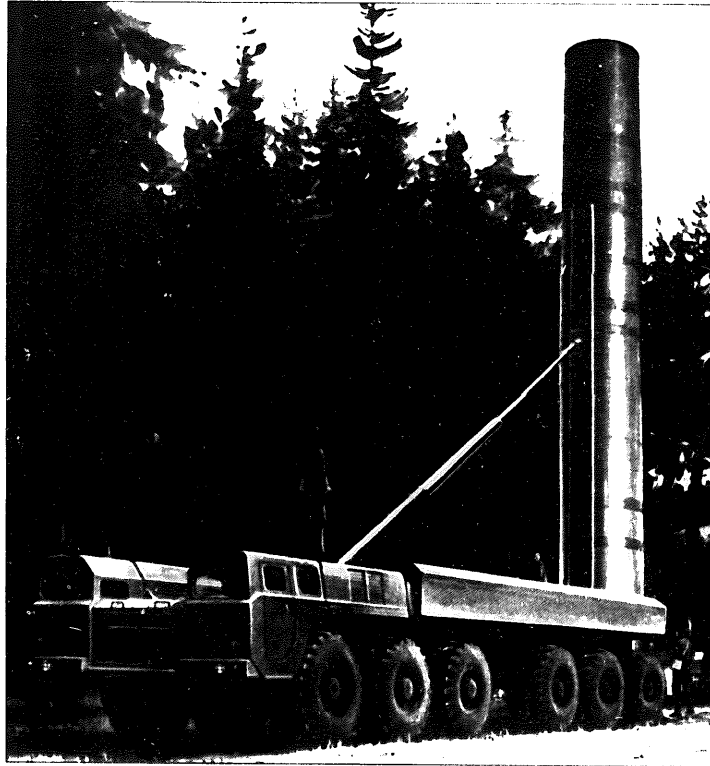


Figure 50: SS-20 TEL

(3.25 ft) diameter. The Pershing II uses the MAN 8x8 truck. The Pershing is deployed as a battalion of four batteries of three platoons, each with three TELs per battery.

Tactical Units SRBM (SSM)

There are many tactical surface-to-surface missile systems presently deployed. These systems all fall under the classification of SRBM. Most of the systems are nuclear capable.

The SRBMs include the Lance (MGM-52). The Lance is a fully mobile system mounted one missile per M⁵² tracked TEL (a lightweight wheeled TEL is also deployed). The TEL is accompanied by an M688 tracked loader transporter

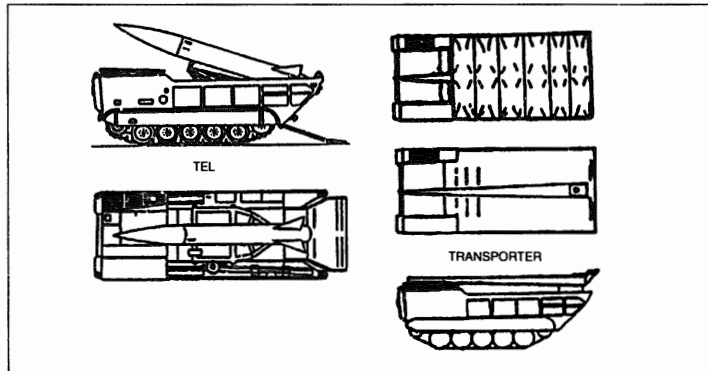


Figure 51: Lance SRBM

equipped with two reloads and a missile hoist. The TEL and transporter are 4.87 by 2.69 meters. The missile is 6.2 m (20.25 ft) long and 0.6 m (1 ft 10 in) in diameter.

Pluton

Pluton is a fully mobile system mounting one missile per AMX-30 MBT tracked TEL. The TEL is accompanied by two Berliet support trucks and a Berliet truck-mounted battery control, communications, and intelligence center. The TEL is 6.59 by 3.10 meters. The missile is 7.64 m (25 ft) long and has a diameter of 0.65 m (26 in). Deployment is in regiments. Each regiment has an HQ company, 3 launcher batteries, a transport unit, and a security element of 10 AMX-10P APCs.

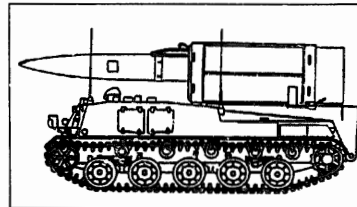


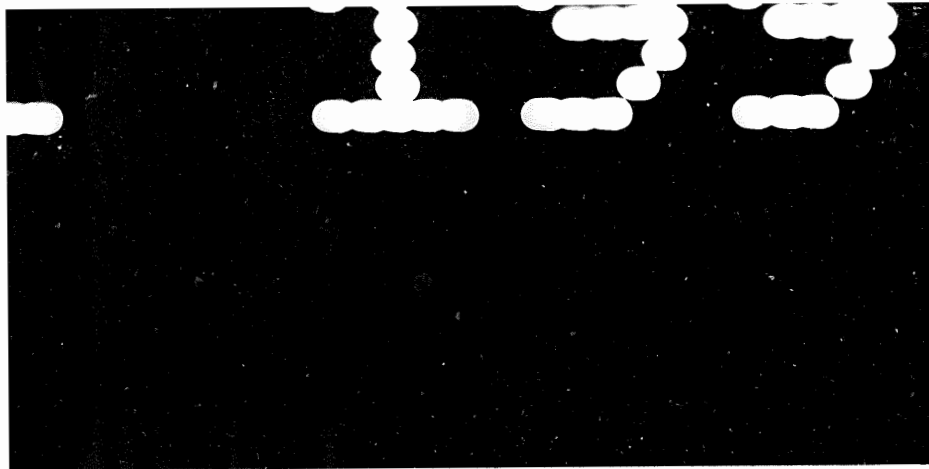
Figure 52: Pluton SRBM

Hades

Hades is also a fully mobile system mounted on a 4x4 truck and semi-trailer TEL with one ready missile and one reload. The Hades system is totally self-contained with all equipment carried onboard the one vehicle.

MLRS

A recent development is a modification of the U.S. Multiple Launch Rocket System (MLRS) allowing the deployment and firing of two Army Tactical Missile System (ATACMS) missiles from the MLRS. The ATACMS is a 2 foot diameter maneuvering ballistic missile with a range of 60 miles.



Cultural Areas

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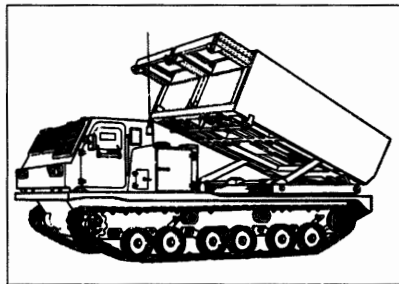


Figure 53: MLRS

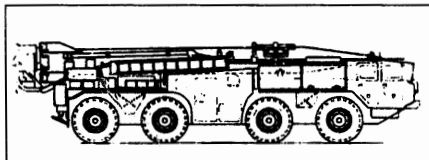


Figure 54: SS-1e (SCUD-B) TEL



Figure 55: SS-21 TEL

SCUD

SS-1e (SCUD-B/C) is a fully mobile system mounted one per 8x8 wheeled TEL. Deployment is in brigades of 12 – 18 launchers. The liquid fuel four fin missile is 9.5 – 10.4 m (31 – 34 ft) long and .790 – .890 m (31 – 35 in) in diameter. The TEL is 11.5 m (37.6 ft) long and 3.3 m (10.7 ft) wide.

SCARAB

SS-21 (SCARAB) is a fully mobile system mounted one per 6x6 wheeled TEL. The SS-21 is currently replacing the FROG rocket launchers. Deployment is in brigades of 18 launchers. The missile is 6.0 m (19.6 ft) long and has a diameter of 0.85 m (2 ft 10 in).

SCALEBOARD

The SS-22 (SCALEBOARD) is a fully mobile Short Range Ballistic Missile, mounted on an 8x8 wheeled TEL. The SS-22 replaced the SS-12 missile and launcher that was identical in appearance to the newer SS-22. This system differs in appearance from the SCUD-B Surface to Surface Missile only in the protective environmental cover over the SS-22 missile. Deployment is brigades of 12 – 18 launchers.

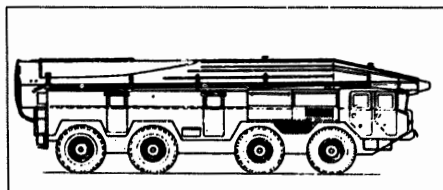


Figure 56: SS-22 (SCALEBOARD) TEL



Figure 58: SS-23

SPIDER

SS-23 (SPIDER) is a fully mobile system mounted one per 8x8 wheeled TEL. This system is the planned replacement for the SS-1 in the Russian inventory.

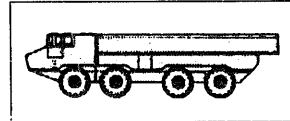


Figure 57: SS-23B TEL

Surface-to-Air Anti-Ballistic-Missile (ABM)

ABM systems are designed for the point defense of very high priority targets. Such targets normally are restricted to the National Command Authority, capital cities, or the military command structure. Presently there exist three true ABM systems, the Soviet ABM-1, -2, and -3. Three other systems offer some ABM capabilities. These are the Soviet SA-10 and SA-12 and the U.S. MIM-104. An ABM system is a complex network of missile launchers, engagement and tracking radars, and early warning radar and communication systems.

For example to support the ABM-1 system around Moscow, 11 HEN HOUSE detection and tracking radars sited at six locations around the perimeter of the Soviet Union provide target-tracking information. Besides the large phased-array radars, the Russians maintain 7,000 radar systems at 1,200 sites to provide medium to high altitude coverage throughout the country.

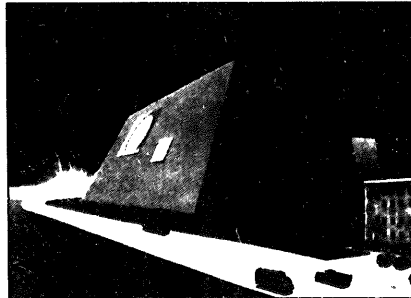


Figure 60: Pushkino ABM Radar

GALOSH

The ABM-1 (GALOSH) is a fixed ABM system only deployed around Moscow. Each multi-stage exo-atmospheric interceptor is housed and launched from gimbal-mounted cylindrical single-missile launchers. Sixty-four (64) missiles are deployed at four launch complexes. Each launch complex has six TRY ADD guidance and engagement control radars. The four complexes are jointly served by DOG HOUSE and CAT HOUSE target tracking radar. Additional radar support is provided by the Pushkino phased array early warning and tracking systems, PILLBOX radar. The missile is 18 – 19 m (59 – 62 ft) long and 2.4 – 2.7 m (95 – 106 in) in diameter.

GORGON

The ABM-2 GORGON is a silo launched high altitude long range missile. The GORGON (SH-04) is an exo-atmospheric missile that probably has anti-satellite capabilities. The GORGON is the GALOSH replacement. With the completion of the update, 100 ABM launchers will circle Moscow.



Figure 61: ABM-1B

GAZELLE

The ABM-3 GAZELLE is a silo launched high acceleration endo-atmospheric missile. This missile is designed to intercept targets missed by the GORGON or as a point tactical missile defense.

GRUMBLE

Several surface-to-air systems also perform ABM roles. A full discussion of these systems will be found in the following chapter on surface-to-air missiles. These systems include the SA-10 (GRUMBLE), an air defense system consisting of fully mobile wheeled vehicles. The system can operate as point defense against ballistic missiles. The TEL carries four missiles housed in circular canisters arranged in a square. A battery consists of eight TELs, a 3-D surveillance radar, and a search and acquisition radar, all mounted on 8x8 trucks.

GLADIATOR & GIANT

The SA-12 systems can engage SRBM and cruise missile targets. The SA-12A (GLADIATOR) and SA-12B (GIANT) air defense system is a fully mobile track-mounted system. SA-12A missiles are carried four to

a TEL, in a linear array of circular canisters. Each TEL has an integral guidance radar (mast) at the front of the TEL. A battery consists of six TELs, six launch and reload vehicles, one phased array missile guidance radar, and command vehicles. The battle unit, composed of four batteries, provides a detection/designation station, Command Post vehicle, panoramic surveillance radar, and a sector scanning radar. All are mounted on tracks.

PATRIOT

The MIM-104 (PATRIOT) system has limited anti-missile capabilities. The original system, Theater High Altitude Area Defense (THAAD) was an anti-tactical ballistic missile (ATBM) with full anti-missile capabilities. However, to comply with SALT treaties, the software has been purposely degraded to preclude use against ballistic warheads and missiles. The Patriot (MIM-104) is a fully mobile wheeled system. Each TEL carries four missiles in rectangular canisters arranged in a square. The TEL has a small radio mast at rear of the vehicle. Each battery consists of eight TELs, one AN/MPQ-53 phased array radar (surveillance, IFF, acquisition, target tracking, and guidance functions), one AN/MSQ-104 engagement control station, and one AN/MJQ-24 electric power plant. A battalion will consist of six batteries.

Surface-to-Air Missiles (Anti-Aircraft)

Anti-aircraft systems include both anti-aircraft artillery (AAA) and surface-to-air missiles (SAM). Since AAA and SAMs perform the same function, the location and configuration are similar. AAA and SAMs protect critical targets from attack from aircraft, cruise missiles, and ballistic missiles. Each system has a design envelope limiting the type and speed of possible targets and the maximum range and altitude for engagement. This design mandates both the location of the battery and the configuration of the weapons and support elements. Often AAA is sited to provide additional protection for the SAM batteries from air assault.

The SAM employment is influenced by two concepts, point or area defense. Point defense is protection of a specific target. The target can be a particular industrial or military complex, or an entire city. Point defense sites are

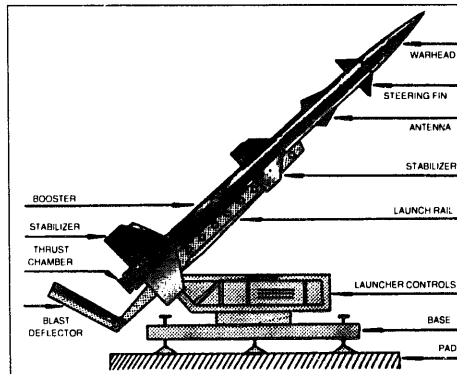


Figure 62: Typical SAM

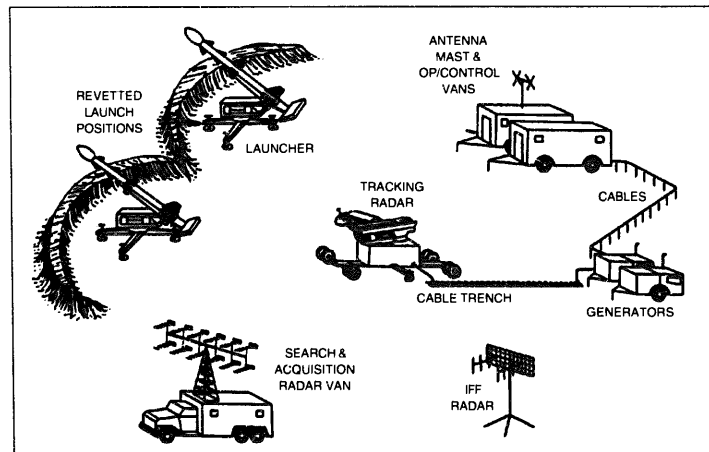


Figure 63: Typical SAM Site

normally clustered in concentric circles around the defended target. Point defense SAMs are often short range and include most mobile tactical systems. Area defense is the interception of attackers at a distance remote from targets. The line of SAMs is located away from the targets being defended. Area defense missiles include long range and high altitude strategic fixed systems. Area defense systems are sited to provide overlapping protection. Point defense systems may be incorporated within the area defense systems to protect these systems from attack.

SAM systems are composed of several identifiable elements that include the launch site, the acquisition radar and guidance site, and the assembly site. The assembly point is where the missile is received, stored, and checked out. This is usually a sheltered building or underground bunker. The type and quantity of associated equipment vary with the missile system. Some typical equipment includes missile storage and shipping canisters, missile transporters, cranes, support trucks, and checkout vans. For strategic missiles, the site is usually central to several missile launch sites. Tactical mobile units carry all the required equipment in associated vehicles.

The radar acquisition site may be separate from the missile launch site. Acquisition radar keeps track of possible targets and target information such as number, speed, altitude, and range of enemy planes or missiles. The information is sent to the missile launch site. Acquisition sites receive information from long range or early warning radars. This allows for a directed search for targets. Guidance sites may be incorporated within the missile launch site. The guidance site provides the particular type of information and control the system needs to intercept the target using various radar and radio control and direction methods. Possible modes include command, beam-riding, or semi-active homing.

Launch sites contain the missiles, launchers, and the necessary support equipment. The site varies with the system and mobility type.

AntiAircraft Artillery (AAA)

All AAA is emplaced to provide the guns with a clear field of fire against a line of restricted approach. Emplaced guns are arranged in pattern outlines from groups of guns. The battery is usually not camouflaged because of the requirement for unobstructed field of fire and quick gun tracking. Most light AAA has integral fire control radar. Heavier weapons may have a separate and external fire control radar and fire control.

Antiaircraft machine guns (AAMG) and light antiaircraft artillery (LAA) are light-weight and extremely mobile. They may be sited on top of buildings, towers, or on high ground. The lighter weapons are sometimes located within the actual target area. This caliber of weapon is used in defense against high speed low altitude aircraft. Entrenched emplacement is not always used. The AAMG (less than 20 mm) may be laid out in irregular patterns, clusters, straight lines (most common), or box patterns of 4-guns. Emplacement size for the AAMG is 1.2 – 3.7 m (4 – 12 ft). LAA (20 – 75 mm) are commonly laid out in 4 or 6 gun patterns, within emplacements of 4 – 6 m (13 – 20 ft) diameter.

Medium anti-aircraft artillery (MAA) can engage targets at medium to high altitudes. The MAA will be located in road accessible open areas (fields). The MAA is located within several thousand meters of the target area. MAA (76 – 100 mm) batteries are deployed in groups of 4, 6, or 8 guns. The 5 – 8 m (16 – 26 ft) diameter revetments are typically in box, circle, semicircle, trapezoid, straight line, or staggered line patterns.

Heavy anti-aircraft artillery (HAA) engages high altitude targets. The HAA (>101 mm) is deployed in the same manner as the MAA. The revetment size is more than 8 m (26 ft) in diameter. The pattern of revetments is similar to MAA, guns are usually in groups of 4 or 8 (rarely 6 or 12) guns.

Fixed Systems

Fixed systems are all those SAMs that are non-mobile or have limited mobility. These SAMs are sometimes referred to as strategic defensive missiles since they protect large or vital fixed targets of national importance. Some of these systems have limited mobility in the sense that they can be relocated. But the relocation is difficult and time consuming. Several major strategic systems will be discussed, however, the list only includes NATO or former USSR systems. Some systems have been developed by Communist China, North Korea, and several additional countries. Many of these missile systems are copies or modifications of NATO and Soviet design.

No matter which system is deployed, fixed strategic SAM sites have several features in common. The site has a ready missile storage area containing sufficient missiles for several engagements. The storage may be located near the launch points when rapid reloading facilities are present. Typical storage is in under-

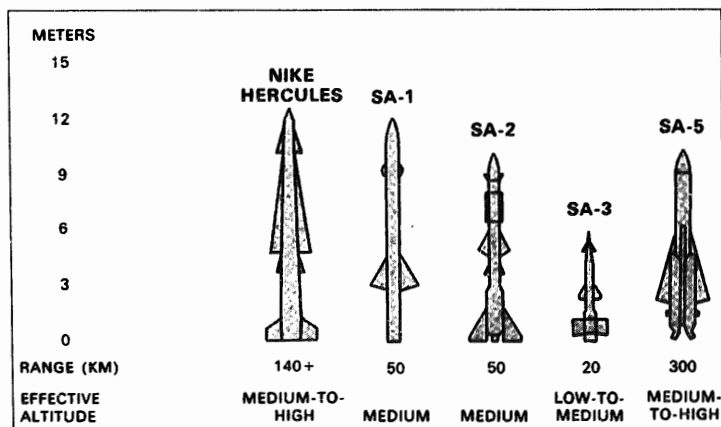


Figure 64: Strategic SAM Systems

ground bunkers or bermed buildings. Bulk fuel (liquid) storage will be located some distance from the complex and pipelines will link the bulk fuel facilities to launchers or revetted fuel transfer areas. Almost all modern systems use solid fuel motors and fuel will not require separate storage. Typically the solid fuel motor will be mated with the missile at the assembly point.

Launch, or firing, points consist of revetted circular or rectangular pads. The pads may be surfaced or consist of graded and rolled earth. Surface launchers (permanently fixed) consist of either rails or tables. Underground sites maintain large steel doors through which the launcher is raised for firing. The number and configuration of launch points are dependent on the missile system. The system used is partially dependent on the required reload rate and number of expected targets per engagement. Rails, elevators, trolleys, and other specialized devices transport ready missile reloads to the launcher.

Support equipment will consist of mobile missile transporters and cranes. Virtually every strategic site has a very well developed and well maintained road network linking the complex elements. The entire complex will be protected by security fencing or walls. Radar and radio guidance, tracking, control, and early warning equipment will be visible. This equipment may be centrally located or maintained in a separate location some distance from the actual launch pads.

BLOODHOUND

The Mk 2 Bloodhound is a strategic defensive nuclear capable system deployed in the UK only. The 7.75 m (25.5 ft) radar guided (illumination) surface-to-air missile is deployed as four fixed single rail launchers per battery. The system includes a mast mounted target illumination radar, search and acquisition radar, and a battery control center. The missile has a range of 80 km.

NIKE-HERCULES

The NATO NIKE-HERCULES (MIM-14B) is a long range (160 km) medium to high altitude command guided nuclear capable strategic defense system using a 2 stage 12.7 m (42 ft) long missile.

Nike-Hercules (MIM-14B) may be a relocatable site or a fixed site. Fixed sites consist of a launch area and a guidance site. Launch sites are hard surfaced launch positions with three single missile launchers, three launch positions

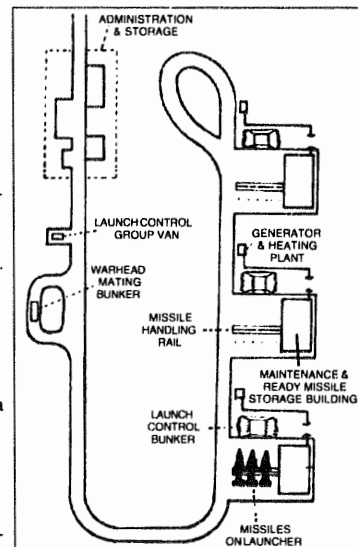


Figure 65: Nike-Hercules Launch Site (In-Line)

per area. The guidance site will be within 5 NM of the launch site within line of sight of the missiles. The battery control center, radar and radar test mast will be located here.

Launch site configuration may be in-line, L, or triangular. Each of three launch sites will have launchers, launch control building, maintenance and ready missile storage, and generator buildings (or vans). There is separate warhead mating building and a launch control group van. At the rear of each launch area is a large peak-roofed maintenance and missile ready storage building that services the three launchers. Each launch site has concrete earth covered control bunker, at the side.

Administration and security buildings are near the entrance to the site. The launch control van is located near the administration area. The warhead mating building is located on a loop road situated between the administration area and the launch area.

The guidance area has a generator, battery control center building, and a radar test mast (test mast is 150 m (500 ft) distant from the battery control center (BCC) and will be to the rear). Radars are in-line and consist of a target tracking radar, a target ranging radar, a missile tracking radar, a low-powered acquisition radar, and a high-powered acquisition radar.

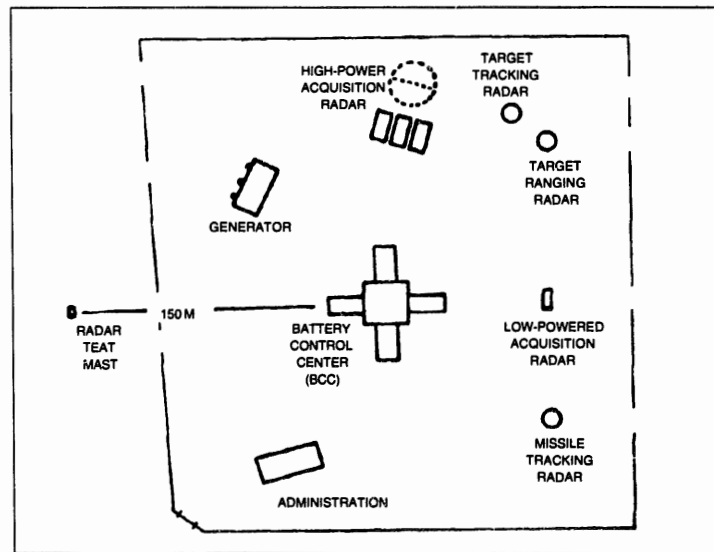


Figure 66: Nike-Hercules Guidance Site

SA-1

The SA-1 (GUILD) Soviet medium altitude missile is 12 m (39 ft) long and has a diameter of 0.70 m (27.6 in) with a range of 50 km. This almost obsolete missile is deployed at only three locations within Russia. The launcher is a modified V-2 (German A-4) table. The system launches from a vertical position. Guidance and radio command are by Yo-Yo radar.

SA-2

The fixed or semi-mobile (relocatable) missile is 11.3 m (37 ft) long and a diameter of 0.6 m (2 ft) with a range of 50 km. Soviet designation for the SA-2 (GUIDELINE) is S-75. This is a medium level surface-to-air missile is fired from fixed single-rail launchers. A battery consists of six launchers. Tracking and guidance is by FAN SONG (fire control) and SPOON REST (target acquisition) radars. The missiles are transported by a ZIL-157 truck tractor and semi-trailer. Transporter overall length is 14.5 m (47.5 ft) and width is 2.3 m (7.5 ft).

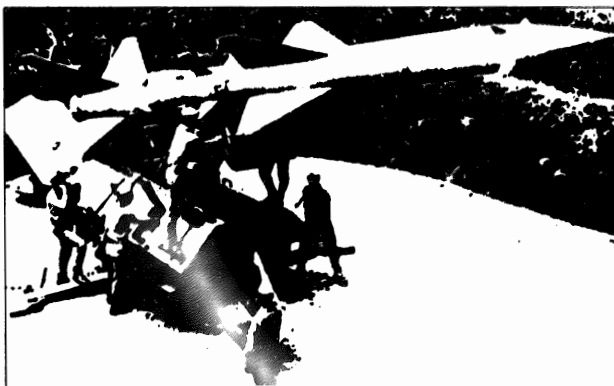


Figure 6.3.67: SA-2 (GUIDELINE) launcher

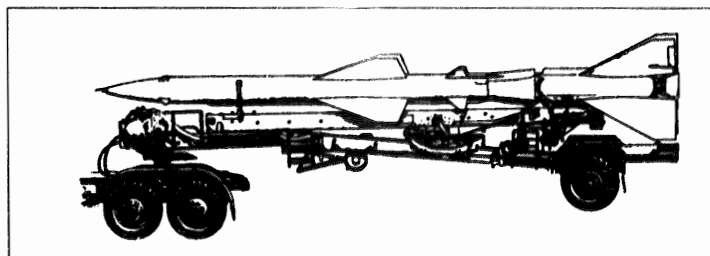


Figure 68: SA-2 (GUIDELINE) on Transporter

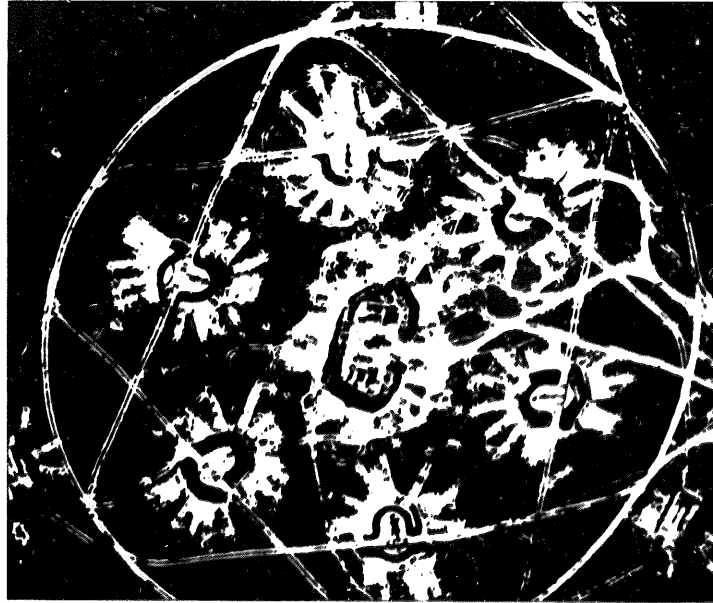


Figure 69: SA-2 Site Configuration

SA-3

The 2 stage solid fuel missile is 6.2 m (20.3 ft) long and has a diameter of 0.3 m (1 ft). The SA-3b (GOA) is a medium to low altitude system with a range of 20 km. Soviet designation for the SA-3 is S-125. The fixed non-mobile sites are deployed as batteries of four launchers, with each launcher holding two or four missiles. Radars include FLAT FACE (van mounted target acquisition), LOW BLOW (fire control) and SQUAT EYE (target acquisition) systems. Missiles are transported two per truck on a ZIL-157.

SA-5

This medium to high altitude long range (300 km) system is used for national air defense and is deployed only within the borders of Russia, former Soviet republics, and select client states, notably in the Arab states. Soviet designation for the nuclear capable SA-5 (GAMMON) is S-200. The missile is 10 m (33 ft) long and 0.875 m (34 in) in diameter. The SA-5 (GAMMON) surface-to-air missiles are deployed in batteries of six launchers. Radar is SQUARE PAIR.

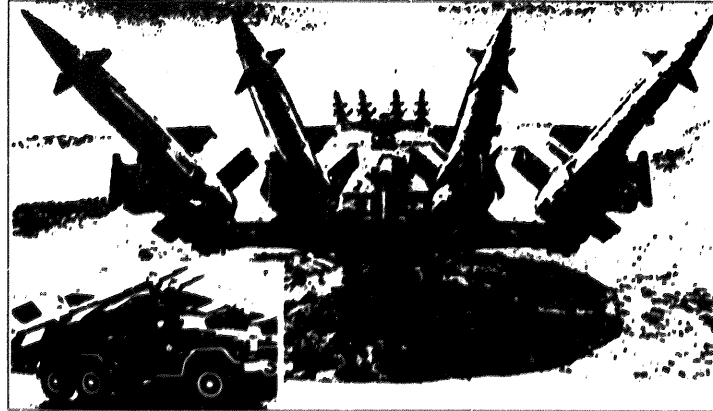


Figure 70: SA-3 (GOA) Launcher and Transporter

Mobile Systems

Although the operational concept of mobile and fixed systems are the same, there are some differences in the facilities. All fully mobile SAM systems have solid fuel motors. There is no requirement for fuel trucks, refueling points, or bulk fuel storage. Guidance and control systems are deployed in mobile vans and trailers. Support equipment is specialized missile transporters, maintenance vans, and security elements (using standard military vehicles). The firing points vary from any suitable cleared area for the fully mobile tactical units to revetted emplacements with a road network for units expecting long term deployment.

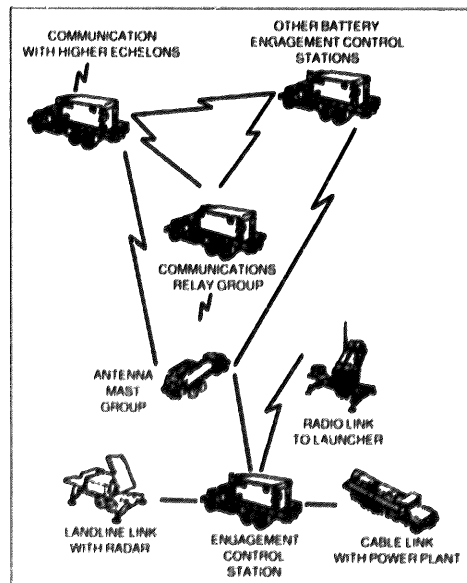


Figure 71: Integrated Communications Network (Patriot)

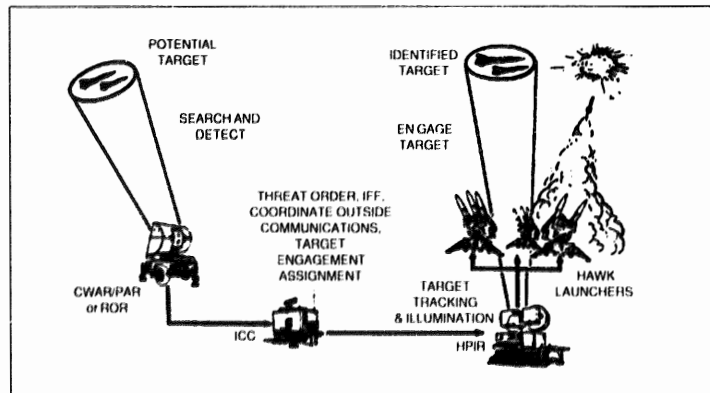


Figure 72: SAM Operations (HAWK)

An integrated air defense network not only is required to protect one area of operations, but is required to defend a large area. For this reason, numerous SAM batteries have to coordinate communications and operations. Each SAM unit has several communication and control channels available.

CHAPARRAL

The CHAPARRAL (MIM-72/MIM-72 C/F) is a low altitude, short-range, surface-to-air missile. The command to line-of-sight system uses a modified IR seeker derived from the Sidewinder AIM-9D. The 2.87m long missile has a range of 17.7 km, a speed of MACH 2.5, and an altitude limit of 6.1 km. Target acquisition is visual or radar with IR missile homing.

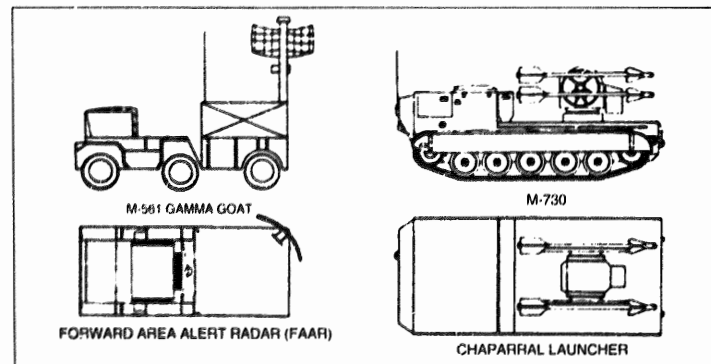


Figure 73: CHAPARRAL

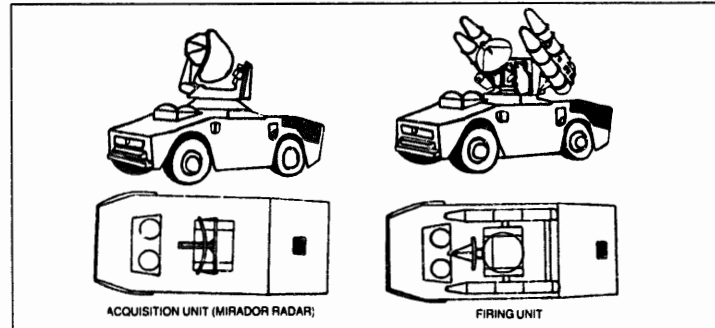


Figure 74: CROTALE

The fully mobile TEL is a tracked M730 carrying 4 ready to fire missiles in rotating turret and 12 reloads. The acquisition vehicle is a M561 Gamma Goat 6x6 truck carrying an AN/MPQ-49 surveillance radar. Normal U.S.A. deployment is in air defense battalions of 2 Chaparral batteries (total 24 launchers) and 2 M-167 (self-propelled Vulcan 20mm AAA). Each launcher unit operates independently and there is no set battery configuration.

CROTALE

The CROTALE is a short range, low altitude, all weather, surface-to-air missile. The command to line of sight MACH 2.3 missile has a range of 10 km operating at altitudes of 15 m – 4 km. Also known as the CACTUS Air Defense System the missile is 2.89 m in length.

The fully mobile system is based on the P4R 4x4 truck. Deployed as one acquisition unit, three TELs, and reload units. The acquisition unit carries the acquisition radar. The TEL carries tracking radar for missile tracking and guidance, and four R440 missiles in tubular launchers. The reload unit is a truck with a crane. Before the 4000 series, units were connected by landline cabling with a maximum

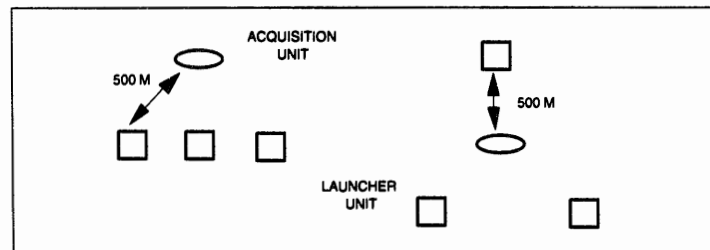


Figure 75: Field Deployment for CROTALE

separation of 800 m. Series 4000 and later have radio linkage permitting separation of 2 kilometers between system components. Series 5000 permits the addition of four short range, point defense missiles to be added to the exterior of two of the R440 canisters for saturation defenses. The trucks are 6.22 by 2.65 m.

The CROTALE is field deployed in a line formation of three TELs with the acquisition radar a maximum of 500 m from the farthest TEL. An alternative formation is a triangular arrangement with the radar occupying the center position.

The SAHV-3 is a replacement system for CROTALE consisting of a new turret and upgraded missile using the standard CROTALE chassis.

HAWK

The NATO HAWK (MIM-23) or I-HAWK (MIM-23B) is a mobile system using semi-active radar homing. The missile is 5.03 m in length with a range of 40 km at 2.5 MACH with operational ceiling of 15 m – 16.5 km.

Deployment is in 2 launch areas with three 3-rail launchers and a continuous wave illumination radar (CWILL) in each area. (Normal deployment of the HAWK is 6 launchers per battery. For the I-HAWK, deployment is 9 launchers per battery [TRIAD].) Both areas share a pulsed acquisition radar (PAR), a continuous wave acquisition radar (CWAR), a range only radar (ROR), an AN/TSW-8 battery control center (BCC), an AN/MSW-11 Platoon Command Post, and a communications area (AN/MSQ-95 Information Coordination Central van).

There is 1 AN/MPQ-50 PAR per battery for volume search of targets. Each battery uses 2 AN/MPQ-48 CWAR (3 in TRIAD battery) for low altitude search. One AN/MPQ-51 ROR is a J-Band unit used to defeat ECM. The AN/MPQ-46 CWILL provides missile guidance, there are 2 in standard batteries and 3 in TRIAD batteries.

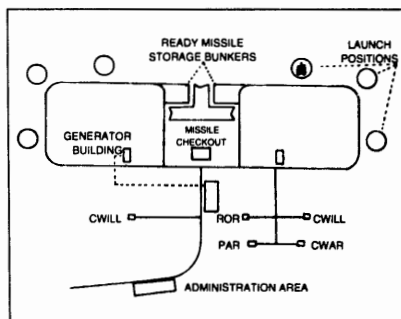


Figure 76: HAWK Strategic Site

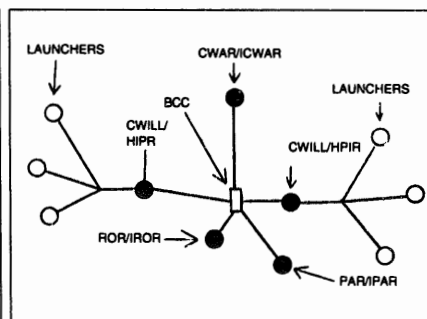


Figure 77: HAWK Tactical Site

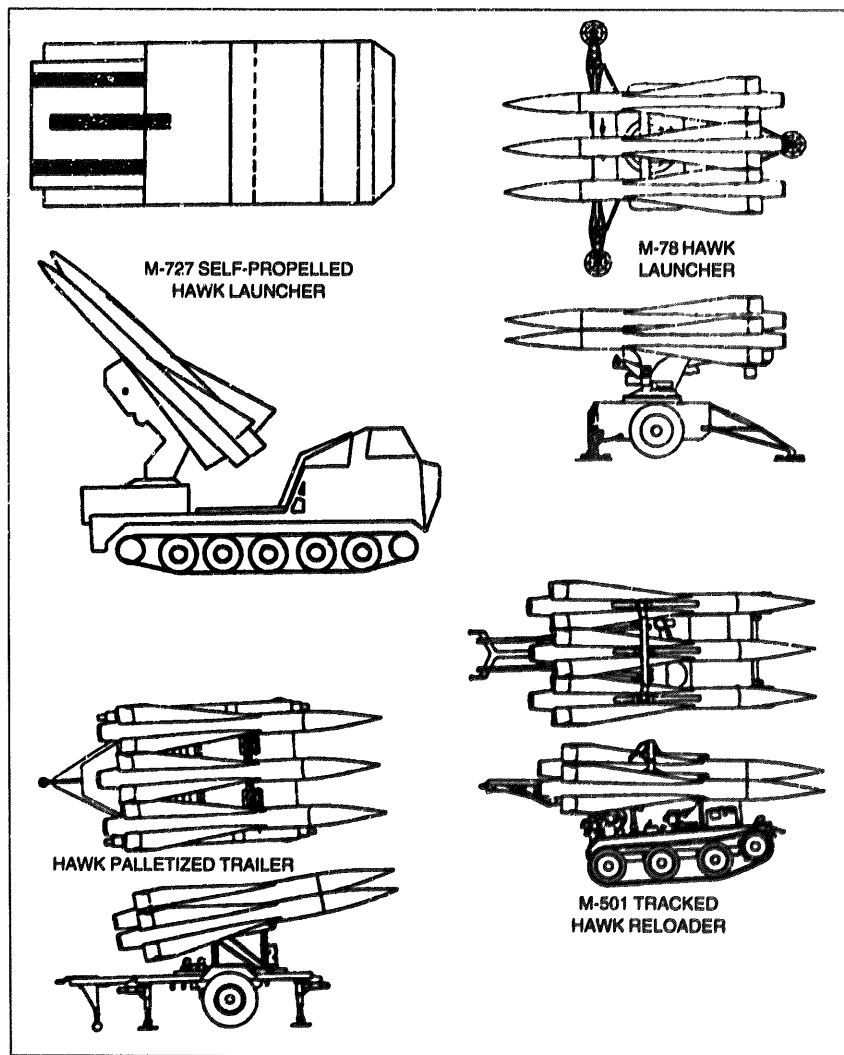
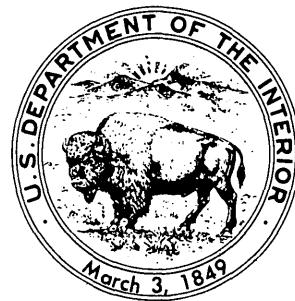


Figure 78: HAWK (or I-HAWK) Missiles and Transporters

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Land Use/Land Cover and Environmental Photointerpretation Keys

U.S. GEOLOGICAL SURVEY BULLETIN 1600



Land Use/Land Cover and Environmental Photointerpretation Keys

By George L. Loelkes, Jr., Gordon E. Howard, Jr.,
Eddie L. Schwertz, Jr., Phillip D. Lampert,
and Stephan W. Miller

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PREFACE

In 1975, the U.S. Geological Survey initiated production of land use and land cover and associated maps for the United States. Documenting the land use categories shown on the maps and providing insight into the environmental effects of land use have been long-standing user requirements. This USGS publication illustrates the various land use categories in order to provide the user with a means of interpreting these categories from aerial photographs. Comments on potential environmental impacts are included.

Geographic areas to be used for this publication were reviewed in depth. Missouri was selected because land use and land cover map compilation for that area was complete. We reviewed and considered several well-known and respected thematic maps in an attempt to identify meaningful regions in the State which would be viewed as a framework for developing land use and land cover category documentation. Among these maps were Kuchler's Potential Natural Vegetation map of the United States, Lobeck's Physiographic Provinces, Fenneman's Physical Divisions, and Hammond's Classes of Land Surface Form in the Forty-Eight States. While all of these maps portray basically similar themes, each addresses only a specific characteristic relating to the surface of the land. None of the maps provides a logical framework for all the land use and land cover categories. Accordingly, it was decided to use the USGS Land Use and Land Cover maps of Missouri to select the locations of specific land use and land cover patterns illustrated in this publication.

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LAND USE/LAND COVER AND ENVIRONMENTAL PHOTOINTERPRETATION KEYS

By George L. Loelkes, Jr.¹, Gordon E. Howard, Jr.², Eddie L. Schwertz, Jr.¹,
Phillip D. Lampert¹, and Stephan W. Miller¹

ABSTRACT

The preparation of land use maps requires a basic understanding of photointerpretation principles, land use taxonomy, and the proper use of mapping specifications. Each of these topics is developed in sufficient detail to ensure that the reader is exposed to these basics. Since the use of the land can present different environmental impacts, the potentials for environmental degradation are analyzed. Perhaps the most difficult tasks involved in land use mapping is recognition of the different land use types. Aerial and ground photographs, when combined with narrative descriptions, can provide a ready reference for the photointerpreter. Over 230 illustrations and narrative descriptions meet this need.

SECTION 1: INTRODUCTION

This publication has been jointly prepared by the U.S. Geological Survey and the Environmental Protection Agency (EPA) as a means of disseminating information on the U.S. Geological Survey land use and land cover mapping effort and the potential effects of land use on the environment. Primarily, the guide is intended for use by land resource and

environmental planners and managers who utilize land use and land cover maps in decisionmaking.

This guide serves as a learning tool for the use of remote sensing technology and land use and land cover classification and mapping, (table 1-1), as well as an environmental guide and photointerpretation key to help users better understand the photographic recognition features of the various land use and land cover categories. It documents the existence of various Missouri land use and land cover categories as they are portrayed on the maps produced by the U.S. Geological Survey. Finally, it provides a set of environmental keys which can be correlated with various land use and land cover categories and patterns (figure 1-1).

The guide is designed to demonstrate the applicability of land use and environmental keys; to develop data acquisition techniques for compilation of the keys; and to indicate the potential effects of various land uses on the environment.

Ultimately, it may be possible to produce a series of regionally oriented guides to provide land use and land cover and environmental keys for the United States.

The State of Missouri was chosen for the first guide for several reasons. Missouri contains a variety of topographic forms, vegetative cover, agricultural practices, and urban areas of various sizes and patterns. Second, the land use and land cover and associated maps of the State of Missouri had been completed. Finally, since the authors work in Missouri, the cost of acquiring photographs and field data could be kept to a minimum.

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Table 1-1.--USGS Land use and land cover classification system for use
with remote sensor data

(Anderson and others, 1976, p. 8)

Level I	Level II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Built-up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural areas
	23 Confined Feeding Operations
	24 Other Agriculture Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forested Wetlands
	62 Nonforested Wetlands
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

MISSOURI

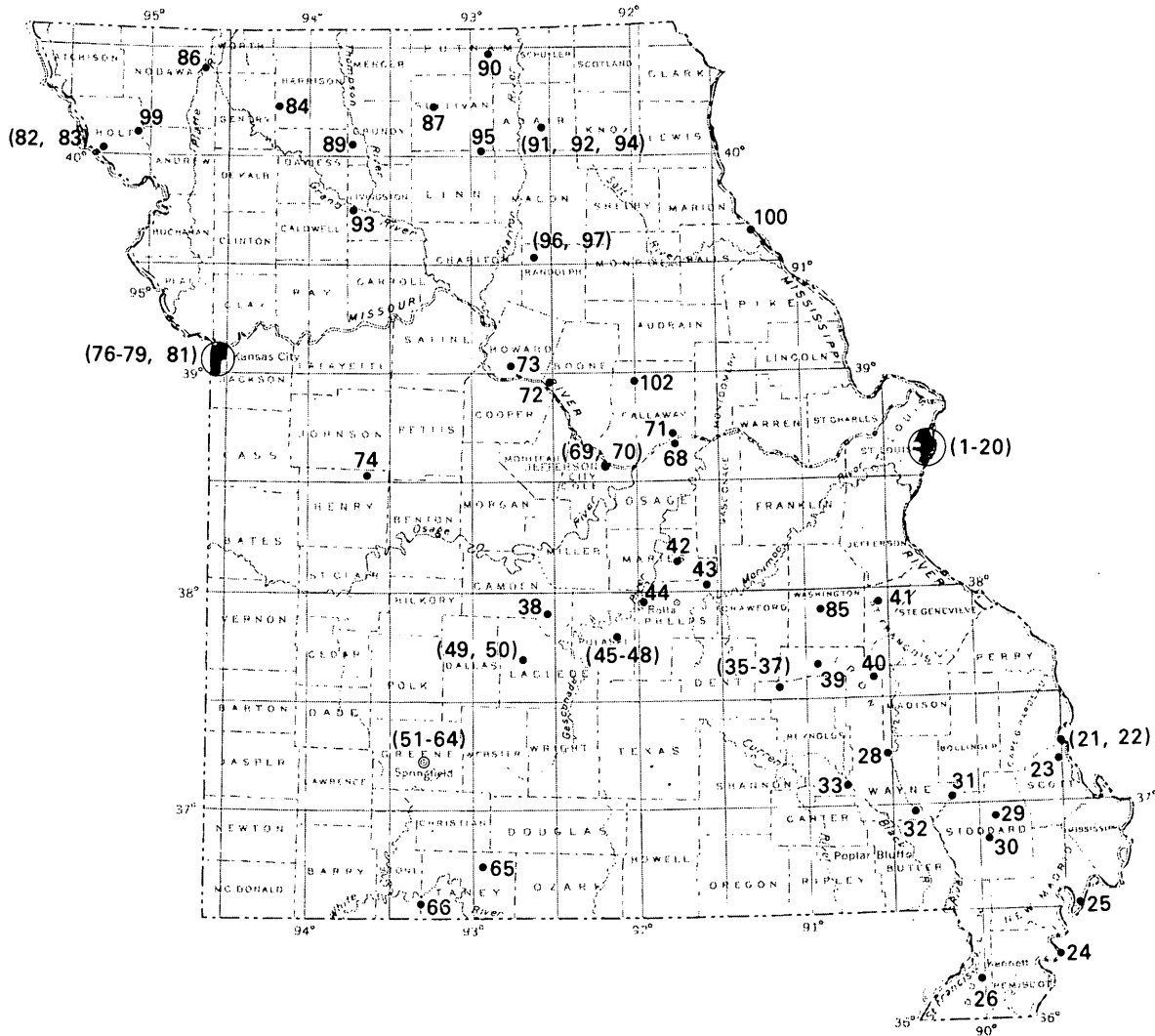


Figure 1-1.--Photointerpretation keys--site locations.

SECTION 2: REMOTE SENSING FOR LAND USE INTERPRETATION

What is Remote Sensing?

Remote sensing can be defined as the acquisition of information by a detection device that is not in physical contact with the object or phenomenon under study. Remote sensors for land analysis are of two major types: photographic and nonphotographic.

Photographic sensors produce an image directly on a film emulsion from reflected electromagnetic radiation of wave lengths in the visible and near-infrared portions of the electromagnetic spectrum. The common camera is the best-known photographic sensor.

In comparison, nonphotographic sensor images are captured by a suitable detector and stored as electronic impulses by a recording device. Nonphotographic sensors operate in the ultraviolet, visible, infrared, and microwave portions of the electromagnetic spectrum.

Nonphotographic sensors can be further classified as passive or active. Nonphotographic, passive remote sensing systems detect energy emitted or reflected as radiation from a given scene. The system produces, transmits, and records no energy of its own. Two of the most frequently used nonphotographic, passive remote sensing systems are multispectral scanners, such as those on board the Landsat satellites, and the thermal infrared scanners used to detect temperature contrasts in water bodies, forest fires, and home insulation efficiency analyses (thermograms).

Nonphotographic, active remote sensing systems transmit their own electromagnetic signals at objects and then record the energy reflected or refracted back to the sensor. Radar remote sensing devices are the most commonly used nonphotographic active remote sensors. Radar sensors are particularly well suited for imaging landscapes obscured by clouds.

The illustrations used in section 6 were obtained with conventional photographic cameras. The reader should refer to available textbooks on remote sensing or photogrammetry for more specific information or details on photographic or nonphotographic sensors (see "Selected References").

Resolution

Resolution refers to the minimum separation between two objects at which the objects appear distinct and separate on an image. The

greater the ability of the remote sensor system to distinguish separate objects, the greater the image resolution. Image quality is a function of the remote sensor system's component resolving powers. The combined effect of the system components, such as camera focal length, shutter speed, film type, and sensor altitude (together with other factors such as Earth curvature or atmospheric haze), contributes to the overall resolution of the image.

Although the term "resolution" is used to describe the capabilities of photographic sensors to produce sharply defined images, it is also used to refer to the capabilities of nonphotographic sensor systems to produce sharply defined images. However, unlike photographic sensor systems in which resolution is expressed as line pairs per millimeter, nonphotographic sensor resolutions are expressed in a variety of ways (see Reeves, 1975).

The theoretical maximum resolution of a sensor system is rarely achieved in actual operation. Although resolution is admittedly an important aspect in mission planning, one should remember that resolution is the minimum separation between two objects for which the images appear distinct and separate; it is not the size of the smallest object that can be seen on an image. With the knowledge of the smallest objects that will have to be identified and their spacing characteristics, one can plan a mission (Sabins, 1978, p. 22-25).

Although most planners and natural resource agency personnel believe that scale is the most important factor in producing thematic map products, it should be noted that remote sensor system resolution is usually more critical than the original photographic or nonphotographic scale. The scale of an image can be enlarged or reduced; however, nothing can be done to increase the degree of detail captured as a function of the remote sensor system resolution once the mission has been completed.

Scale

Scale refers to the mathematical relationship between a distance on an image and the corresponding distance on the Earth. The larger the scale, the closer the image size is to the actual size of the object. For example, a scale ratio of 1 inch on the photograph equals 1 inch on the Earth means that an exact one-to-one relationship exists. This relationship can be expressed as a ratio

with a colon (1:1) or as a representative fraction, with the numerator referring to the measurement on the photograph and the denominator referring to the measurement on the Earth's surface. When referring to scale, it is important to remember that the relationship expressed is a ratio. Therefore, it does not matter whether one uses inches, miles, or any other unit of measurement; only that the same units be used for both the image and its corresponding distance on the Earth's surface.

Camera scale is also the ratio of the focal length of the camera to elevation of the camera above the terrain being photographed. Mathematically, the scale is calculated as follows:

$$\text{Scale} = \frac{H-h}{f}$$

H = aircraft altitude above mean sea level

h = mean ground elevation

f = focal length

For example, suppose an aircraft is flying at an altitude of 22,000 feet above mean sea level (msl), with a 6-inch (0.5 foot) focal length camera, over an area with a mean ground elevation of 2,000 feet. Inserting these values into the above equation yields the following results. Accordingly, the scale of this photograph is 1/40,000.

Scale =

$$\frac{(22,000 \text{ ft.} - 2,000 \text{ ft.})}{0.5 \text{ ft.}} = \frac{20,000}{0.5} = 40,000$$

It should be noted that different focal lengths or different altitudes of the aircraft will result in different photographic scales. For example, if the camera focal length in the preceding example were increased to 12 inches, the scale would become 1:20,000. Suppose it was necessary to obtain the larger scale photographs but a 12-inch focal length camera was not available. The larger scale photographs could be obtained using a 6-inch focal length camera by reducing the flying altitude to 12,000 feet msl. However, every time the scale is increased by a factor of two, four times as many photographs are required to cover the same area.

Remote Sensing Platforms

The term "remote sensing platform" refers to objects, structures, or vehicles upon which

remote sensing devices are mounted. Remote sensing platforms can range from truck booms, to aircraft, to Earth-orbiting satellites. The decision to use a particular platform is primarily a function of the altitude, stability, and temporal requirements for a specific remote sensing project.

Although there are three main categories of remote sensing platforms--ground-based, aircraft, and spacecraft--only aircraft and spacecraft will be addressed in this section.

Even though it is quite common to have both photographic and nonphotographic sensors (such as multispectral scanners, thermal scanners, and radar) mounted on aircraft, photographic sensors are carried on board spacecraft to a far less extent than on aircraft. Some notable exceptions include cameras which were carried into space on board Apollo flights, Skylab, and the Space Shuttle.

The list of specific types of aircraft and spacecraft platforms is very long. The reader should refer to the Manual of Remote Sensing (Reeves, 1975, pp. 539-588) for descriptions of these platforms.

Photographic images are classified according to platform type as either aerial photographs or satellite photographs. Aerial photographs can be further categorized as low-, medium-, or high-altitude photographs. Although the specific values for each of the three ranges differ from user to user, a practical method of altitude classification takes into consideration aircraft operational characteristics and the suitability of the final photographs for topographic and/or planimetric mapping.

Most fixed-wing propeller-driven aircraft operate below 24,000 feet msl. Aerial photographs acquired below 24,000 feet msl will generally have a medium to large photographic scale. Photographs obtained below this altitude can be classified as low-altitude aerial photographs. Photographs acquired above 24,000 ft. msl will have a medium to small photographic scale and are most often classified as high-altitude photographs.

Photographs of the Earth have been taken on the Gemini, Apollo, and Skylab missions. For example, Skylab was placed in orbit about 270 miles (435 km) above the Earth. On board Skylab was a six-lens multispectral camera system with a 6-inch focal length and an Earth terrain camera system with an 18-inch focal length. Both of the camera systems were used extensively to test different film/filter combinations from space.

Nonphotographic remote sensors have been mounted on a variety of aircraft and spacecraft platforms. Since this guide is

aimed toward the use of conventional aerial photography and its interpretation, the topic of nonphotographic remote sensors will not be covered in depth. In addition to the photographic sensors onboard Skylab, five nonphotographic sensors were operated: an infrared spectrometer, a multispectral scanner, a microwave-scatterometer, an altimeter, and an L-band radiometer.

Landsats 1, 2, and 3 have been equipped with a return beam vidicon (RBV) television camera and multispectral scanning (MSS) system.

Figures 2-1, 2-2, 2-3, and 2-4 illustrate scale and ground resolution differences from four different remote sensor platforms.² Figure 2-1 is an MSS band 5 image from Landsat 1 taken from approximately 570 miles (918 km)--ground resolution approximately 200-250 m, approximate scale 1:1,000,000 (Sabins, 1978, p. 69). Figure 2-2 is a black-and-white reproduction of a color-infrared (CIR) satellite photograph obtained from Skylab 2 at approximately 270 miles (435 km) with an 18-inch focal length camera--ground resolution 30-40 m, approximate scale 1:950,000. Figure 2-3 is a black-and-white reproduction of a high-altitude CIR photograph taken from approximately 65,000 feet msl with a 6-inch focal length camera--ground resolution 4-5 m, approximate scale 1:130,000. Finally, figure 2-4 is a black-and-white USGS aerial photograph taken from an altitude of approximately 15,000 feet



Figure 2-1.--Portion of a Landsat 1 MSS Band 5 image of St. Louis, Mo., (near center of image) October 20, 1972, (approximate scale: 1:1,000,000).

²Ground resolution refers to the smallest object size or distance on the ground which can be identified. As a "rule-of-thumb," ground resolution is four times the overall system resolution (detection resolution).

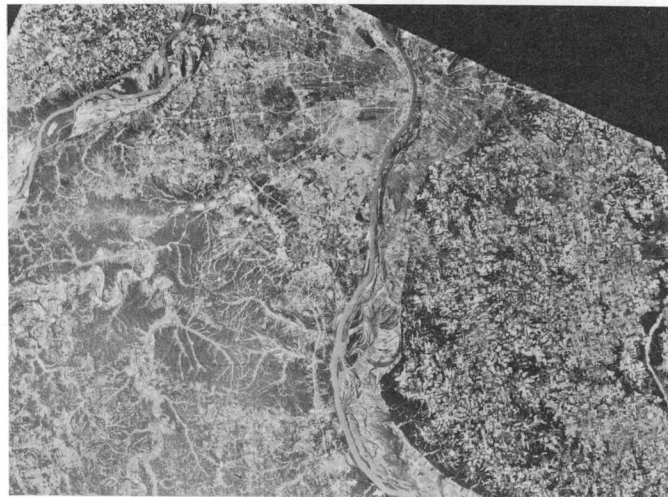


Figure 2-2.--Black-and-white reproduction of a portion of a Skylab 2 color-infrared satellite photograph of St. Louis, Mo., (top-center of photograph) September 6, 1973 (approximate scale: 1:950,000).



Figure 2-3.--Black-and-white reproduction of a portion of a NASA high-altitude, color-infrared photograph of St. Louis, Mo., October 9, 1974, (approximate scale: 1:130,000).

msl with a 6-inch focal length camera--ground resolution 1-2 m, approximate scale 1:30,000.

Note that as the remote sensor altitude decreases, the photographic resolution increases, and the ground resolution (the smallest recognizable object size) increases.

At present, detailed land use mapping relies most heavily on high-resolution aerial photographs. Satellite photographs and spacecraft multispectral scanner images, for

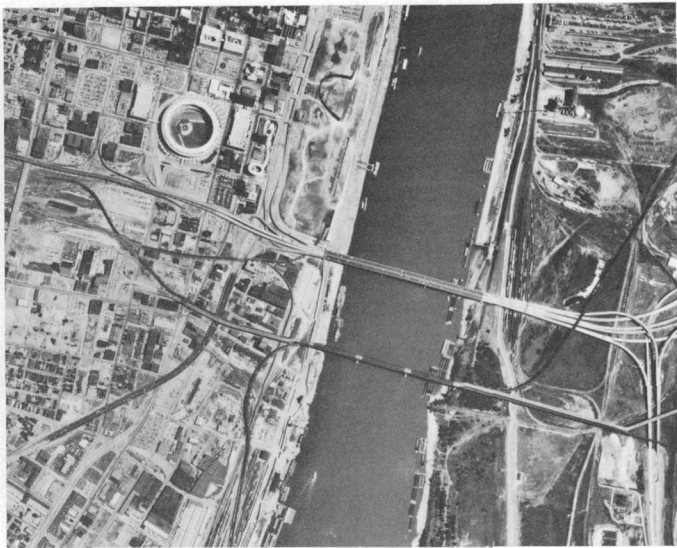


Figure 2-4.--Portion of a black-and-white vertical mapping photograph of downtown St. Louis, Mo., July 30, 1974, (approximate scale: 1:30,000).

example, Landsat images, are used for more generalized land cover mapping (see table 1-1, Level I categories).

As explained in the following section, the primary photographic data source for the USGS national Land Use and Land Cover Level II mapping program is either NASA "U-2" high-altitude color-infrared (1:120,000- to 1:130,000-scale) photographs or 1:80,000-scale black-and-white USGS quad-centered photographs.

Aerial Film Types

Photographic film consists of a cellulose acetate or polyester base coated on one side with a light-sensitive layer (the emulsion) and on the other side, with an antihalation backing--a light-absorbing coating which prevents backscatter of the photographic image beyond its proper boundaries. Silver halide crystals suspended in a gelatin are the main active ingredients in the film emulsion.

During the time that the camera shutter is open, light strikes the emulsion and the image of the scene is recorded on the film as a reversed, or negative, image. The amount of light reaching the film base determines the film density (opaqueness) for any specific area of the film. The greater the amount of light reflected from an object, the more dense the film's area for that object. When positive images are printed from the negative film, the dense areas of the negative hold back light and produce light tones on the print, whereas the less dense areas allow more

light to be transmitted to produce darker tones on the print.

The resolving power of the film affects the final resolution of the photograph. Among the factors that affect the film resolution is the size of the silver halide crystals or grains, which determines the exposure time required for correct density and contrast. Earlier, it was noted that the amount of light reaching the film base determines the film density for any specific area of the film. As the size of the silver halide crystals in the emulsion increases, the amount of light required to produce the correct density and contrast decreases. A fast film having rather large silver halide crystals in its emulsion layer requires a short exposure time. However, the large silver halide crystals reduce the film's ability to produce sharp images (film definition) and therefore reduce resolution.

The motion, particularly forward speed, of the remote sensor platform also has a bearing on choice of film speed. To compensate for the degrading effects of image motion, one must use a fast shutter speed and therefore a fast film to reduce blurring. However, as noted above, fast films have lower resolutions.

In general, black-and-white films have higher resolution than color or color-infrared films of comparable camera speed.

The most common type of film used for aerial mapping and photointerpretation is panchromatic film (see figure 2-5). Since panchromatic film is sensitive to the same wavelengths as the human eye (about 0.36 to 0.72 micrometers), the relative tonal values of objects on panchromatic photographs are similar to those seen by the human eye--a characteristic which facilitates the photo-identification process. Although panchromatic film is excellent for distinguishing between objects of different colors, it lacks sensitivity in the green portion of the electromagnetic spectrum, thus making distinctions between vegetative cover types difficult. Panchromatic film is the least expensive of the aerial films to process and develop.

Color aerial films are basically of two types--reversal and negative films. Reversal films, after the first stage of developing, are positive transparencies. Negative films, however, yield a negative transparency. A black-and-white reproduction of a color photograph (see figure 2-6) can be used for comparison with a panchromatic print (see figure 2-5).

Today's color aerial films have improved speeds, definition, and less granularity. When used with appropriate filters to reduce haze effects, color aerial films increase the photointerpreter's ability to distinguish and identify forest types, degree of sediment load



Figure 2-5.--Black-and-white mapping photograph of downtown St. Louis. Notice the dark gray tones of the buildings and the light gray tones of nearby parking areas.



Figure 2-6.--Black-and-white reproduction of a color photograph of downtown St. Louis. Notice the lack of vegetation associated with the central business district (CBD).

in water bodies, and other landscape and manmade features exhibiting distinctive colors.

Aerial color-infrared (CIR) film, originally known as "camouflage detection film" and occasionally referred to as "false-color film," is sensitive to both the visible and reflected infrared portions of the electromagnetic spectrum (approximately 0.4 to 0.9 micrometers). Therefore, instead of being sensitive to blue, green, and red reflected light, its emulsion is sensitive to green, red, and infrared light when exposed through the required yellow (minus-blue) filter.

Aerial color-infrared film has excellent haze-penetrating capability because the yellow

filter eliminates the scattered blue wave lengths comprising most of the haze. In addition, since it is more sensitive to the near-IR portions of the spectrum, it is very useful in distinguishing land cover types based on different moisture contents. For this reason, it is used to discriminate camouflaged areas and diseased vegetation from healthy vegetation. Healthy vegetation appears red to magenta on CIR photographs whereas diseased vegetation appears darker red.

Color-infrared film is also helpful in identifying land/water interfaces, deciduous versus evergreen forest types, wetland areas (grayish-green to dark magenta colors), silt-

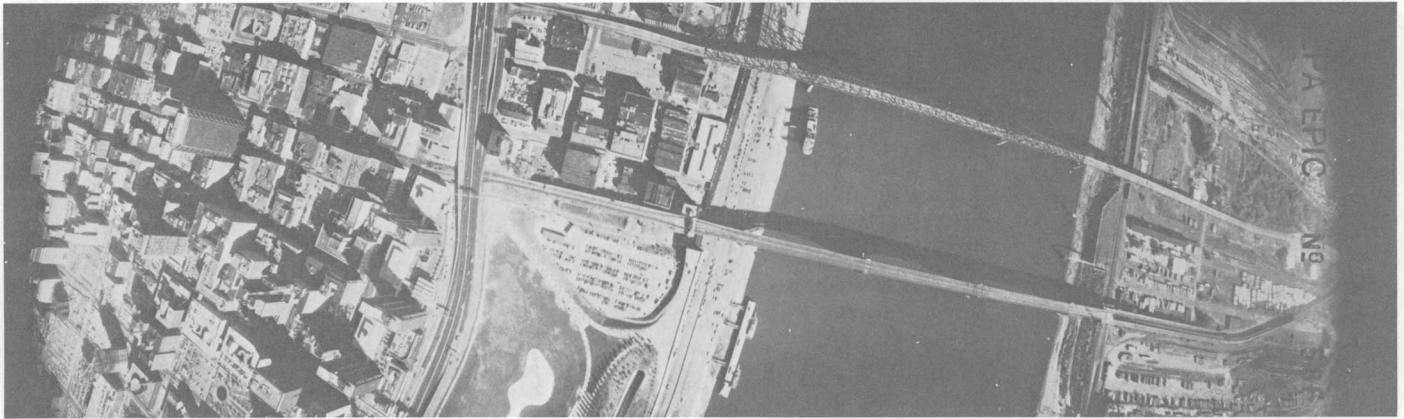


Figure 2-7.--Black-and-white reproduction of a color-infrared photograph of downtown St. Louis taken 3 months later. Note the loss of detail in shadow areas.

laden (light blue to white) versus clear water (dark blue to black) bodies, and delineating central business district (CBD) areas (bluish white) (Sabins, 1978, p. 44; Richason, 1978, p. 202-204). A black-and-white reproduction of a color-infrared photograph (see figure 2-7) may be compared for tonal differences with the panchromatic print (see figure 2-5) and the black-and-white reproduction of a color print (see figure 2-6).

Aerial Cameras

Aerial cameras can be classified by use (mapping, reconnaissance, or special), type (frame, panoramic, strip, or multiband), angular field of view (normal angle--up to 75°, wide angle--75° to 100°, super-wide angle--over 100°), and focal length (short--up to 6 inches, normal--6 to 12 inches, long--over 12 inches) (see Slama, 1980, p. 187-277). Probably, the most important distinction in cameras concerns their use--particularly mapping versus reconnaissance cameras.

Mapping cameras, often referred to as metric or cartographic cameras, are equipped with high-quality lenses to obtain the highest possible resolution and to reduce photographic distortions. Accordingly, the resulting photographs allow precise photogrammetric measurements. Aerial mapping cameras generally are of the frame type; that is, a camera in which an entire frame or format is exposed simultaneously through a lens that is a fixed distance from the film plane. Their total

field of view (angular coverage) across the diagonal is from 90° to 120°; that is 45° to 60° either side of the vertical position of the camera. Aerial mapping frame cameras generally use a 9- x 9- inch (23- x 23-cm) film format size.

The black-and-white photograph shown in figure 2-4 was taken with an aerial mapping frame camera. Section 6 of this guide, "Photointerpretation Keys for Missouri," contains various photographs taken with aerial frame mapping cameras.

Reconnaissance cameras are designed to provide maximum image resolution and only moderately good positional accuracy. These cameras are primarily used for intelligence gathering, land use change detection, and environmental monitoring. Reconnaissance cameras can be of the frame type or the panoramic type (see Reeves, 1975, p. 282-283). The large-scale photographs in the photointerpretation keys (Section 6) were acquired with cameras housed in an Enviro-pod. The Enviro-pod contains two KA-85A panoramic reconnaissance cameras. The cameras have a 3-inch focal length, 40° x 130° angular coverage (that is, 40° front-to-back along the flight line and 130° side-to-side perpendicular to the flight line), and a 70-mm-wide film. The cameras are mounted in a two-section aluminum housing. The camera in the forward section takes vertical photographs, while the camera in the rear section takes forward oblique photographs 45° down from the flight horizon. Figure 2-8 shows the Enviro-pod camera system strapped to a Cessna 172 aircraft.



Figure 2-8.--Cessna 172 aircraft with Enviro-pod camera system.

Although the cameras exposed color reversal film, the illustrations appearing in this guide are produced in black-and-white. Normally, exposures were made from an altitude of approximately 2,500 feet above mean ground level. Since the cameras have a 3-inch focal length, the scale at the center of each vertical photograph is approximately 1:10,000. Away from the center of the photograph, particularly near the sides, the scale becomes smaller and distortions increase significantly.

Since special-purpose cameras such as multiband cameras and special-effects cameras will not be discussed in this guide, the reader may wish to refer to Reeves, 1980, pages 187-232, for further information.

Although it is desirable to have mapping and/or reconnaissance aerial photographs, one should not overlook the utility of the hand-held camera. Photographs obtained from these cameras can be used to document land use changes and to verify photointerpretations. The traditional viewing angles offered by these cameras are more easily related to the understanding of land use and land cover categories. Therefore, the photointerpretation keys will often display ground-level or low-altitude snapshots of the objects being described to further assist the user in recognizing a particular land use or land cover type.

Photointerpretation

Photointerpretation is the detection, identification, description, and assessment of the significance of objects and patterns on a photograph. With respect to land use mapping, photointerpretation requires that land areas

be identified and assigned (classified) to a category in accordance with a land use classification scheme. In addition, the photointerpreter must follow specification guidelines for minimum area size and/or width measurements, density of occurrence (for example, four structures per 10 acres), and other relevant criteria to ensure consistent cartographic delineation of land use types.

The U.S. Geological Survey uses the classification scheme developed by Anderson and others (1976) and the mapping specifications (guidelines) as presented by Loelkes (1977).

Almost everyone can recognize and subsequently classify natural and manmade (cultural) features or objects from a vertical aerial photograph. Through our visual experiences, we unconsciously assemble a mental image library of recognition characteristics that describe the outward or physical appearance of an object--either natural or manmade. Typical characteristics are patterns, size, shapes, tones (gray-scale values on black-and-white photographs) or colors, textures (degree of roughness as exhibited on the photograph), shadows, and site associations.

Pattern. One of the most intriguing recognition characteristics of natural and manmade features are the patterns they make when viewed from the air. For example, an orchard planted in evenly spaced rows displays a characteristic grid pattern. The pattern of houses is significantly different for older, inner-city residential neighborhoods when compared to newer, suburban residential neighborhoods. Common terms used to describe landscape patterns include linear, circular, rectangular, square, concentric, radial, symmetrical, regular, irregular, random, and busy or congested.

Some features may be discernible as patterns at only certain scales. For example, an orchard becomes a texture at a smaller scale and a series of orchards may once again reveal a pattern at an even smaller scale.

Size. Both relative and absolute size aid in identifying features; for example, note the relative size differences between shrubs and trees and the absolute size difference between two parking lots. Because of the number of people who arrive each day, a shopping center requires more parking spaces than an industrial plant. Relative size comparisons are possible from an unscaled photograph; absolute size measurements require that the photographic scale be known or calculated.

Shape. Manmade objects tend toward straight linear shapes while natural features such as rivers or lakes tend toward irregular shapes with generally irregular boundaries. Easily recognized shapes include tennis courts, ball parks, shopping malls, highway cloverleaves, and schools. The terms used to describe shapes generally parallel the terms used to describe patterns.

Tone and Color. Photographic tone is the characteristic shade of gray exhibited by black-and-white photographs and is a function of light reflectance characteristics. Once a photointerpreter learns the different reflectance characteristics of objects, he or she can use this knowledge to help identify different land use types. For instance, cultivated fields tend to be darker than fallow fields, deciduous forests are lighter than evergreen forests, and commercial areas are lighter than residential areas. In general, higher moisture content yields darker tones.

Although the human eye can separate only 200 gray-scale values, it can separate over 5 million color combinations based on hues, values, and chromas (Reeves, 1975, p. 268). Because it is harder to learn to recognize objects by their tones (values) of gray than by color, it is easily understood why many interpreters prefer color photography. For example, Heller reported that the accuracies with which tree species could be identified were 17 percent higher on large-scale color transparencies than on panchromatic prints of the same scale (Lintz, 1976, p. 144).

Texture. Photographic texture is a function of the size of objects photographed and the scale of the photograph. Texture refers to the degree of roughness exhibited in a photograph.

On black-and-white aerial photographs, it is the arrangement of tonal repetition in objects which produces the texture characteristic. On large-scale photographs (for example, 1:4,800), individual tree crowns might be recognized, while on smaller-scale photographs (1:24,000 and smaller), the tree crowns are so small that only a texture appears. In general, coniferous forests exhibit a smoother texture than deciduous forests. Likewise, pasture provides a smoother texture than rangeland. Commonly used terms for texture are coarse, medium, smooth, fine, and mottled.

Shadow. Although most aerial photographs are obtained within 2 hours of solar noon, any shadows cast by objects can further aid in identification of an object. For example, the shadow cast by a cross helps to identify a

church, or the shadows cast by communication towers, monuments, trees, bridges, or oil tanks can also provide information to help verify their identity.

Shadows may also help to determine the size and height of an object. Knowing the scale and Sun angle of a photograph, one can measure the length of a shadow and calculate an object's height. If a shadow is cast by an object of known height (for example, a TV tower), a ratio calculation can approximate the unknown height of another object.

Site Association. Natural and manmade features often occur in certain places or in proximity to other objects. For example, willow trees are natural occurrences on floodplains or river sandbars. Likewise, cultural landscapes follow certain patterns of development. Elementary schools are located away from main traffic arteries, while shopping centers and other commercial establishments are found along or at the junction of major transportation routes. Heavy industry locates near railroads or along navigable waterways. High schools frequently have recreation areas and sports fields.

Interpretation Aids

The photointerpreter should not restrict identification of objects on photographs solely to the photographs. Any additional information should be used that will aid in the identification process. Reference materials, comparative photographic coverage, magnifiers, and stereoscopic viewing can each play a beneficial role in photointerpretation and verification.

Reference Materials. Perhaps one of the most useful sources of auxiliary reference information is the mental image library which a photointerpreter acquires by residing in a specific geographic area. However, the job of the photointerpreter normally extends well beyond his own geographic area. Lacking personal knowledge, one can refer to available planning and resource studies, maps, checklists, photointerpretation keys, or recognition manuals.

Planning and resource studies are usually available from local or regional agencies. Quite often, planning agencies have compiled various thematic maps, such as land use maps, which can also be of assistance to the photointerpreter.

Topographic maps, which present the horizontal and vertical positions of natural and manmade features, are readily available from the U.S. Geological Survey through its National

Cartographic Information Centers (NCIC) and through selected dealers in most larger cities. Topographic maps are very useful in identifying elevation interrelationships; for example, the occurrence of wetland tree species in low-lying, moist areas. Topographic maps further assist the photointerpreter by displaying detailed natural and manmade features from which additional significant information can be derived.

Checklists can give natural or manmade features which may occur in a geographic area or which are known to occur in proximity to one another. For example, Avery (1977, p. 24-25) has prepared a list of the kinds of features commonly occurring on aerial photographs. In addition, checklists are generally available for most natural resource professions (for example, see Avery, 1978, p. 13).

Photointerpretation keys illustrate recognition characteristics of particular features or groups of objects.

There are two types of photointerpretation keys: selective and elimination. Selective keys, of which this guide is an example, provide typical illustrations and descriptions of features in a specific category. The photointerpreter selects the key example that most nearly agrees with the object to be identified.

Elimination keys require the photointerpreter to follow a step-by-step elimination process from the general to the specific until the possible identification has been narrowed to one choice. This type of key is also called a dichotomous key (Avery, 1977, p. 25-26).

Finally, recognition manuals have been used primarily by the military to assist photointerpreters with recognition of military equipment: airplanes, ships, tanks, etc. More recently, recognition manuals have become available for natural resource features like tree species and for certain types of manmade features. For example, the State of Texas prepared a recognition manual for use in determining substandard housing structures (Texas Office of the Governor, 1972).

Stereoscopic Viewing. Stereoscopic viewing permits the photointerpreter to view objects in three dimensions and, because of the magnification of the viewing instrument, at a slightly larger size. With binocular vision, the photointerpreter views objects from slightly different angles with each eye, which

the brain interprets as relative distance. People having vision in only one eye are unable to view an object from two angles simultaneously, and therefore do not possess stereoscopic depth perception. Binocular vision can be simulated through use of aerial photographs taken of the same area from two different positions. The area common to both photographs can then be viewed in three dimensions.

The ability to view an object or feature stereoscopically adds yet another dimension to photointerpretation, particularly in identifying and differentiating vegetative types. Selected stereopairs have been included in the photointerpretation keys (section 6) where three-dimensional viewing would assist in identification.

Magnification. Quite often, even though a photograph's resolution has captured sufficient object detail, the photointerpreter is unable to recognize an object because of the photo's small scale. Magnifying equipment can enlarge the object and thereby add to the photointerpreter's ability to identify various features.

Comparative Coverage. Certain vegetative features (for example, deciduous trees) can be more easily identified if comparative photographic coverage exists. Since deciduous trees lose their leaves, comparative late fall or winter photographs facilitate the differentiation of deciduous from coniferous trees.

In addition to using seasonal photography, the photointerpreter may have access to color, color-infrared, or different-scale photographs. Therefore, the availability of comparable coverage should always be investigated.

Summary

Land use and land cover interpretation from remote sensing products requires knowledge of system components and characteristics of conventional aerial photographs--resolution, scale, platforms, and film and camera types. An understanding of how components interrelate to produce the final product is a key to successful photointerpretation.

Land use and land cover interpretation requires assignment of features to land use and land cover categories. The following section is devoted to this topic.

SECTION 3: LAND USE AND LAND COVER CLASSIFICATION SYSTEMS

Development of the Land Use and Land Cover Classification System

Background

Development of a regional comprehensive plan for natural resources is based, at least partially, on such factors as land use, soils, slope zones, geology, and drainage areas. Land use information, a main ingredient to the planning function, is an example of data generally not contained in a form suitable for correlation. Since land uses change faster than any other factor usually included in the planning process, land use information must be made available as quickly as possible.

Federal, State, and local agencies, as well as private consultants, have been producing land use and land cover maps for many years. These maps were compiled for specific programs or projects and have used a variety of land use and land cover classification schemes. These classification schemes were, for the most part, designed to meet the requirements of a particular program or project, and have such a diversity of content as to make them difficult to combine into a single comprehensive map.

U.S. Geological Survey Land Use And Land Cover Classification System

Knowledge of the character and utilization of land resources must be available if land resource-related problems are to be understood and controlled. In order to adequately inventory land resources, however, a classification system is needed to ensure that the data on cover characteristics and discernable activities related to land resources are objectively and consistently classified. Such a classification system has been developed by the U.S. Geological Survey for the national land use and land cover mapping program.

Land use surveys have been conducted for centuries, primarily for taxation. Agencies at all levels of government currently collect land use-related data for planning and analysis of land resource utilization. Such data are necessary if problems related to environmental degradation, loss of agricultural lands, wetlands, and wildlife habitats are to be reconciled with the need for sustained economic growth and energy development. Unfortunately, the result of many past inventory efforts has been duplication of effort and, conversely, data that subsequent to its first use, are of very limited value even when used for similar purposes.

The need for standardization among various agencies and recent developments in remote sensing and data processing technologies precipitated the U.S. Geological Survey's involvement in formulating a land use and land cover classification system. In 1971, an Inter-Agency Steering Committee on Land Use Information and Classification was formed including representatives from USGS in the Department of the Interior, the National Aeronautics and Space Administration (NASA), the Soil Conservation Service (SCS) of the Department of Agriculture, the Association of American Geographers, and the International Geographical Union.

The Committee sought to develop a classification system that would accommodate data from remote sensors on high-altitude aircraft as well as from conventional sources such as topographic maps or ground surveys. Although the Committee was formed to standardize classification used by Federal agencies, it was clear that a standard system could also provide a base for local, regional, State, and other agencies to use in formulating more detailed, compatible classification systems.

From the work of the Committee, as well as from consultation with States and other public agencies that had worked with classification systems employing remotely sensed data, the late James R. Anderson, USGS, developed a prototype for a national system. The system was designed with consideration of other classification systems and inventory efforts in use by the Federal government. This included the land use coding scheme promulgated by the Bureau of Public Roads in 1965, the Inventory of Major Land Uses conducted by the Economic Research Service of the Department of Agriculture, and the Conservation Needs Inventory of the SCS. The original version of the USGS classification system was published in Circular 671 in 1972.

Previously, the USGS had tested several classification systems in a series of pilot projects including the Census Cities Project, the Central Atlantic Regional Ecological Test Site (CARETS) study, the Phoenix Pilot Project, and the Land Use Mapping Project for the Ozarks Regional Commission. The latter project utilized high-altitude photographs and 1:250,000-scale topographic maps for the mapping effort. Many of the techniques involved in this project evolved into those used in the national land use and land cover mapping program now carried on by the USGS.

The categories of land use and land cover in Circular 671 were delineated to the second level of detail. Land use was defined as man's activities related to land resources, and land cover, as vegetation or artificial structures covering the landscape. The distinction is important, particularly for this classification system which, in contrast to other systems, attempted to cover all elements of the landscape in an equitable degree of detail.

Circular 671 suggested that Level I land use and land cover categories could be mapped using satellite imagery alone. Level II categories would require high-altitude aerial photographs (1:40,000 to 1:120,000) and the supplemental data which could be obtained from topographic maps. Level III categories would require medium-altitude photographs (1:20,000) combined with information from detailed topographic maps and other supplemental data sources. Level IV categories would require low-altitude large-scale photographs (larger than 1:20,000), but actually most data would be obtained from supplemental sources such as detailed large-scale maps or ground surveys.

The classification system proposed in Circular 671 was revised after several years of additional testing and research. The revised system is presented in USGS Professional Paper 964 (Anderson and others, 1976; see table 1-1 preceding). Like the prototype system, the revised classification system provides a Level II delineation of land use and land cover categories. General criteria for developing the classification system include the following considerations:

(1) The minimum level of interpretation accuracy in identifying land use and land cover categories from remote sensor data should be at least 85 percent.

(2) The accuracy of interpretation for the several categories should be about equal.

(3) Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another.

(4) The classification system should be applicable over extensive areas.

(5) The categorization should permit vegetation and other types of land cover to be used as surrogates for activity.

(6) The classification system should be suitable for use with remote sensor data obtained at different times of the year.

(7) Effective use of subcategories that can be obtained from ground surveys or from using larger scale or enhanced remote sensor data should be possible.

(8) Aggregation of categories must be possible.

(9) Comparison with future land use and land cover data should be possible.

(10) Multiple uses of land should be recognized when possible.

The categories of land use and land cover presented in Professional Paper 964 (Anderson and others, 1976) are being used for the national land use and land cover mapping program. Operational definitions of the classes and specifications for the national land use mapping effort are provided in USGS Open File Report 77-555 (Loelkes, 1977).

Characteristics of the USGS Classification System

The USGS classification system is compatible at the more generalized levels with previously developed classification systems and inventory efforts. An important difference between the USGS system and others is the fact that the system is designed to support extensive surveys of land use and land cover with consistent and uniform delineation of all elements of the landscape. This is in contrast to other systems in which one or a few land use and land cover types are differentiated in great detail while others are omitted or classified as miscellaneous.

An example of such a system is the Standard Land Use Coding (SLUC) system developed by the Bureau of Public Roads in conjunction with the Urban Renewal Administration (see table 3-1). This system based its classes upon economic activity and utilized, insofar as possible, the codes and description activities employed by the standard classification system of the U.S. Department of Commerce. The resultant system was extremely detailed so that groups of classes could be formed to meet the specific needs of different communities. Data for this system were generally collected through field survey methods or local knowledge of an area.

The SLUC system has been employed successfully in urban areas for community, transportation, and other forms of urban planning. Unfortunately, this classification system does not provide enough categorical detail for land areas which do not have an established economic activity related to the land resource. Such areas are simply aggregated into the category of "undeveloped land and water areas." For the purpose of land resource management and environmental impact assessments, this obviously does not provide enough detail. Wetland areas, wildlife habitat areas

Table 3-1.--Standard land use code (SLUC)--first and second level categories

(U.S. Urban Renewal Administration, 1965, p. 30)

Code	Category	Code	Category
2	Manufacturing	26	Paper and allied products--manufacturing
		27	Printing, publishing, and allied industries
		28	Chemicals and allied products--manufacturing
		29	Petroleum refining and related industries
3	Manufacturing (continued)	31	Rubber and miscellaneous plastic products--manufacturing
		32	Stone, clay, and glass products--manufacturing
		33	Primary metal industries
		34	Fabricated metal products--manufacturing
		35	Professional, scientific, and controlling instruments; photographic and optical goods; watches and clocks--manufacturing
		39	Miscellaneous manufacturing; NEC*
4	Transportation, communication, & utilities	41	Railroad, rapid rail transit, and street railway transportation
		42	Motor vehicle transportation
		43	Aircraft transportation
		44	Marine craft transportation
		45	Highway and street right-of-way
		46	Automobile parking
		47	Communication
		48	Utilities
		49	Other transportation, communication, and utilities, NEC*
5	Trade	51	Wholesale trade
		52	Retail trade--building materials, hardware, and farm equipment
		53	Retail trade--general merchandise
		54	Retail trade--food
		55	Retail trade--automotive, marine craft, aircraft, and accessories
		56	Retail trade--apparel & accessories
		57	Retail trade--furniture, home furnishings, and equipment
		58	Retail trade--eating and drinking
		59	Other retail trade, NEC*
6	Services	61	Finance, insurance, and real estate services
		62	Personal services
		63	Business services
		64	Repair services
		65	Professional services
		66	Contract construction services
		67	Governmental services
		68	Educational services
		69	Miscellaneous services
7	Cultural, entertainment, & recreational	71	Cultural activities & nature exhibitions
		72	Public assembly
		73	Amusements
		74	Recreational activities
		75	Resorts and group camps
		76	Parks

*Not elsewhere coded.

associated with particular vegetative cover types, and other diverse types of land cover conditions are not differentiated in the SLUC system.

A second major distinguishing characteristic of the USGS system is that it is a hierarchical system. Numerical codes are used for the various categories in the USGS system and the number of digits reflects the level of detail in the classification system being used (table 1-1). The first digit identifies the Level I class, the second digit the Level II class, and so on.

With a hierarchical scheme, the derivation and definition of the categories are more easily understood. Also, the hierarchical nature of the USGS system helps promote development of more detailed classification systems. At Level III, for example, the Level II category "Cropland and Pasture" (21) can be divided into two additional categories--211 (Cropland) or 212 (Pasture).

The State of Florida developed such a system which it adopted for use by State and regional agencies (see table 3-2).

Table 3-2. State of Florida Level I, II, and III, land use codes

(Extracted From Florida Department of Administration, 1976, p. 12.)

Level I	Level II	Level III
100 Urban or Built-up	170 Recreational	171 Swimming Beaches & Shores
		172 Golf Courses
		173 Parks, Zoos
		174 Marinas
		175 Stadiums
		176 Fairgrounds
		177 Community Recreational Facilities
		178 Racing Tracks
		179 Other Recreational
	180 Mixed--Any mixture of Urban or Built-up where no single use predominates	
	190 Open Land and Other	191 Undeveloped Land Within Urban Areas
		192 Inactive Land with Street Patterns but Without Structures
		193 Land Undergoing Active Development Without Indication of Intended Use
200 Agriculture	210 Cropland and Pastureland	211 Row Crops
		212 Field Crops
		213 Improved Pasture
	220 Orchards, Groves (except citrus), Vineyards, Nurseries and Ornamental Horticultural Areas	221 Tropical Fruit Orchards
		222 Deciduous Fruit Orchards
		223 Nurseries
		224 Ornamental Horticultural
		225 Vineyards
	230 Citrus Groves	231 Orange
		232 Grapefruit
		233 Other Citrus

Table 3-3. Sample multilevel land use classification system

(Developed by Geographic Investigations Office, Mid-Continent Mapping Center, Rolla, Missouri, 1980)

Commercial & Services ¹		SIC ²	SLUC ³
121 Wholesale Trade			
1211	Motor Vehicles & Automotive Parts	501	511
1212	Drugs, Chemical, & Allied Products	512, 516	5121, 5129
1213	Food & Farm Products	091, 097, 514, 515, 518, 5194	841, 514, 515, 5105
1214	Dry Goods & Apparel	513	513
1215	Electrical	506	516
1216	Hardware, Plumbing, & Heating Supplies	507, 5198	517, 5122
1219	Other Wholesale Trade	502-505, 508, 509, 511, 517, 5191, 5199	518, 5191-5194, 5196, 5197
122 Retail Trade			
1221	Building Materials, Hardware, & Farm Equipment	521, 523, 525-527	521-525
1222	General Merchandise	531, 533, 539	531-535, 539
1223	Food Stores	541-546, 549	541-546, 549
1224	Automotive, Marine, & Aircraft	551-557, 559	551-553, 559
1225	Apparel & Accessories	561-566, 568, 569	561-569
1226	Furniture, Home Furnishings, & Equipment	571-573	571-573
1227	Eating & Drinking	581	581, 582
1229	Other Retail Trade	591-594, 596, 598, 599	591-599
123 Commercial Services			
1231	Business Services	075, 731-737, 739, 893	631-636, 6391-6306, 6399, 6593, 6509
1232	Construction Services	152-154, 161, 162, 171-179 601-605, 611-616, 621-623, 628, 631-633	661, 662
1233	Finance, Insurance, & Real Estate Services	635-637, 639, 641, 651, 653-655, 661	611-616, 619

¹Only the Commercial and Services categories are presented here; however, a complete classification system was developed²U.S. Executive Office of the President, 1972³U.S. Urban Renewal Administration, 1965

The USGS also worked with the Water Pollution Control Department of Kansas City, Kansas, to develop a classification system for land use at Level IV (table 3-3). In addition, the system was cross-referenced to the Standard Land Use Coding Manual and the Standard Industrial Classification scheme.

It should be noted that a complete subdivision of all categories is not essential.

Table 3-4. Sample Level IV forest classification system

(Same categories would be repeated for Evergreen Forest Land and Mixed Forest Land; from Cook, 1980, exhibit 3, p. 1-2)

41	Deciduous Forest Land
411	10 - 39 Percent Canopy
4111	Sawtimber
4112	Poles
4113	Reproduction
4114	Mixed
412	40 - 69 Percent Canopy
4121	Sawtimber
4122	Poles
4123	Reproduction
4124	Mixed
413	70 - 100 Percent Canopy
4131	Sawtimber
4132	Poles
4133	Reproduction
4134	Mixed

Flexibility of the system allows modifications of the system to support a wide range of applications. For example, for forest management applications, it may be necessary to further subdivide the Level II categories of Deciduous (41), Evergreen (42), and Mixed Forest Land (43). These subcategories could be based on such factors as average stand height, crown closure density, or diameter of trees as indicated by their economic classes (see table 3-4).

For other applications, categories within the classification system can also be aggregated. In these cases, all lower level codes and categories can be grouped together to provide data for more-general codes and categories. As an example, acreage statistics for Level II categories 21, 22, 23, and 24 can be grouped together to provide statistics for Agricultural Land (Level I, code 2).

Summary

Inventories of land use and land cover require a standard classification system to ensure that data are objectively and consistently classified.

The USGS has fully defined a classification system to the second level of detail for the national land use and land cover mapping program. All elements of the landscape are provided consistent categorical detail. In addition, since the classification system is hierarchical in nature, it can be expanded to accommodate the need for greater detail.

With a viable land use and land cover classification system and suitable photographic source materials, one may proceed with the task of compiling a land use and land cover map.

SECTION 4: LAND USE AND LAND COVER MAPPING

Background

Land use and land cover mapping may be defined as "the systematic delineation of man's activities and the surface cover of the land." The maps produced by the USGS are specialized in that they use a unique set of mapping specifications and a classification system. They depict the land use and land cover classification categories and associated maps uniformly for the entire United States (see table 1-1).

The national land use data base was developed with three constraints in mind: (1) the mapped data should be compiled and published at the largest scale possible; (2) the map series utilized as a base must be complete for the entire United States; and (3) the map series used as a base must have a geographical format suitable for computer application.

The standard 1:250,000-scale topographic map series is the largest scale available that also meets the other requirements. Therefore, the 1:250,000-scale map series was selected as the standard base map for land use and land cover mapping. Certain areas, however, have been mapped at the 1:100,000-scale using the same specifications used as for the 1:250,000-scale map compilations.

For future efforts, it has been decided that revision of land use/land cover maps will be completed on the 1:100,000-scale map bases wherever possible. There have also been demonstration projects completed at a scale of 1:24,000. These large-scale land use and land cover mapping projects were limited in size and designed to test utilization of the land use and land cover classification system and specifications at larger scales.

When the land use and land cover program was initiated, the USGS determined which other types of map overlays should be correlated with the land use and land cover maps to provide the user community the greatest effectiveness in problem solving. From the multitude of maps considered, ranging in complexity from county boundaries to detailed soil types, the following map themes were selected: (1) political boundaries, (2) hydrologic units, (3) census county subdivision, (4) Federal land ownership, and (5) State land ownership.

The last two are only prepared when an entire State is compiled. Also, the State land ownership overlay is compiled only when a State furnishes the data.

The associated maps portray natural or administrative information and provide the user with the opportunity to utilize, either individually or collectively, the land use and land cover maps and data to produce graphic or statistical data for the areas portrayed on the associated maps. The mapping system is constructed in such a way that the graphical and statistical land use and land cover data can be related to other resource data sets such as soils, geologic, and hydrologic data as well as demographic and socioeconomic data.

Product Preparation

The Geological Survey's land use and land cover and associated maps are compiled in the Western Mapping Center, Menlo Park, Calif.; Rocky Mountain Mapping Center, Denver, Colo.; Mid-Continent Mapping Center, Rolla, Mo.; or Eastern Mapping Center, Reston, Va.

Before an area is authorized for compilation, it is necessary to determine the availability of source materials for the area. The prime source materials for small-scale land use mapping are aerial photographs which meet the following specific requirements: (a) the photographs should not be more than 3 years old; (b) there should be no more than 10 percent cloud or snow cover; (c) photographic scale should be 1:80,000 or smaller; (d) photographs must be tilt correctable when necessary; and (e) photographs should be acquired during leaf-off conditions.

Although all photographic source materials are examined for possible use, the most commonly used in the national land use mapping program are:

1. Color-infrared photographs taken at altitudes between 60,000 and 65,000 feet (scale between 1:120,000 and 1:130,000).

2. Black-and-white panchromatic photographs taken from altitudes of approximately 40,000 feet (scale of 1:78,000).

3. The National High-Altitude Photography (NHAP) program; scheduled to provide high-altitude photographic coverage for the entire United States every 7 years. The photographs collected consist of color-infrared photographs from a camera with an 8.25-inch focal length, and panchromatic high-resolution photographs taken with a 6-inch focal length camera.

For small areas not having photographs meeting the requirements, searches are made from other sources such as the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture.

When mapping land use and land cover at intermediate scales of 1:24,000 to 1:100,000, the photographs should be less than 18 months old at completion of compilation and range in scale from 1:20,000 to 1:60,000, depending on the scale of compilation. The remaining photographic requirements are the same as those for the 1:250,000-scale mapping program.

The source materials needed to compile the associated maps are gathered from various State and Federal agencies. The information needed to compile the political units map and the census county subdivision maps are obtained from Geological Survey topographic maps and the Bureau of the Census. The Geological Survey, Water Resources Division, provides published Hydrologic Unit State Maps at a scale of 1:500,000 from which the hydrologic units maps are compiled. State land ownership maps are compiled under a cooperative agreement with a State only if the source material is furnished by the State in a format acceptable for compilation. The Federal Land Ownership maps are compiled from data obtained from the various Federal agencies whose data will be shown on the finished map.

Other types of maps can be added to this set, such as soils, geology, utilities, highways, and floodplains. When adding other mapped data sets to the original land use and land cover data sets, data should be compatible in scale and content.

Field Activities

Field activities support two distinct phases of compilation of land use and land cover maps. These are (1) precompilation fieldwork, and (2) field checking of compiled sheets.

To accomplish precompilation field activities, the area is reviewed to determine the types and extent of land use patterns to be mapped. Air traverses, flown in a light aircraft at low altitudes (500 to 1,500 ft.) provide the opportunity to obtain low-altitude oblique photographs of the land uses. Data from the photographs are then plotted on a 1:250,000-scale topographic map and used along with a written report to brief the compiler on the area by comparison of the large-scale photographs with the vertical mapping photographs.

Post-compilation field checks allow the interpreter to classify difficult-to-interpret areas and to check the general accuracy of the map. If classification of problem areas cannot be resolved from an aircraft at a low altitude, a ground visit to the site is made. The areas

covered by field check photographs are plotted and a field report is written. The necessary corrections are made, and the map is forwarded for final reproduction.

Land Use and Land Cover Minimum Size Specifications

The minimum size specifications for delineation of the 1:250,000- and 1:100,000-scale land use polygons are as follows.

Polygons to be delineated must meet minimum size requirement, regardless of whether they were published at 1:250,000 or 1:100,000. The following categories must have a minimum area of 4 hectares (10 acres): all Urban or Built-up Land (11-17); Confined Feeding Operations (23); Other Agricultural Land (24); Water (52-54); Strip Mines, Quarries, and Gravel Pits (75); and Transitional (76), if urban. All other categories of land use and land cover have a minimum area of 16 hectares (40 acres).

In all categories mapped using a 4-hectare (10-acre) minimum mapping unit, the minimum width of a feature must be 200 m (660 ft.). This minimum width precludes delineation of very narrow or very long 10-acre tracts. All categories mapped using the 40-acre minimum mapping size use 400 m (1,320-ft.) minimum widths. Exceptions to this specification are limited access highways and all "double-line" streams on the 1:250,000-scale base map. Such areas have to have a minimum width of 100 m (300 ft.).

Land Use and Land Cover Delineation

Interpretation of the detail on aerial photographs and transferral of this information to the map base is accomplished by stereocompilation techniques or direct detail transfer. When stereocompilation techniques are used, maps are compiled at 1:250,000 or 1:100,000 scale with the use of a pantograph attached to a photogrammetric instrument (see figure 4-1).

The direct detail transfer technique (also known as monoscopic compilation) uses a modified microfiche viewer with 20x magnification (see figure 4-2). Using this technique, the photograph is scaled to fit the base map. In the case where the scale of a block of photography does not differ in scale by more than 3 percent, it is simpler to enlarge the base map to the average scale of the photograph. Transfer of land use polygon data from the photograph to the base map can be completed by sliding the photograph under the base map and

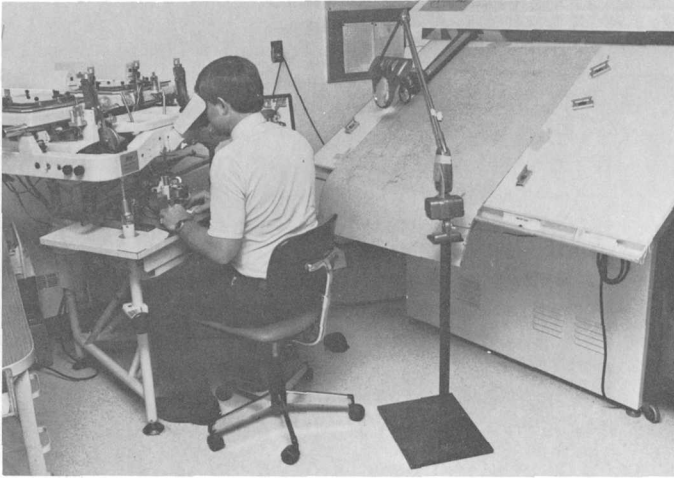


Figure 4-1.--Photogrammetric land use and land cover compilation.



Figure 4-2.--Direct detail transfer land use compilation.

aligning the photographic detail with the map detail. The detail viewed on the screen of a microfiche viewer can then be transferred to the map transparency by coordinating the image with the same image on the photograph positioned under the base map.

Generally, compilation by photogrammetric methods can be completed more quickly than by direct detail transfer; however, more time and effort are required for editing. With editing, the overall time required to compile any given area is found to be approximately equal for monoscopic and stereocompilation methods.

Associated maps are compiled on scribe coats at publication scale.

Political units map boundaries follow those county boundaries shown on the base map but must be verified with the County Subdivisions-Townships and Places maps from the Bureau of the Census. Political units map polygons are identified by five-digit codes obtained from the Geographic Identification Code Scheme (U.S. Bureau of the Census, 1972b).

Hydrologic unit boundaries and identifying eight-digit codes follow those shown on the State Hydrologic Unit Maps prepared by the U.S. Geological Survey. A legend of polygon unit names and codes is also compiled at this time from the USGS lists of "Boundary Descriptions and Names of Regions, Subregions, Accounting Units, and Cataloging Units," Water Resources Division, USGS, 1982.

The Census County Subdivision Map portrays census county subdivisions for nonmetropolitan counties and census tracts for Standard Metropolitan Statistical Areas (SMSA) as defined in the 1970 or 1980 Census of Population. Maps compiled prior to the 1980 census use 1970 census data, those compiled after the 1980 census use 1980 data. The political units boundaries from the Political Units Maps form the framework for delineation of the census county subdivisions. The County Subdivisions-Townships and Places map, and the maps from the appropriate Census Tracts: SMSA publications of the Bureau of the Census are used to obtain boundaries for this map. A legend of census county subdivision names and codes is also compiled at this time from the Geographic Identification Code Scheme (U.S. Bureau of the Census, 1972b).

The Federal land ownership map is compiled showing only surface areas of federally owned land occurring in units of 40 acres or more. A two-digit code is used to identify parcels of federally owned land.

The State Land Ownership map is completed only for those States which have a cooperative agreement with the National Mapping Division. Under this type of agreement, the agency must furnish the necessary compilation source information for compiling such maps. The code referencing system is designed separately for each State.

During the compilation process, all maps are checked with adjacent maps to ensure continuity. Map editing consists of an overall review of the manuscript for cartographic errors, such as missing identification numbers, broken lines, improper fittings, and any other obvious cartographic errors. In addition, a comparative review is made with the source

materials to ensure that map compilation meets specified requirements for photographic interpretive accuracy and delineation of polygons.

Quality Control

Quality control consists of an in-depth review of the map manuscript to determine if category definitions and specifications for interpretation and compilation have been consistently followed. A complete cartographic review includes reviewing the accuracy of interpretation, proper placement of identification numbers, adherence to specified minimum sizes for the land use and land cover categories and use of specified line weights. Errors are noted for correction on a stable-base overlay or diazo copy of the manuscript.

Three types of accuracy checks are performed. The first accuracy check is for interpretation. Various field validation techniques and processes are used to establish the accuracy of land use and land cover interpretations. The second accuracy check concerns delineation of polygons compared to boundaries existing on the Earth's surface. Since delineations are taken from photographic source materials, the outline is as precise as the scale of the photograph will allow. The third accuracy check is for positional accuracy. The positional accuracy of the maps must be consistent with that of the published map used as the compilation base.

In addition to quality control of individual sheets which make up the land use and land cover and associated map set, there must be a composite quality control of all sheets in the set. Table 4-1 shows some of the types of correspondence which must be achieved.

Final Reproduction and Release

After a final review, reproductions are made and the maps are released to open file in the appropriate regional mapping center along with a copy of the planimetric base. Copies are also sent to the various State cooperators and USGS outlets as required.

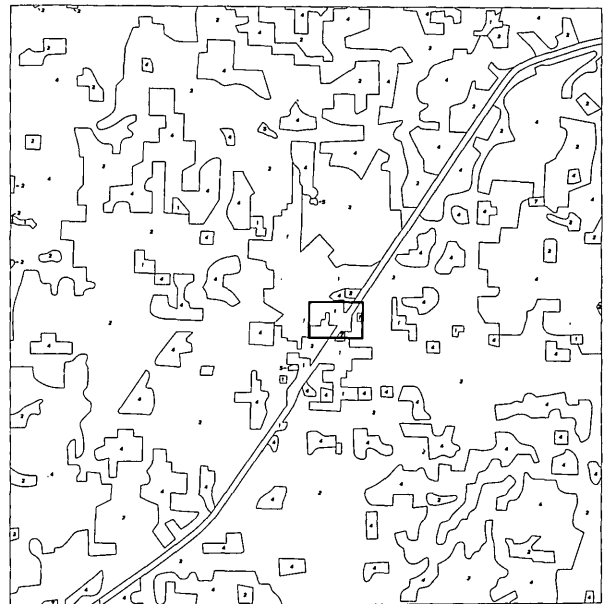
Land Use and Land Cover Mapping Specifications at Scales of 1:100,000 and Larger

Regional and local natural-resource managers often require that their land use and land cover maps be more detailed and at a larger scale. For more detailed and larger

scale land use maps, the source photographs must be more recent and larger scale and the minimum polygon size and minimum polygon width must be smaller. Table 4-2 illustrates the relations among the levels of land use and land cover classifications, base map scales, photographic scales, minimum polygon sizes and widths, and sources required for delineation of land uses.

To further illustrate these relationships, several land use and land cover maps at various scales and classification levels follow.

Figure 4-3 illustrates the Level I land uses around Lebanon, Mo. Figure 4-4 shows the same geographic area at a Level II land use. Specifications used for both compilations were those detailed in Open-File Report 77-555 for 1:250,000-scale compilations.



Scale 1:250,000

LEVEL I EXPLANATION

1. Urban or Built-up Land
2. Agricultural Land
3. Rangeland
4. Forest Land
5. Water

Figure 4-3.--Level I land use and land cover map, Lebanon, Mo.

Table 4-1.--Composite editing overlay registration checklist

(From Loelkes, 1977, p. 60.)

LAND USE AND LAND COVER	HYDROLOGIC UNITS		FEDERAL LAND OWNERSHIP		POLITICAL UNITS		CENSUS COUNTY SUBDIVISIONS	
	Check joins with surrounding map compilations.	Map sheets along coast- lines must comply with compilation specifica- tions.	Those bound- aries for ownership should encom- pass Category 12. Where delineated boundaries are same, lines must coincide.		Map sheets along coast boundaries must be in compliance with compi- lation speci- fications.		Map sheets along coastlines must be in compliance with compilation specifications.	
LAND USE AND LAND COVER	No set pattern. Check unit boundaries to ensure lines only cross large rivers. Close units along shorelines.		No set pattern.		Be sure all areas of other than inland water have been properly coded.		No set pattern.	
	Check Category 12 occurrence within Federal land ownership boundaries	No set pattern.			Many times county & State lines are used for Federal land ownership.		No set pattern.	
FEDERAL LAND OWNERSHIP	For map sheets along coast- line, check compilation for specifica- tion compliance.	No set pattern.	Many times, county & State lines are used for Federal land ownership.				All common lines must coincide: county-State CCS-county SMSA-county CCS-State SMSA-State	
	No set pattern.	No set pattern.	No set pattern, except where political units form boundaries.		All common lines must coincide: county-State CCS-county SMSA-county CCS-State SMSA-State			

LAND USE
AND
LAND COVER

HYDROLOGIC
UNITS

FEDERAL
LAND
OWNERSHIP

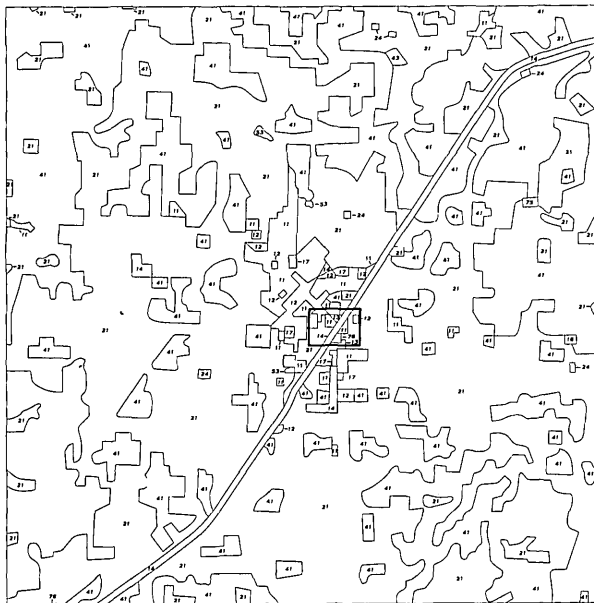
POLITICAL
UNITS

CENSUS
COUNTY
SUBDIVISIONS

Table 4-2. Land use/land cover specifications matrix

Levels of Land Use/Land Cover Classification	Base Map Scale	Effective Photo Source Scale	Minimum Polygon Size(1)	Minimum Polygon Width(1)	Sources Required for Land Use Delineations
I	smaller than 1:250,000	smaller than 1:125,000	greater than 40 acres	greater than 660 feet	100 percent photographic
II	1:250,000 to 1:100,000	1:125,000 to 1:60,000	40 acres and 10 acres	1,320 feet and 660 feet	98 percent photographic 2 percent other source materials
III	1:63,360 to 1:24,000	1:60,000 to 1:20,000	2.5 acres	125 feet	75 percent photographic 25 percent other source materials
IV	1:24,000 to 1:6,000	1:20,000 to 1:6,000	2.5 acres and 1 acre	125 feet and 50 feet	25 percent photographic 50 percent other source materials 25 percent ground truth
V	1:6,000 and larger	1:6,000 and larger	1 acre and smaller	50 feet and smaller	10 percent photographic 40 percent other source material 50 percent ground truth

¹Since different minimum polygon size and width values are recommended for urban versus rural land use types, two values are listed in these columns.



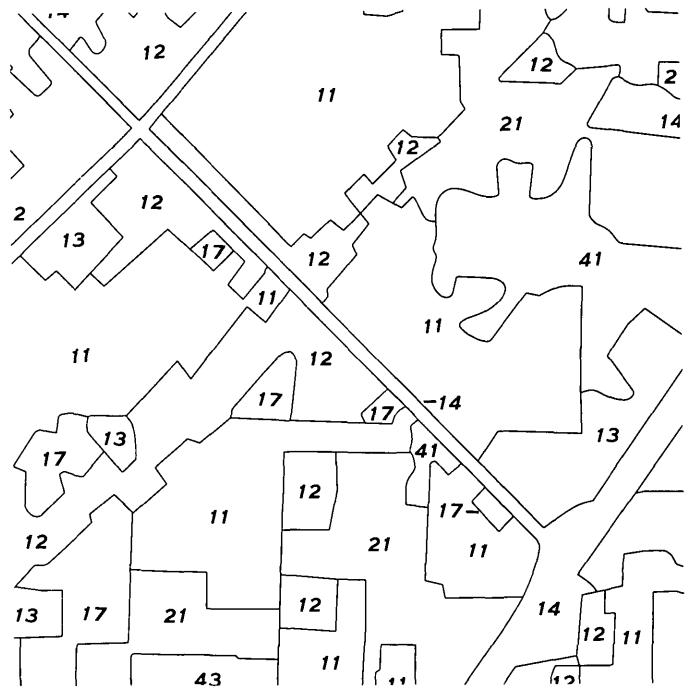
Scale 1:250,000

LEVEL II EXPLANATION

- 11 Residential
- 12 Commercial and Services
- 13 Industrial
- 14 Transportation, Communications,
and Utilities
- 17 Other Urban or Built-up Land
- 21 Cropland and Pasture
- 24 Other Agricultural Land
- 41 Deciduous Forest Land
- 53 Reservoirs
- 76 Transitional Areas

Figure 4-4.--Level II land use and land cover map, Lebanon, Mo.

Figure 4-5 depicts a Level II land use and land cover map of Lebanon at the 1:24,000-scale, while figure 4-6 of the same area was compiled at Levels II and III.

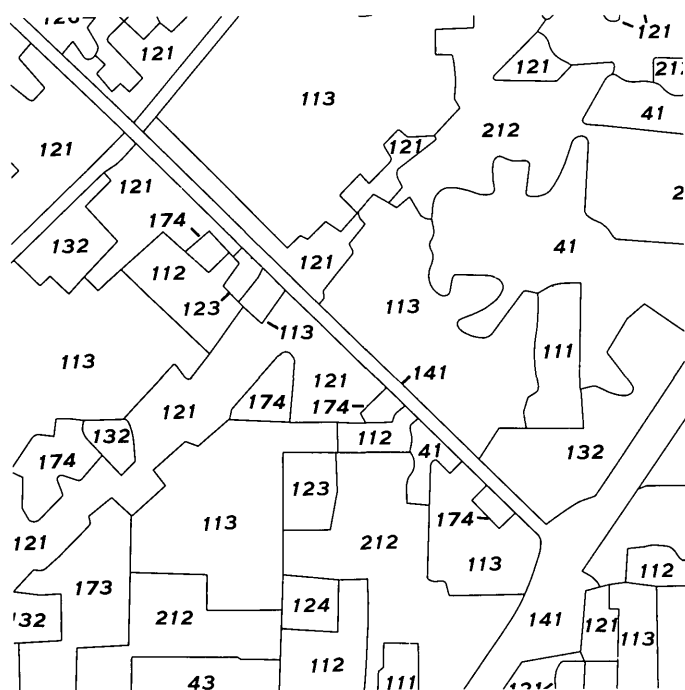


Scale 1:24,000

LEVEL II EXPLANATION

- 11 Residential
- 12 Commercial and Services
- 13 Industrial
- 14 Transportation, Communication,
and Utilities
- 17 Other Urban or Built-up Land
- 21 Cropland and Pasture
- 24 Other Agricultural Land
- 41 Deciduous Forest Land
- 43 Mixed Forest Land
- 53 Reservoirs
- 76 Transitional Areas

Figure 4-5.--Level II land use and land cover map, Lebanon, Mo.



Scale 1:24,000

LEVEL II AND LEVEL III EXPLANATION

111	One and under dwelling units per hectare (DU/hectare)
112	Two to eight DU/hectare
113	Nine and over DU/hectare
121	Retail and wholesale
122	Commercial outdoor recreation
123	Education
124	Hospitals, rehabilitation centers and other public facilities
126	Other public institutions and facilities (other than educational)
132	Light industry
141	Highway
142	Railway
146	Sewage treatment
172	Cemeteries
173	Parks
174	Open space-urban
41	Deciduous forest land
43	Mixed forest land
53	Reservoirs

Figure 4-6.--Level II & III land use/cover map, Lebanon, Mo.

The 1:24,000-scale map compilations are the same areas as those set off by the heavy black rectangles in figures 4-3 and 4-4. The classification system used for the compilation of figure 4-5 followed a multilevel classification system prepared for the Kansas City, Kan., land use test and demonstration project as shown in table 3-3 (Sosinski, 1980). Figure 4-6 followed a classification system used by San Mateo, Calif. The specifications used for compilation were as follows: (1) polygons to be delineated had to have a minimum size of 2.5 acres for Levels II and III, (2) all categories mapped with this mapping unit size had to have a minimum width of 125 ft.

Summary

Compilation procedures and techniques used by the U.S. Geological Survey for land use and land cover mapping at a scale of 1:250,000 or 1:100,000 can be used to compile any scale natural resource thematic map. Specifications to compile mapped data, the level of classifications, and the different types of social and natural resource data input requirements, all fall under these procedures and techniques. The items must, however, be compatible in scale, detail, and specifications. Time spent in project planning to ensure compatibility of the project data will assure successful completion of a mapping project. Table 4-2 showed the relationship of these various aspects of land use mapping. The information contained in this table was prepared primarily for land use and land cover mapping; however, it can be expanded or modified to include other types of natural resource data requirements as well.

SECTION 5: LAND USE AND THE ENVIRONMENT

As the Earth's population has increased and man has become technologically more advanced, his needs for natural resources and space have also increased. These needs, although economically and socially beneficial, have often had an adverse effect on the environment. The shift from an agrarian to an industrialized society has at times changed a pristine environment to an environment of polluted air, water, and soil. Some areas have been polluted to the extent that they are no longer useful.

All uses of land and types of cover either produce or are impacted by some form of pollution. This may range from air quality problems caused by the natural decomposition of organic matter in forested areas, to the illegal disposal of hazardous waste materials. Some forms of pollution have purely aesthetic impact, while others are lethal. Recent episodes, such as the Love Canal area near Buffalo, N. Y., have dramatically shown the far-reaching implications of the improper disposal of chemical wastes. One of the purposes of this guide is to provide the user with some insight to the use of remote sensing and land use and land cover maps and to aid in the understanding of environmental/land use relationships.

Since most types of pollution result from the activities of man, it is easily understood why many of these pollution types are a direct result of man's use of the land. Consequently, an existing land use map, compiled from recent aerial photographs, can be an invaluable tool in attempting to access real or potential environmental problems. The products available through the U.S. Geological Survey's national land use and land cover mapping program can greatly assist environmental specialists and natural-resource planners by narrowing their geographic search area to those land use categories most likely to create pollution problems.

Application of remote sensing for environmental monitoring is well established and documented. Many governmental agencies whose mission involves resource management and mapping have utilized aerial photographs since the mid-1930's. Because of the time-consuming nature of ground investigations, it became readily apparent that only aerial images could provide information in a timely, efficient, and cost-effective manner.

Of the many agencies employing remote sensing, the Environmental Protection Agency (EPA), realized in the late 1960's the benefits which could be derived from imaging sensors.

Since that time, a variety of remote sensor studies have been made of regulated pollution sources.

A very basic type of study, an inventory of pollution sources, can be easily carried out using aerial photographs. While the majority of stationary point sources require permits, there are many nonpoint sources which do not. A nonpoint source is an area type source; examples include junkyards, construction sites, landfills, feedlots, and freshly tilled agricultural fields. The major problem associated with nonpoint sources is degradation of water quality caused by surface runoff entering both ground and surface water supplies. Aerial photographs provide an ideal means of analyzing large geographic areas for this type of pollution source.

A new analytical technique developed by EPA for detection of failing septic tank fields uses large-scale color and color-infrared photographs. The technique, used successfully in various regions of the country, is based on the fact that a failing system increases the nutrient levels and available moisture to surface vegetation thereby causing vigorous growth which can be readily observed on color-infrared photographs. It is believed that this technique has saved hundreds of thousands of dollars over conventional field investigations. Data from these studies are used to determine the need for new or expanded waste water treatment facilities.

Aerial images have also been effective in monitoring oil and hazardous materials spills. In such episodes, the images are obtained, processed, and analyzed in the shortest possible time--usually less than 24 hours--to provide information directly to cleanup personnel. A recent development has been installation of a color television camera in the oblique position of the Enviro-pod camera system (see figure 2-8). The aircraft's ground track is recorded on videotape and played back at the spill command post shortly after the plane lands. The vertical Enviro-pod camera photographs are retained for documentation and more detailed analysis at a later time. The television system has also been used to monitor aerial spraying of pesticides. A direct air-to-ground transmission system is presently being developed.

Environmental surveys using aerial imagery have proven invaluable in intensive site analyses of known potential hazardous waste sites. In addition to recent imagery, historical photographic coverage can often be obtained and analyzed, thereby providing a comprehensive site picture. The types of information extracted include areal extent, types of wastes disposed, presence of liquid

storage areas, offsite contamination, vegetation damage or stress, surrounding land use, and onsite or offsite drainage.

Use of imaging systems for environmental monitoring is, as yet, still in its infancy. The vast majority of pertinent data are presently collected using conventional photographic imagery. The Environmental Protection Agency, along with other governmental agencies, is investigating a number of other remote sensing monitoring methods such as laser fluorosensing; light intensification, detection, and ranging systems (LIDAR); and multi-spectral imaging systems. However, for detection, location, and analysis of pollution sources, the use of conventional photographs has been the most consistent and reliable method.

The basic types of pollution attributable to the Level I land use and land cover categories are discussed in the following paragraphs to facilitate an understanding of the sources of these pollutants and their potential effect on the environment.

Urban Pollution Sources

The main types of pollution in the urban environment are water, air, and noise. The first, water pollution, is caused primarily by improperly treated sewage and waste-water discharges. In residential areas, failing septic tank systems or overloaded sewage disposal plants are sources of water pollution. In commercial areas the large expanse of concrete and asphalt used for street paving and parking areas provide an impervious surface which allows rainfall runoff to convey residual tar, automobile fluids, and litter into streams and rivers. The predominant waste-water problem associated with industrial areas is brought about by the outdoor storage of raw materials and finished products. In addition, improper disposal of waste products can become a major source of pollution. Land used for transportation and utilities contributes to urban pollution primarily from the use of fossil fuels. Both the burning of fossil fuels and the storage and transportation of these fuels are potential pollution sources. Burning coal has also been directly connected to "acid rain." Runoff from highways, railroads, and airports is also among the list of potential water-pollution sources.

The other types of pollution, air and noise pollution, are generally caused by such

activities as railroads and airports as well as vehicular operation, industrial plant operations (especially plants burning various types of fossil fuels), and heavy construction operations. Although man's activities in the urban environment do constitute a wide range of potential pollution sources, not all of the Urban or Built-up Land uses are sources of pollution. Public parks, golf courses, lakes, and various other types of greenbelt areas are generally not urban pollution sources.

Agricultural Pollution Sources

The primary source of pollution from agricultural areas are nonpoint, or areal, in nature. Since agricultural practices require large field patterns to be economically efficient, it is of little surprise that these areas are, or at least may become, sources of nonpoint pollution.

Nonpoint pollutants are most often associated with chemical or physical water quality degradation. Following periods of moderate to heavy precipitation, overland runoff passes through agricultural areas, and chemical (such as pesticides and fertilizers) and physical (primarily surface soil particles) contaminants are carried to nearby water bodies.

Accordingly, farmers should be encouraged to use agricultural practices which will lessen the magnitude of nonpoint pollution.

Rangeland Pollution Sources

Rangelands are natural areas by definition and generally are not pollution sources.

Forest Pollution Sources

Forested areas, like agricultural areas, are prime candidates for nonpoint pollution contaminants. These contaminants, primarily loose soil particles and residual herbicides, insecticides, and fertilizers, like nonpoint pollution contaminants from agricultural areas, are transported to nearby water bodies by overland runoff.

Of the above contaminants, soil erosion is by far the greatest nonpoint pollution source resulting from silvicultural practices. Clear cutting activities and use of heavy machinery to construct logging roads are the main offenders.

Water Pollution Sources

Water bodies generally are not pollution sources. However, they serve as the transfer mechanism for chemicals, soil particles, and other organic pollutants that can impact the Earth's ecosystems.

Wetland Pollution Sources

Wetland areas can be subjected to a number of adverse environmental hazards created by human activities. Drainage systems act as transportation routes for distributing pollutants; dumping and filling activities may introduce toxic substances into nearby wetland areas; and adjacent agricultural activities may introduce fertilizers, pesticides, and animal wastes into nearby wetland areas.

Barren Land Pollution Sources

The only Barren Land categories that occur in Missouri are Sandy Areas other than Beaches; Strip Mines, Quarries, and Gravel Pits; and Transitional Areas. Of these categories, the Strip Mines, Quarries, and Gravel Pits category is the most frequent source of pollution. In addition to contributing to air and noise pollution, these areas are often a source of chemical and/or physical contaminants which can enter nearby water bodies.

The above pollution source descriptions are only generalizations. However, as each Level II land use and land cover category is covered in section 6 of this guide, more detailed environmental considerations will be included for that category.

SECTION 6: PHOTOINTERPRETATION KEYS FOR MISSOURI

INTRODUCTION

This section presents the land use and land cover photointerpretation keys and the possible environmental impact of each type of land use or land cover in Missouri. The interpretation keys follow the land use and land cover categories as shown in table 1-1. Each of the Level I land use and land cover categories has a brief general discussion followed by the Level II categories. Each Level II land use and land cover category includes a general description and the possible environmental impact of the category, and is illustrated by a number of sites. Each site is identified by (1) a site number, the general location of which is shown on a map of Missouri (figure 1-1), (2) a short title for the site, (3) the name of the nearest populated place, county, and State name, and (4) the location of each site by latitude and longitude.

In addition to the photographic illustrations, a more complete discussion of the category, and, where appropriate, an environmental statement are included with each of the sites.

In those cases where a second level land use and land cover category can best be represented by the most predominant type, only one site example is presented. In some cases, several examples are provided because of the need for more complete recognition and description of the category. For example, land use categories such as category 41 (Deciduous Forest) may be illustrated well with only one or two examples. However, category 11 (Residential) involves single-family homes, duplexes, garden apartments, trailer parks, high-rise apartments, and inner-city housing. The predominant example of this category, however, is the suburban single-family home. The prime illustration for this category is an area of single-family homes. However, because the category includes the other residential types, they are also illustrated with a very brief description.

Appendix A lists all site information by site number.

LEVEL I, CATEGORY 1 - URBAN OR BUILT-UP LAND

The areas which comprise Urban or Built-up Land are those of intensive use. These areas have a predominance of the land covered with structures. These structures are

associated with cities and towns, and other developments such as industrial and commercial areas. It is not necessary that the structures which comprise this category be within, or adjacent to, towns and villages; in fact, they may be completely isolated from urban areas.

As development progresses, land having less intensive or nonconforming use may be located in the midst of Urban or Built-up areas and generally will be included in this category. Agricultural land, forest, wetland, or water areas on the fringe of Urban or Built-up areas will not be included except where they are surrounded and dominated by urban development. The Urban or Built-up category takes precedence over others when the criteria for more than one category are met. For example, residential areas that have sufficient tree cover to meet Forest Land criteria will be placed in the Residential category.

Category 11--Residential

Category Description. Residential land uses range from high-density multiple-unit structures to low-density single-family houses on large suburban lots. Included in this category are single-family residences, apartments, condominiums, mobile homes, recreational homes, and any other building or structure used as a residence. The most common residential type of this category is the single-family home.

Environmental Considerations. The residential category has potential for impacting the environment in several ways. Among these are sewage, waste-water, air, and noise pollution.

Sewage and waste water are a major source of water pollution directly linked to residential development. Direct sewage outfalls and the introduction of untreated sewage effluent into surface and ground-water sources are major pollution problems. Residential areas that are not served by collector sewers must rely on subsurface, on-site, sewage disposal systems (septic tanks) which may malfunction due to soil and geologic problems or adverse seasonal conditions. When septic systems fail towards the ground surface, the runoff of untreated or partially treated sewage effluent can be a major source of surface-water contamination and lake eutrophication, as well as being an immediate health problem to the community. When septic systems are used in areas where the soil is sandy and/or very permeable, ground-water contamination may

occur as the septic effluent moves too rapidly through the soil resulting in inadequate attenuation and filtration of biodegradable particles prior to reaching ground-water level.

Even in residential areas where collector sewer service is available, the waste-water treatment facilities may be inadequate or overloaded and cause the discharge of an effluent that does not meet water quality standards.

Other water pollution sources associated with residential areas include runoff from driveways, parking lots, and solid waste disposal areas (landfills). Surface waters may also be contaminated from runoff containing fertilizers and pesticides used in lawn and garden care.

Additional pollution sources associated with residential areas include air pollution from auto emissions, home heating furnaces, and fluorocarbons in aerosol sprays. Changes in microclimates can occur as a result of thermal discharges. Noise pollution can result from construction activity and nearby highways.

Interpretation Keys. Six residential sites are illustrated ranging from high-rise apartments in an urban renewal area to recreational houses on a lake in rural Missouri. The principal example of this category is a recent suburban residential development of single-family homes on the periphery of a large metropolitan area.

Site No. 1 (Single-Family Homes)
Location: Manchester
St. Louis County, Missouri
Geographic Coordinates: 38°36'N
90°31'W

The small-scale vertical mapping photograph, figure 6-1, shows an expanded view of this area of single-family residential homes. Most single-family residences exhibit the same photographic signature of pattern, tone, size, and symmetry. In the upper left portion of the photograph is a subdivision under construction (point A, figure 6-1). Notice how the ground is cleared of vegetation before construction is started.

In the design of subdivisions, there are always areas which cannot be developed because of the topography or hydrologic conditions. These areas are generally left as undisturbed areas of natural vegetation. Two such dark-toned areas, without streets and houses, are shown at A and B in figure 6-2.



Figure 6-1.--Small-scale mapping photograph of suburban residential area in Manchester, Mo.



Figure 6-2.--Low-level oblique photograph of wooded areas left undeveloped.

Streets with circular drives and cul-de-sacs are easily identified by their pattern and light tones.

Ranch-style homes with attached garages of various sizes and shapes can be seen equidistant and symmetrical to the streets (figure 6-3). Upon close examination, sidewalks and driveways are visible. Many of the driveways are probably made of a blacktop material as they are darker in tone than the streets.

In the center foreground of the large-scale vertical photo (figure 6-3, point A) a small park can be identified with its small pool, tennis courts, parking area, and lake.



Figure 6-3.--Large-scale vertical photograph of a subdivision layout and park.

Site No. 2 (Inner-City Residential)
 Location: St. Louis
 St. Louis County, Missouri
 Geographic Coordinates: 38°36'N
 90°14'W



Figure 6-5.--Large-scale photograph of inner-city residential area, St. Louis.

In most inner-city residential areas, particularly in the older sections of cities, residences are either duplexes or multi-family structures. A typical duplex is shown in figure 6-6.

The key identification features of inner-city multiple-family residences are the rectangular street patterns, closely spaced buildings with little or no yard space, garages behind the buildings accessible only by the alleys in each block, and the similarity of the shape of the buildings (see figures 6-4 and 6-5).



Figure 6-4.--Small-scale photograph of inner-city residential area, St. Louis, Mo.



Figure 6-6.--Ground photograph of multi-family inner-city residential area in St. Louis, Mo.

Many of the older sections of town have local commercial shops and schools intermixed with the residential areas. In figure 6-7, a commercial area is shown at A while a school is located at B.



Figure 6-7.--Low-altitude oblique photograph of inner-city residential area with commercial and school areas.

Site No. 3 (High-Rise Residential)
 Location: St. Louis
 St. Louis City, Missouri
 Geographic Coordinates: $38^{\circ}31'N$
 $90^{\circ}13'W$

High-rise residential areas may be either apartments or condominiums. These structures are generally 4 to 12 stories in height and may be found within the city limits or in the adjacent suburbs. The buildings, if more than one, are constructed in a geometric pattern (see figure 6-8).



Figure 6-8.--High-rise apartments in an urban renewal area. The stereogram gives an excellent view of the height of the buildings and their similar shapes and sizes.

For convenience of the residents, the parking facilities are located next to the building and around the periphery of the building area (figure 6-9).



Figure 6-9.--High-rise residential apartments with internal and external parking facilities.

These high-rise residences are located in an area of urban renewal. The area has undergone change since the photograph in figure 6-8 was taken in July 1974. The change is illustrated by the absence of buildings at A in figure 6-10, taken June 1980.



Figure 6-10.--Urban renewal area undergoing change.

The play area for the building tenants is shown in figure 6-11. This figure also illustrates the size of the buildings and the

walkways which connect each of the floors in adjacent sections of the complex.



Figure 6-11.--Ground photograph of high-rise recreational area, St. Louis, Mo.

Site No. 51 (Garden Apartments)
Location: Springfield
Greene County, Missouri
Geographic Coordinates: 37°11'N
93°19'W

Garden apartments are generally found in the suburban area on the outer fringes of larger cities (figure 6-12).

The structures are generally one to three stories in height. They are generally constructed in a rectangular pattern but can be almost of any design, from circular to star shaped. They are referred to as garden apartments because of large grass areas surrounding the buildings and separate entrances (figure 6-13).

Figure 6-13 illustrates garden apartments at A and common-entrance apartments at B. Notice the proximity of parking to the garden apartments as compared to the common parking areas provided for the apartments at the right.

In figure 6-14, which shows garden apartments in midst of single-family homes in Springfield, Missouri, the dark-toned apartments can be identified by their size, shape, and similarity. Parking areas in front of each building make the streets look wider. On the right side of the photo, four separate parking lots are visible at B. Garden apartments usually include recreational facilities within the building complex area.

Figure 6-15 is a ground photograph of typical garden apartments.



Figure 6-12.--Small-scale photograph of garden apartments, Springfield, Mo.



Figure 6-13.--Large-scale photograph of garden apartments in Springfield, Mo.



Figure 6-14.--Low-level oblique photograph of garden apartments in Springfield, Mo.



Figure 6-15.--Garden apartments in Springfield, Mo.

Site No. 52 (Mobile Homes)
 Location: Springfield
 Green County, Missouri
 Geographic Coordinates: 37°11'N
 93°22'W

Mobile homes can be found throughout the countryside, however, they are primarily located in suburban areas in courts or parks (figure 6-16).



Figure 6-16.--Mapping photograph of mobile home park at Springfield, Mo.

Most mobile homes are secured on a permanent foundation and usually parked in a trailer court or park. Large mobile homes are parked perpendicular to or at an angle to the

streets in the court. This practice facilitates the maximum utilization of a limited area. Mobile homes are long and narrow as compared to a house, lighter in tone, and are usually arranged in a regular pattern (figure 6-17).

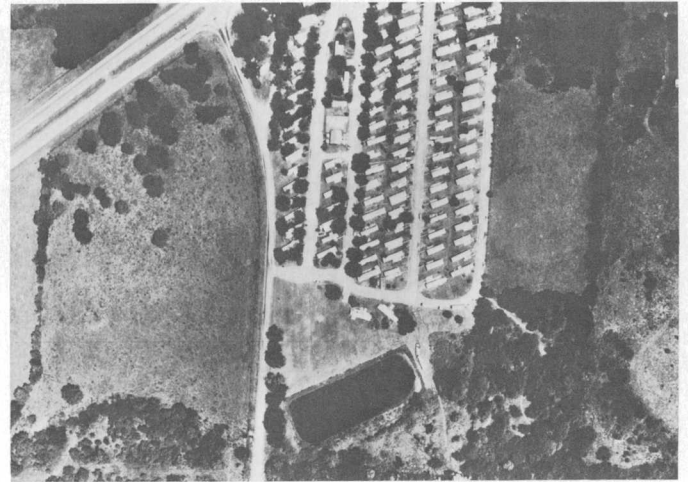


Figure 6-17.--Large-scale vertical photograph of mobile home park, Springfield, Mo.

Utilities are generally run between the backs of the mobile homes, with a gas or oil tank and an electric meter for each home. The water and sewage lines also run between the homes. The general method used for sewage disposal outside the city limits is usually a sewage lagoon (A, figure 6-18). Figure 6-19 presents a ground perspective of a typical mobile home park.

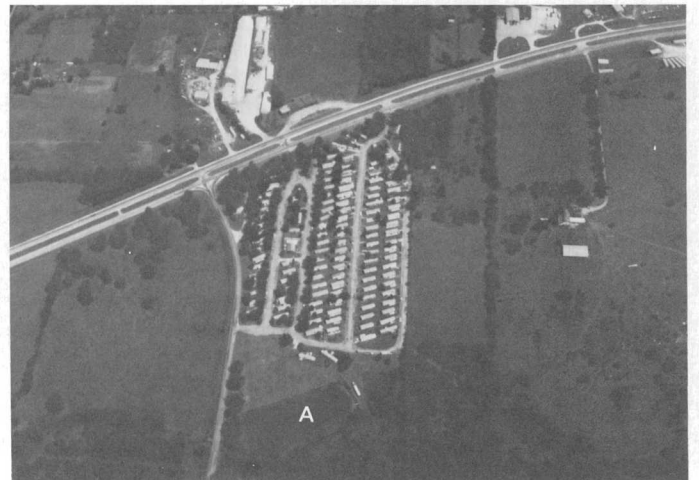


Figure 6-18.--Mobile home park and sewage lagoon near Springfield, Mo.

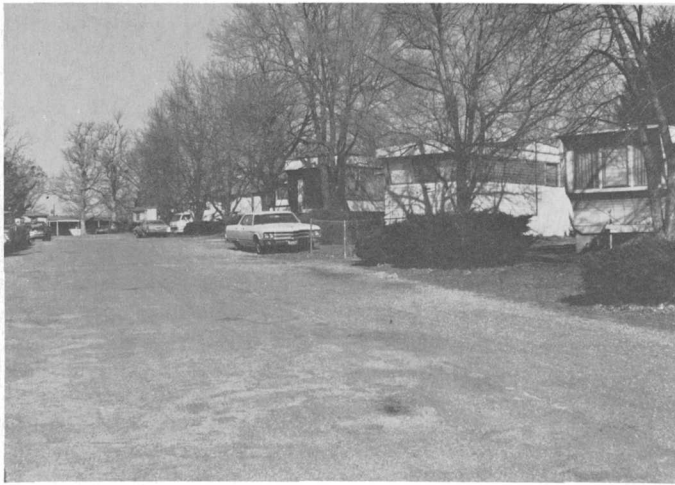


Figure 6-19.--Ground photograph of a typical street in a mobile home park.

Site No. 89 (Recreational Homes)
 Location: Trenton
 Grundy County, Missouri
 Geographic Coordinates: 40°06'N
 93°44'W

Recreational homes are frequently very close to water bodies, or in wooded areas, and provide outdoor recreational activities easily accessible to their occupants. This recreation area borders Lake of the Woods. The key identification features of recreational home areas are the road patterns and the different sizes and shapes of the buildings, boathouses, and docks. The general scattering of houses and vacant lots are also common. Figure 6-20 illustrates a rectangular road pattern which gives way to separate access roads to each residence as one approaches the lakeshore.



Figure 6-20.--Small-scale mapping photograph of recreational homes at Lake of the Woods, Mo.

The various shapes and sizes of the buildings are indicative of recreational homes. These homes can be year-round residences or seasonal cabins. Boathouses and boat docks are visible at every lakeshore lot. Wooded areas are considered an asset in recreational developments and therefore are usually not removed during construction (see figure 6-21).



Figure 6-21.--Large-scale vertical photograph of Lake of the Woods residential area.

Figure 6-22 illustrates a recreational home site area with the scattering, almost random, placement of structures.

This particular site is associated with a rather large lake. There are large numbers of recreational areas developed in mountain-type terrain. The lot layout and building type are mainly the same as for lake development. The recreational facilities, however, are in the form of smaller lakes and golf courses which tend to be more centrally located within the development.

These examples illustrate a cross section of the various types of dwelling units which comprise the residential category. There are many other types which are variations of the examples shown, but these examples can be considered typical.



Figure 6-22.--Low-altitude oblique photograph of recreational home area.

Category 12--Commercial and Services

Category Description. Areas which contain structures predominantly used for the sale of products or services are classified as commercial. Included in this category are central business districts, shopping centers, commercial strip developments along highways, and junkyards. The main buildings, secondary structures, and supporting areas--office buildings, parking lots, landscaped areas, and waste-disposal areas--are also included in this category. Institutional land use, such as educational, religious, health, correctional, and military facilities are likewise included in this category. Cultural and recreational areas that can be identified on aerial photos, and included in this category, are commercial sports arenas, drive-in theatres, amusement parks, and commercial campgrounds. At military bases and institutional facilities, areas not specifically related to the purpose of the institution should be placed in the appropriate category.

Environmental Considerations. Commercial and Services land use areas share the following general potential for environmental effects. Extensive concrete and asphalt coverings cause

high rates of surface water runoff which can affect water quality and quantity. The runoff is capable of carrying residual tar, oil, automobile fluids, litter, and other solids into storm sewers and eventually into nearby streams. The extent to which water quality is affected depends upon where the water has traveled during its course. Quantity is influenced by the impervious layers blocking the percolation and absorption of water into the Earth to replenish the ground water aquifer supplies. Excessive runoff can cause flooding during heavy rainfalls in commercial areas or in nearby residential communities. Commercial areas in general have high rates of consumption and discharge of water. This results in large sewage volumes and depletion of local water reserves. Specific pollution hazards to water quality from commercial land uses include chemical contamination, thermal contamination, and over nutrification. Of all the commercial establishments in land use category 12, the activity which has one of the largest potentials for pollution is salvage yards. Salvaging of batteries and autos can contaminate soil, water, and air with toxic chemicals, lead, and iron oxides. The burning of auto interiors pollutes the air and can spread noxious odors to nearby communities.

Air quality is also affected by activities of commercial districts. High-volume traffic contributes exhaust emissions, dust levels are higher, and power generators can contribute particulate matter into the air. Airborne lint and debris can also effect air quality in these regions.

A noticeable byproduct from high-density commercial areas is excessive noise. Vehicles, heavy machinery, loudspeakers, and loading areas all contribute to abnormally high noise levels. These noises can be intensified by nonabsorbing building materials which can create echos. Noise levels may also be high at certain times in the neighborhood of concert halls, sports arenas, and fairgrounds.

The most noticeable detrimental environmental effect of a commercial area is its high-density land use. Sparse vegetation is common and "heat islands" are likely in sections devoid of greenery. The alteration of the terrain by heavy urbanization affects hydrology, vegetation, climate, and habitat.

Not all commercial land uses should be considered detrimental. Hospitals, schools, and other institutions provide open areas which, for the most part, are nonpolluting and aesthetically pleasing.

Interpretation Keys. Presented on the following pages are examples of Commercial and Services land uses in Missouri.

Site No. 4 (Shopping Center)
Location: Mehlville
St. Louis County, Missouri
Geographic Coordinates: 38°31'N
90°20'W

Large shopping centers are usually located in the suburbs of urban areas. The key identification features are large or interconnected buildings surrounded by well-paved parking lots and its location near an interchange or a four-lane divided highway for easy access and exit.

The small-scale mapping photograph (figure 6-23) shows the location of a Mehlville shopping center. The intersection of two interstate highways and major arterial streets provide easy and convenient access to the facility. Some of the surrounding residential and commercial development served by this shopping center is also visible. Since the date of the mapping photograph, July 1, 1974, the shopping center has expanded as evidenced in the photograph in figure 6-24, taken in June 1980. The dark rough-textured area to the west of this complex at A, is an area of trees which may eventually be converted to additional parking or other commercial activities. The photograph shows the large retail building completely surrounded by well-marked paved parking facilities.

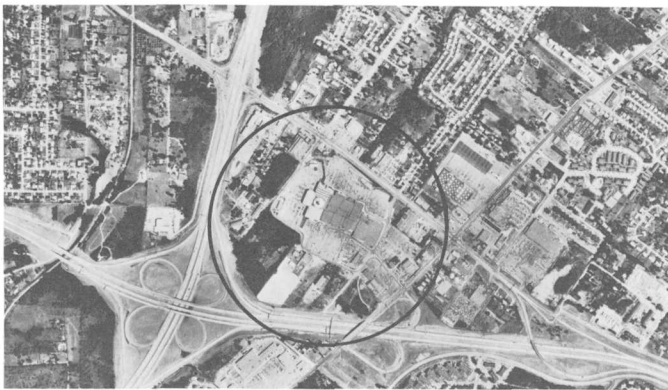


Figure 6-23.--Small-scale mapping photograph of shopping center near St. Louis, Mo.

Figure 6-25 provides a ground perspective of the complex and some of the well-marked paved parking facilities.

Large shopping centers such as this site are built to have large covered malls. The various stores within the building open onto the outside of the building as well as the malls. When major chain stores are involved

with the shopping center, they will generally build with a characteristic design which will be evident in all shopping centers the store occupies.



Figure 6-24.--Large-scale vertical photograph of shopping center at Mehlville, Mo.



Figure 6-25.--Ground photograph of shopping center.

Site No. 53 (Shopping Mall)
 Location: Springfield
 Greene County, Missouri.
 Geographic Coordinates: 37°10'N
 93°16'W

The small-scale photograph shown in figure 6-26 locates a Springfield shopping mall in relation to major traffic arteries, surrounding residential structures, and other commercial land uses.



Figure 6-26.--Small-scale mapping photograph of shopping mall at Springfield, Mo.

The mall, Battlefield Mall, is more clearly shown in figure 6-27. In this large-scale photograph the building and parking lot can be easily identified by their lighter tones. The major traffic arteries provide easy access to the mall. Unlike shopping centers, malls have all of the stores under one roof with a walkway (mall) serving all stores.



Figure 6-27.--Low-level oblique photograph of Battlefield Mall, Springfield, Mo.



Figure 6-28.--Battlefield Mall's main entrance and parking lot.

Figure 6-28 shows the main entrance to the mall and associated parking facilities.

Site No. 79 (Central Business District)
 Location: Kansas City
 Jackson County, Missouri
 Geographic Coordinates: 39°06'N
 94°35'W

The stereogram presented in figure 6-29 provides an excellent perspective of the height of the buildings and the extent of parking within this central business district (CBD). Metropolitan CBD's have a large number of high-rise buildings. They usually are easily accessed by interstate bypass routes.

Figure 6-30 illustrates the built-up nature of CBD's. The CBD is the heart of the office/commercial activity of the city. The photograph clearly shows the high-rise buildings surrounded by large, lighter tone parking lots. Most of the lots are full; therefore, it's evident that these photographs were taken during business hours.



Figure 6-29.--Stereogram of portion of the Kansas City, Mo., central business district.



Figure 6-30.--Forward oblique photograph of Kansas City CBD.

Figure 6-31 presents a more familiar view of the Kansas City CBD.



Figure 6-31.--Ground-level view of central business district, Kansas City, Mo.

Site No. 49 (Medium-Size City CBD)
 Location: Lebanon
 Laclede County, Missouri.
 Geographic Coordinates: 37°41'N
 92°40'W

Figure 6-32 shows the central business district's growth away from the city's main

traffic intersection. The central business district originally developed along the railroad and is now expanding in all directions.



Figure 6-32.--Medium-size city central business district, Lebanon, Mo.

Figure 6-33, a large-scale vertical photograph, more clearly illustrates some of the recognition features of a medium-size town CBD. Notice the angle parking at A and the dark roofs of the three and four-story buildings at B.



Figure 6-33.--Large-scale vertical photograph of CBD, Lebanon, Mo.

Site No. 40 (Small-Town CBD)
 Location: Ironton
 Iron County, Missouri
 Geographic Coordinates: 37°36'N
 90°38'W

The main section of the central business district of Ironton is shown in figure 6-34. Small-town CBD's usually parallel the main traffic artery. Two- or three-story buildings line the street. Also shown in figure 6-34, in the west-central sector of the circle is the Iron County Court House. Notice the proximity of the residential structures to the CBD area. This is common in small-town CBD's.

Figure 6-35 provides a more traditional view of this small-town CBD.



Figure 6-34.--Large-scale oblique photograph of Ironton, Mo.

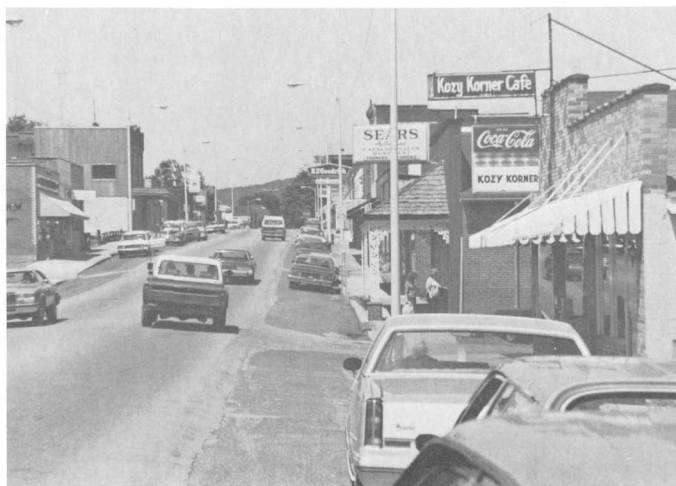


Fig. 6-35.--Ground view of CBD area, Ironton, Mo.

Site No. 46 (Commercial Strip Development)
 Location: St. Robert
 Pulaski County, Missouri
 Geographic Coordinates: 37°49'N
 92°10'W

Commercial development along major traffic arteries and access routes is often referred to as "commercial strip development." These areas provide retail goods and services to nearby residents. Figure 6-36 identifies two commercial strip development areas at A and B which serve the residents of St. Robert and military personnel from Fort Leonard Wood. Area A provides motel accommodations, fast food services, a general merchandise store, a car dealer, and other similar goods and services. Area B, particularly near the bottom of the photograph, provides services normally found to exist near military bases--bars, dry cleaners, groceries, general merchandise stores, a bank, and a TV repair shop.



Figure 6-36.--Mapping photograph of commercial strip development, St. Robert, Mo.

Figure 6-37 is a forward oblique photograph of the commercial strip development near the Fort Leonard Wood main gate. Notice the small parking lot facilities associated with the establishments at A, B, and C. In contrast, look at the large shopping center parking lot for the grocery/general merchandise complex at D. This particular example of commercial strip development illustrates how these types of retail goods and services can be provided without adversely affecting the traffic flow of a major traffic artery. Most larger urban examples of commercial strip development are characterized by commercial structures and parking lots abutting the street.



Figure 6-37.--Low-level oblique photograph of commercial strip development near main entrance of the army base at Fort Leonard Wood, Mo.

Site No. 54 (Motels)
 Location: Springfield
 Greene County, Missouri
 Geographic Coordinates: 37°15'N
 93°16'W

Figure 6-38 identifies an area of motels paralleling one of Springfield's major arterial streets (Glenstone Avenue). To the north of the area lies Interstate Highway 44. Motels are frequently located along major traffic arteries in proximity to interstate highways.

The key to identifying motels on small-scale photographs such as figure 6-38, in addition to their proximity to major transportation routes, is their linear structure, swimming pools, and individual parking facilities adjacent to the structures.

The large-scale photograph in figure 6-39 identifies swimming pools at A and two areas with swimming pools and tennis courts at B. Individual motel parking facilities are noted at C. Also identified in figure 6-39 is the North Park Mall at D.



Figure 6-38.--Mapping photograph of motels along Glenstone Avenue in Springfield.



Figure 6-39.--Forward oblique photograph of Springfield motels.

A ground-level photograph of one of the motels is shown in figure 6-40. Note the restaurant facilities nearby.



Figure 6-40.--Motel and restaurant on Glenstone Avenue in Springfield, Mo.

Site No. 55 (Suburban Office Building)
 Location: Springfield
 Greene County, Missouri
 Geographic Coordinates: 37°11'N
 93°16'W

Suburban office buildings range from two- to three-story structures to high-rise structures. Firms seeking facilities away from the central business district usually select less-expensive suburban locations with easier traffic access. Site 55 is a suburban office building (figure 6-42) in southeast Springfield which was recently constructed in place of a drive-in theater (figure 6-41). If one were categorizing land use as of the date of the mapping photography (January 1975), the drive-in movie theater would also fall under land use category 12.

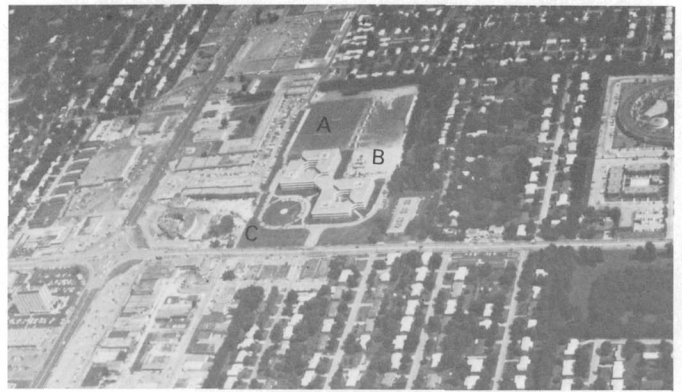


Figure 6-42.--Office building with parking lots.



Figure 6-43.--Ground photograph of office building.



Figure 6-41.--Mapping photograph of drive-in theater, January 1975.

Modern office buildings may take on a variety of shapes and designs. Figure 6-42 presents a modern office building nearing final construction phases. The photograph was taken on a weekday in July 1980. Since there are no cars in the parking lot at A, one can assume that the office building was not yet ready for occupancy. Also visible, at B, were several construction trailers. The alternating rows of white and black of the building structure infer that the structure is multi-story. This fact is supported by the ground-level photograph shown in figure 6-43 taken in January 1981. Notice the cars parked in front of the building. Also notice in figure 6-42 at C the well kept grounds at the front of the building, the circular drive, and the area for temporary parking.

Site No. 69 (State Capitol Building)
 Location: Jefferson City
 Cole County, Missouri
 Geographic Coordinates: 34°50'N
 92°10'W

All Federal, State, and local government buildings and adjacent facilities and grounds are placed in land use category 12. Circled in figure 6-44 is the Missouri State Capitol Building and other nearby State office buildings and grounds. Situated adjacent to the Missouri River in Jefferson City, the Capitol and surrounding facilities and grounds are well maintained.



Figure 6-44.--State Capitol Building,
Jefferson City, Mo.

As with many State capitol structures, the Missouri State Capitol Building structurally resembles the Nation's Capitol Building. Figure 6-45 more clearly presents the building with its graciously adorned cupola, elevated main entrance and steps, and legislative wings for the Senate and House. Also common among State capitol buildings and grounds is the circular traffic pattern surrounding the structure.

Since parking is always a problem around State capitols, many States construct parking garages nearby. Figure 6-45 shows a multi-level parking garage at A. Also shown in this large-scale photograph at B is just one of many of the State's office buildings.

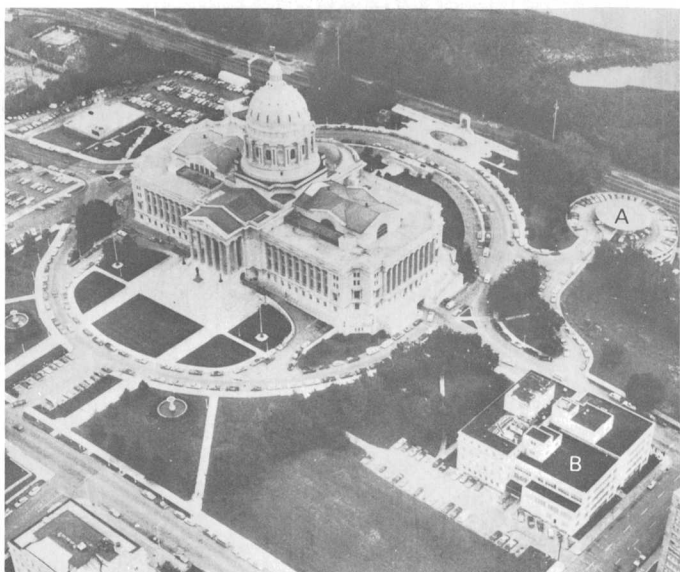


Figure 6-45.--Large-scale oblique photograph
of Missouri State Capitol.

Site No. 76 (Warehouses)

Location: Kansas City

Jackson County, Missouri

Geographic Coordinates: 39°06'N

94°32'W

Warehouses are normally large flat-roof buildings located near rail and/or highway transportation facilities. Although seldom located adjacent to major traffic arteries, they usually are located on secondary arterial streets to facilitate access by large semi-trailers. Figure 6-46 is a forward oblique photograph of a major general merchandise warehouse in east Kansas City. Notice the highway at A, the rail facilities at B, and the new warehouse structure at C. Unlike shopping centers which are seldom over two stories, large warehouses such as this one often have more than two stories. Also notice in this photograph the ease of access provided by the surrounding local streets (D).



Figure 6-46.--Low-level oblique photograph of
warehouse facility in east Kansas City.

Another recognition factor which can be employed in the identification of warehouses is the amount and location of parking facilities. Unlike shopping centers which have large, well-marked parking facilities adjacent to the retail structure, warehouses have much smaller parking lots located away from the structure (see figure 6-47, point A). Since most of the goods stored in the warehouse are moved by mechanized equipment, few employees are needed to operate a warehouse.

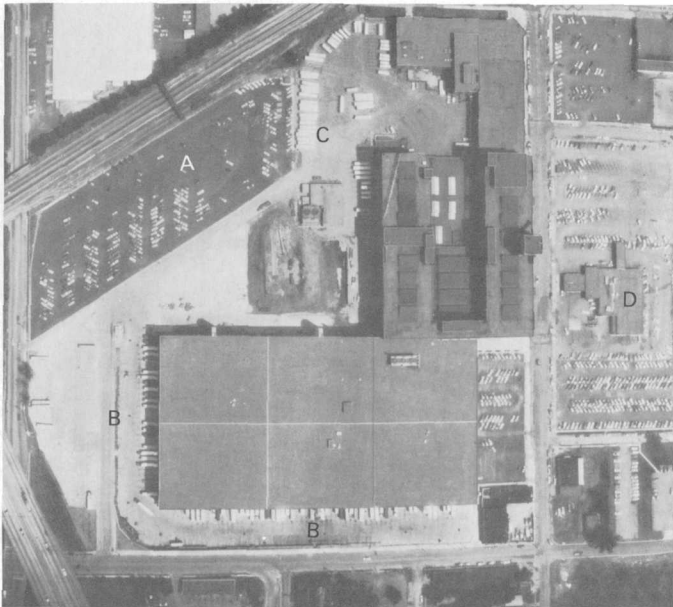


Figure 6-47.--Large-scale photograph of warehouse facility and employee parking area.

Figure 6-47 also shows the areas used to load and unload semitrailers (B). Additional semitrailers not in use are parked at C. A shopping center at D is just east of the warehouse.

A number of semitrailer units are parked at the warehouse loading dock in figure 6-48.

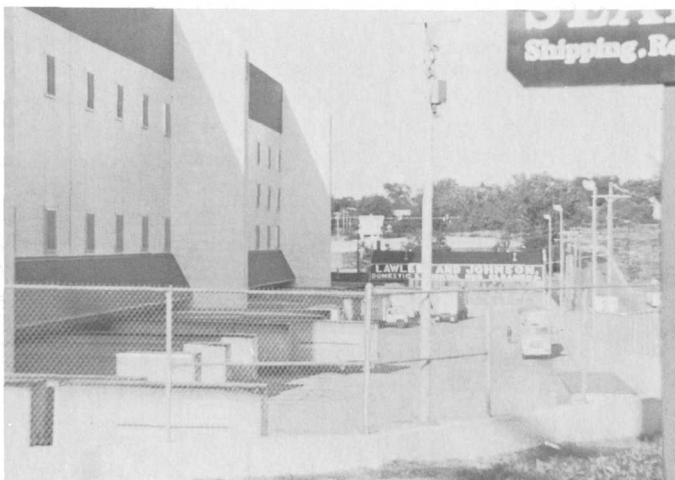


Figure 6-48.--Tractor semitrailers parked at loading dock.

Site No. 77 (Warehouse)
 Location: Kansas City
 Jackson County, Missouri
 Geographic Coordinates: 39°07'N
 94°34'W

Shown in figure 6-49 are just a few of some of the larger regional distribution warehouses located to the northeast of the Kansas City central business district. Notice the railroad facilities at A and the Missouri River at B.

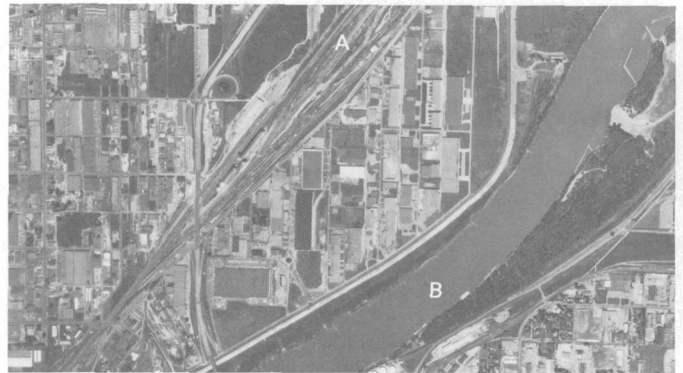


Figure 6-49.--Mapping photograph of warehouse area in Kansas City.

As with the photorecognition characteristics noted earlier for site 76, figure 6-50 shows two other warehouses in which tractor semitrailer units play a major role. The warehouse at A is primarily served by tractor semitrailers, while that at B receives, and possibly ships, goods by rail as well as tractor semitrailers. Notice the six railroad boxcars at the loading docks on the east side of warehouse B. Also note the semitrailers parked on the north side of warehouse A and on the west side of warehouse B.

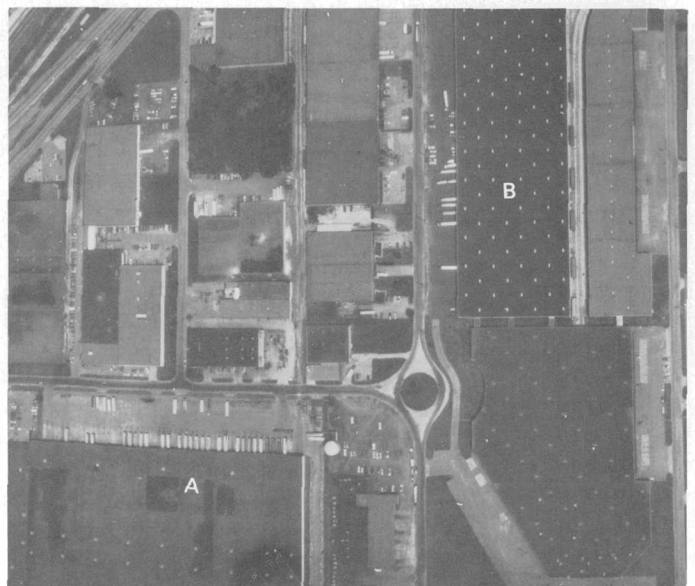


Figure 6-50.--Large-scale photograph of warehouse.

Site No. 72 (Auto Salvage Yard)
 Location: Columbia
 Boone County, Missouri
 Geographic Coordinates: 39°58'N,
 92°26'W

Auto salvage yards, such as the one shown in figure 6-51, are included in land use category 12. This particular auto salvage yard is well organized with autos lining both sides of dirt access roads. If not careful, particularly on small-scale mapping photography, a photointerpreter may at first glance believe the area is one of residential development because of the road patterns. However, on closer inspection, one realizes that the roads are too narrow and the rectangular objects (cars) too small and too close together to be houses or mobile homes. At the top of figure 6-51, at A, is the salvage yard office and workshop.

Most communities consider auto salvage yard operations to be eyesores. Therefore, they require auto salvage yard owners to shield their yards from direct view. In urban built-up areas most auto salvage yards are surrounded by high wooden fences. In rural areas, such as site 72, the yards are surrounded by trees. The shielding trees can be seen in figure 6-51 at B and in the ground-level photograph of figure 6-52 at A.



Figure 6-51.--Large-scale vertical photograph of auto salvage yard near Columbia, Mo.



Figure 6-52.--Ground photograph of auto salvage yard.

Site No. 45 (Auto Salvage Yard)
 Location: St. Robert
 Pulaski County, Missouri
 Geographic Coordinates: 37°48'N
 92°09'W

Figure 6-53 presents another example of an auto salvage yard. This yard is located near the Fort Leonard Wood U.S. Army base just west of the four-lane access road to the base. As with the previous example, notice how the autos are placed in tightly packed rows with dirt access roads. Also notice the sales office/workshop located at A.

Situated in a heavily wooded area, the yard is obscured from view, particularly from the access road. Notice how the owner/operator of the yard is clearing some of the trees near B to make way for more wrecked or junked autos.

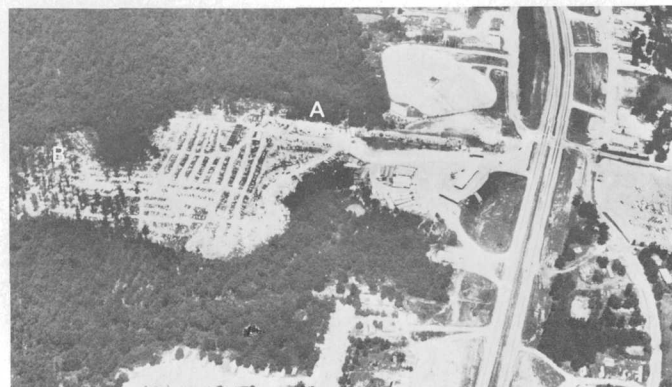


Figure 6-53.--Auto salvage yard at Fort Leonard Wood, Mo.

Site No. 7 (Sports Stadium)
 Location: St. Louis
 St. Louis City, Missouri
 Geographic Coordinates: 38°38'N
 90°12'W

Commercial sports complexes such as stadiums, field houses, racetracks, and other recreational complexes such as amusement parks and golf-course clubhouses are included in land use category 12. Such complexes are characterized by well-organized grounds and/or structures with ample parking facilities. Most of the larger complexes, such as sports stadiums, are located near major traffic access routes in metropolitan areas.

Site 7, Busch Memorial Stadium in downtown St. Louis, is typical of sports complexes included in land use category 12. Figure 6-54 shows a sports stadium with parking facilities at A and major traffic access routes at B.



Figure 6-55.--Ground photograph of Busch Memorial Stadium.

Site No. 78 (Sports Stadiums)
 Location: Kansas City
 Jackson County, Missouri
 Geographic Coordinates: 39°03'N
 94°29'W

The Harry S. Truman Sports Complex, figure 6-56, is a unique twin sports stadium located on the east side of the Kansas City Metropolitan area at the junction of Interstate 70 and the I-435 bypass. The baseball stadium at A is the home of the Kansas City Royals; the football stadium at B is the home of the Kansas City Chiefs. Notice the extensive area of parking surrounding the stadiums. Also notice the additional parking facilities at C, which have been added since completion of the complex.

As with all major sports complexes, ease of traffic access is very important. Notice the numerous parking access points at D.



Figure 6-54.--Busch Memorial Stadium in downtown St. Louis, Mo.

Also notice at C the pedestrian walkways extending to the stadium at C from the parking facilities. The stadium, which seats over 50,000, is the home for professional football, baseball, and soccer teams.

This sports facility in the downtown area of St. Louis is surrounded by many open air parking facilities. These facilities are also used by the people employed in the area during the weekdays. Multistoried parking facilities developed in the area, however, they are very difficult to identify on the photography.

Figure 6-55 shows the walkramps to the stadium.



Figure 6-56.--Small-scale photograph of Harry S. Truman Sports Complex, Kansas City.

Figure 6-57 is a large-scale photograph of the sports complex. Notice the walkramps for both the baseball stadium at the top of the photograph and the football stadium in the foreground. The VIP parking area is shown at A. The dark circular areas surrounding the football stadium are shrubbery areas. Also notice the lighter strips on the football field. At the time of this photograph (June 1980) the artificial turf was under repair.

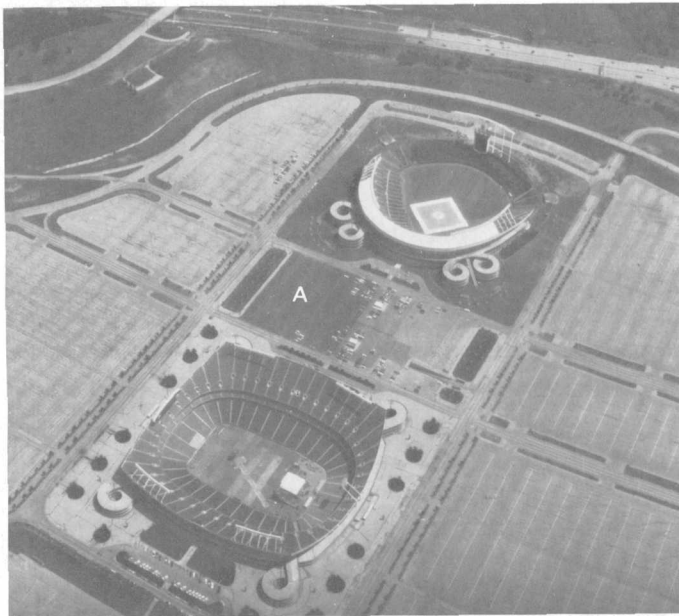


Figure 6-57.--Low-level oblique photograph of sports complex.

Figure 6-58 presents a ground-level view of the sports complex--the football stadium on the left, and the baseball stadium on the right. Notice the spiral walkramp at A.

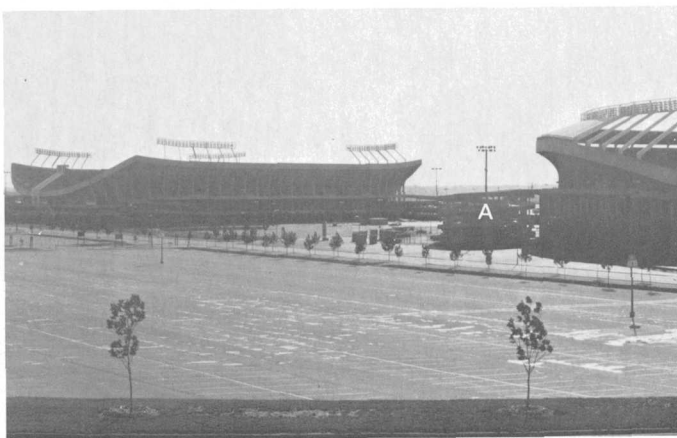


Figure 6-58.--Harry S. Truman Sports Complex.

Site No. 59 (Regional Fairgrounds)
Location: Springfield
Greene County, Missouri
Geographic Coordinates: 37°15'N
93°18'W

Fairgrounds, including associated exhibition buildings, grandstands, racetracks, rodeo arenas, corrals, paddock areas, and midway areas are included in land use category 12. Circled in figure 6-59 is the Ozark Empire Regional Fairgrounds in east Springfield. Originally located away from the Springfield urbanized area, urban encroachment is quite evident in this small-scale photograph. Notice residential structures to the south, Central Bible College to the east, and Hillcrest High School to the north. Figure 6-59 also shows Dickerson Park Zoo, west of the fairgrounds.



Figure 6-59.--Mapping photograph of Ozark Empire Regional Fairgrounds at Springfield.

The facilities associated with this regional fairground area are shown more clearly in figure 6-60. Exhibition buildings are located at A, the racetrack at B, the midway area at C, and the grandstand at D. Notice the lack of parking facilities at the fairgrounds.

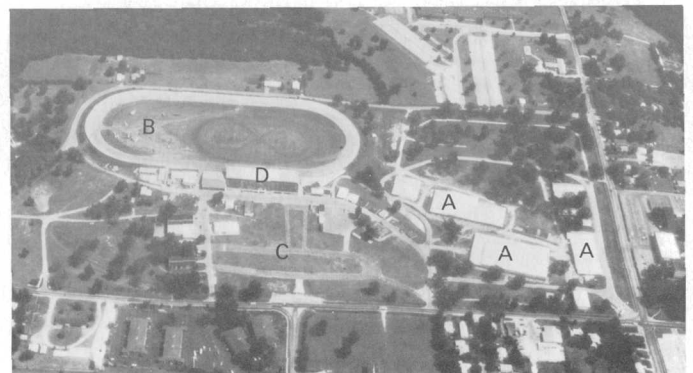


Figure 6-60.--Large-scale photograph of Ozark Empire Fairgrounds.

Figure 6-61 shows one of the exhibition buildings at the fairgrounds.



Figure 6-61.--Exhibition building at Ozark Empire Fairgrounds.

Site No. 5 (Hospital)
 Location: St. Louis
 St. Louis City, Missouri
 Geographic Coordinates: 38°38'N
 90°16'W

Medical and health facilities, such as Barnes Hospital in figure 6-62 are included in land use category 12. Since this particular site is adjacent to other Commercial and Services structures it is difficult to identify the site as a medical complex from aerial photographs. One must rely on ancillary data or ground investigations to identify the site as a hospital.

Some features which should be noted in figure 6-62 are the parking facilities at A, the underground parking facilities at B (where the tennis courts are located), and the interconnecting walkways between the buildings such as those at C.

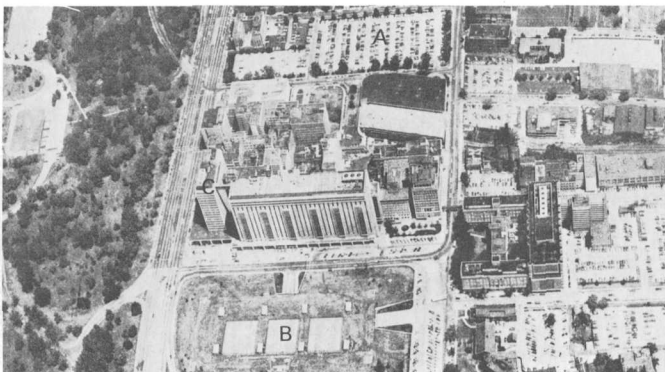


Figure 6-62.--Low-level oblique photograph of Barnes Hospital in St. Louis, Mo.

Pictured in figure 6-63 is a ground-level photograph of the Barnes Hospital complex. Notice the interconnecting walkways at A.



Figure 6-63.--Barnes Hospital, St. Louis, Mo.

Site No. 57 (Hospital)
 Location: Springfield
 Greene County, Missouri
 Geographic Coordinates: 37°11'N
 93°17'W

Figure 6-64 depicts another regional medical complex--Springfield's St. John's Hospital serving southwest Missouri. Unlike Barnes Hospital in St. Louis, this medical complex is more easily identified since it is surrounded by residential structures. As with most medical complexes, the multistory buildings and wings are interconnected. Prominent in figure 6-64 is the main entrance to the hospital with the circular drive and covered entrance. A more recent addition to the hospital--an east wing--is shown at A. Ample parking is available at B.

A ground-level view of the hospital is shown in figure 6-65. Notice the cross on top of the complex at A, and the newer wing at B.



Figure 6-64.--Forward oblique photograph of St. John's Hospital in Springfield, Mo.

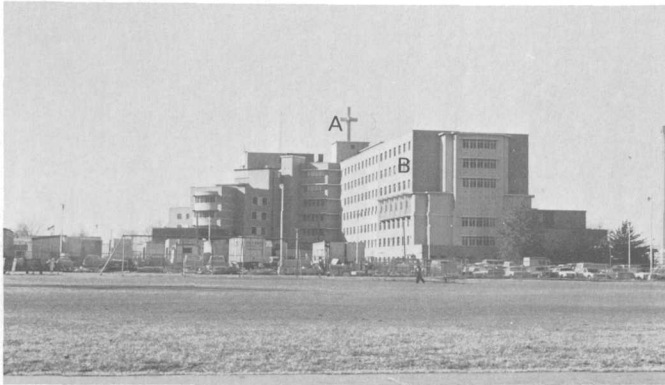


Figure 6-65.--St. John's Hospital,
Springfield, Mo.

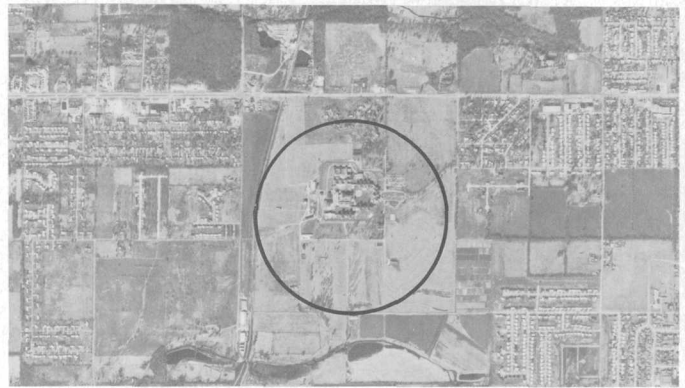


Figure 6-66.--Mapping photograph of Federal
Medical Center at Springfield, Mo.

Site No. 56 (Federal Hospital)
Location: Springfield
Greene County, Missouri
Geographic Coordinates: 37°10'N
93°19'W

Federal and State prisons and medical-correctional institutional areas are also included in land use category 12. Figure 6-66 identifies the Federal Medical Center in southwest Springfield. Once located away from the built-up area, urban expansion has produced residential encroachment.

Even though there has been residential encroachment in the area around the institution, there will be maintained a clean buffer zone between the institution and the nearest built-up area.

The Federal Medical Center is a minimum security complex devoted primarily to mental health care and incarceration of individuals convicted of "white-collar" crimes.

Figure 6-67 provides a clearer view of many of the photorecognition characteristics associated with such an institution. Note the double chain link fence at A, the guard towers at B, and the structural similarity of the buildings at C. Also notice the baseball field at D. This particular area is enclosed by yet another wall (point E). A more secure area of the institution is shown at F. Employee and visitor parking facilities are shown at G.

Institutions such as this normally maintain some of their own fuel and water. Behind the double chain link fence to the west is a water tower at H and a storage tank at I. Also visible is a maintenance building at J.

The main entrance to the institution is shown in figure 6-68. Notice the guard tower at A.

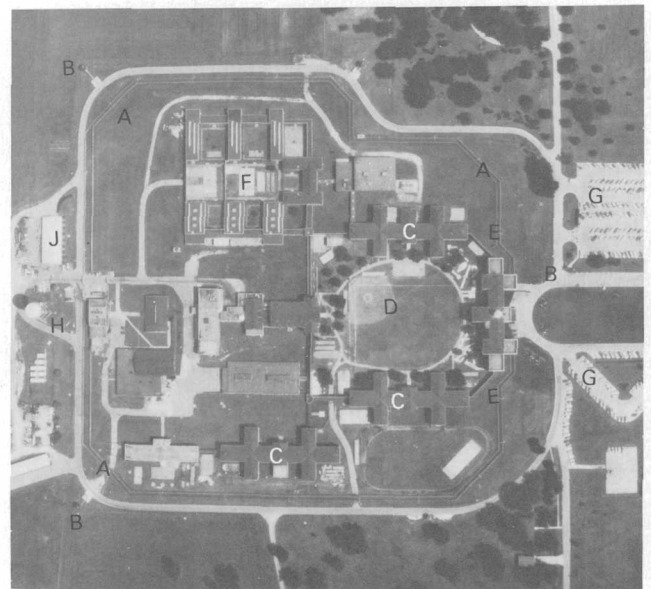


Figure 6-67.--Large-scale vertical
photograph of Federal Medical Center.

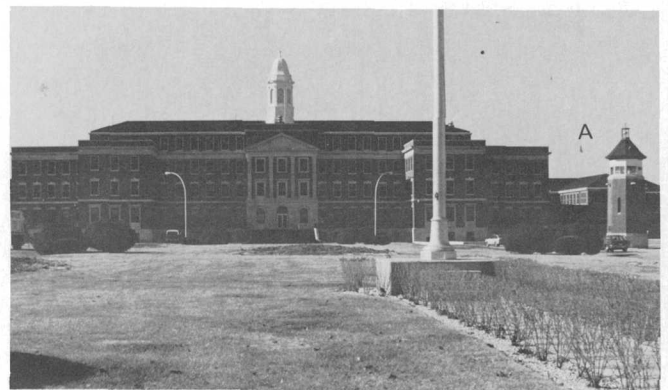


Figure 6-68.--Main entrance to Federal
Medical Center at Springfield, Mo.

Site No. 58 (University)
 Location: Springfield
 Greene County, Missouri
 Geographic Coordinates: 37°12'N
 93°16'W

All buildings, grounds, and parking lots associated with educational institutions are included in land use category 12. The physical layout of Southwest Missouri State University in Springfield is shown in figure 6-69. Identified in this stereogram are the football stadium at A, tennis courts at B, newer, high-rise dormitories at C, and older classroom buildings at D. Note the relative height differences between the high-rise dormitories at C and the older classroom buildings at D.



Figure 6-69.--Stereogram of Southwest Missouri State University campus in Springfield, Mo. (Note that this photograph is oriented with east at top.)

A large-scale vertical photograph of the campus is shown in figure 6-70. Again, note the football stadium at A, the tennis courts at B, and the high-rise dormitories at C. Also note the availability of parking at D. This photograph was taken in July 1980. Had it been taken during the fall or spring, the parking lots would have been full. Other facilities visible in figure 6-70 include the gymnasium and swimming pool at E, the library at F, the student union at G, and the administration building at H. Finally, note the maze of walkways which link the campus structures.

Also shown in figure 6-70 is a practice field at I. Although it is unlikely, these areas may also fall victim to construction someday.

Figure 6-71 presents a ground-level view of Carrington Hall--the administration building on campus.

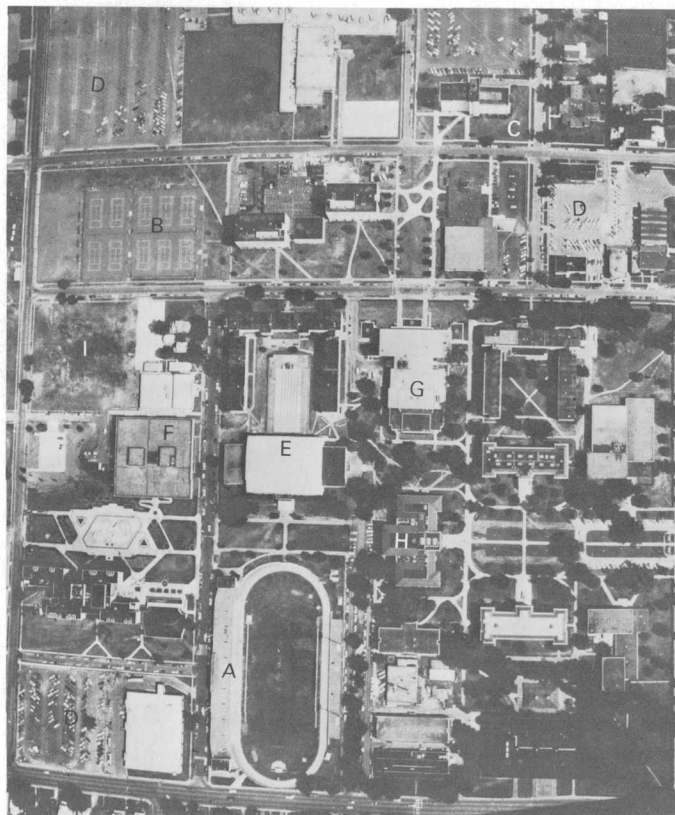


Figure 6-70.--Low-altitude vertical photograph of Southwest Missouri State University campus in Springfield, Mo.



Figure 6-71.--Administration building at Southwest Missouri State University.

Site No. 6 (Intermediate School)
 Location: Webster Groves
 St. Louis County, Missouri
 Geographic Coordinates: 38°34'N
 91°22'W

Elementary and secondary schools are most frequently located in residential neighborhoods

away from high traffic-volume areas. As with other institutional land uses, scholastic buildings, grounds, and associated facilities are included in land use category 12.

Elementary schools usually consist of one building with limited recreational facilities. Junior high schools may consist of several buildings and may even have their own football field or stadium. Intermediate and high schools, however, can be characterized as rather large campuses with several separate buildings (normally connected by covered walkways) or with interconnected buildings, large football/athletic fields with viewing stands, and parking facilities for the faculty and staff as well as for the students.

Figure 6-72 is a mapping photograph of Webster Groves Intermediate School southwest of St. Louis. The intermediate school is shown at point A. At point B can be seen a municipal park and recreation area--two ballfields, a swimming pool, and some tennis courts. This latter area should be classified as land use category 17. Also shown in figure 6-72, just north of the school, is Interstate 44.



Figure 6-72.--Small-scale photograph of intermediate school campus and municipal park and recreation area, Webster Groves, Mo.

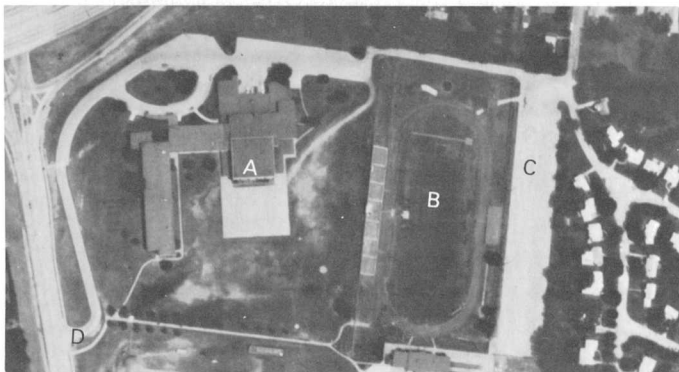


Figure 6-73.--Large-scale vertical photograph of Webster Groves Intermediate School.

Figure 6-73 is a vertical photograph of the intermediate school campus. The school building is shown at A, the football/athletic field at B, and faculty parking facilities at C. Also notice the controlled traffic access at D.

The front entrance to the school and covered passenger loading and unloading area are shown in figure 6-74.



Figure 6-74.--Main entrance and passenger loading area for Webster Groves Intermediate School.

Site No. 48 (Military Installation)
Location: Fort Leonard Wood
Pulaski County, Missouri
Geographic Coordinates: 37°46'N
92°08'W

Figure 6-75 shows several key identification features of most military installations. Point A identifies the main parade ground. Although this particular site is not surrounded by buildings on all sides, most military base parade grounds are surrounded by administrative buildings. Point B, site of the original parade grounds, is now an athletic field. Basic training quarters and instructional buildings are shown at C. On-base, dependent housing facilities are shown at D. A general merchandise warehouse area can be seen at E. Also shown at F is the airfield which serves the base. Point G identifies advanced training barracks and training buildings. Although not shown on this photograph, firing ranges and bivouac areas are located just to the south.

Figure 6-76 presents a large-scale photograph of the main parade grounds at A, the basic training building at B, the base training barracks at C, the base theater at D, and athletic fields at E. Notice the viewing stands on the west side of the parade grounds. Also note the whitish tone of the training area at B where the recruits have denuded the area.



Figure 6-75.--Mapping photograph of Fort Leonard Wood Army base.

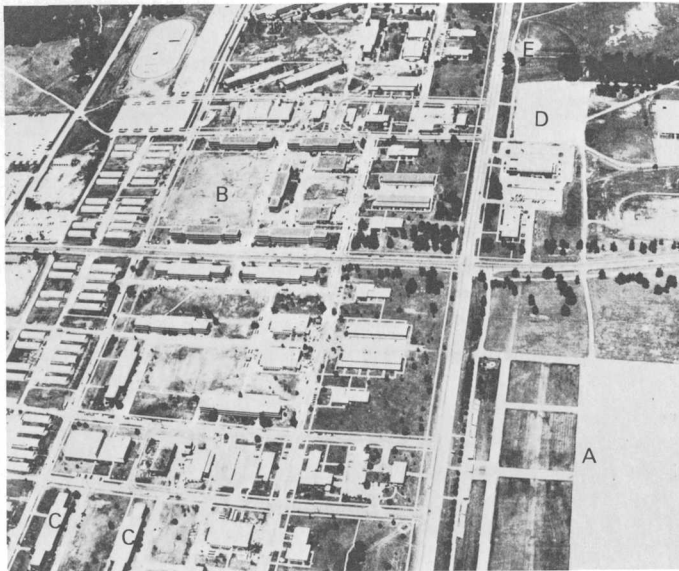


Figure 6-76.--Low-level oblique photograph of main parade grounds and basic training facilities at Fort Leonard Wood, Mo.

Category 13--Industrial

Category Description. Probably no other category in the classification system has such a diversity of structure types as the industrial category. This category covers a wide variety of land uses, from installations involved with product design, assembly, finishing, processing, and packaging to steel mills, cement plants, chemical plants, electric power generators, oil refineries, and mining. In all of these industrial activities, the buildings, parking and shipment areas, and stockpiles of raw materials and waste products are all included in the delineation of the area. For mining, only the surface manifestation of the mining is delineated. That is, the

buildings, mine shafts, and spoil material are included. Underground mining activities are not delineated as industrial but rather are shown by the type of surface cover (i.e., agricultural land, forest land).

Different classification systems separate industries into different sub-categories in a variety of ways. The Standard Industrial Classification Manual, for example, describes industrial categories by the generic type of industry as listed below:

- Division A - Agriculture, forestry, and fishing
- Division B - Mining
- Division C - Construction
- Division D - Manufacturing

Many metropolitan areas use this classification scheme; however, there are several other schemes used to classify industries (processing industries, manufacturing industries, and fabrication industries). Industries, by whatever classification term is used, have identification features unique to each type. Professional Paper 964 (Anderson and others, 1976) only used the term "industrial;" however, in the descriptive text, it refers to a breakout of light and heavy industries.

To illustrate the difference between light and heavy industries, the following descriptions have been used.

Light Manufacturing. "These light industrial activities are focused on design, assembly, finishing, and packaging of products rather than processing of raw materials. Materials used have generally been processed at least once. Included are facilities for administration and research, assembly, storage and warehousing, shipping, and associated parking lots and grounds. Land held in reserve may also be evident. Among the industries in this category are research laboratories, small textile mills, electronics firms, trucking companies, and even such large industries as automobile assembly plants.

"In comparison with heavy industries, these are relatively 'clean'--contributing considerably less smoke, noise, dust, other effluents, and visual 'pollution.'

"Identification of these industries can be based on type of buildings, parking and shipping arrangements, and location in relation to cities or villages. Unlike shopping centers, large commercial establishments or schools, outdoor storage of materials may be discernible along with trailer trucks parked on the premises. Rail lines may be present. Loading docks and power sources (large transformers, power lines, smokestacks, or large

fuel storage tanks) may suggest a manufacturing process rather than retail sales.

"Occasionally, inactive plants are found. Some have been converted to other uses such as retail sales. Where these uses could be detected, they were mapped accordingly. Otherwise, inactive plants are classified by their apparent former use."¹

Heavy Manufacturing. These industrial activities may be thought of as dirty, being devoted to heavy fabrication, making and assembling parts which are, in themselves, large and heavy, or to the processing of basic raw materials, including ore dressing operations.

The following description of heavy processing industries is taken from the Manual of Photographic Interpretation.

"Processing industries subject to accumulated raw materials to treatment by mechanical or chemical means or by heat to render them suitable for further processing, or to produce materials from which finished products can be made. Characteristic facilities for storing and handling bulk materials are useful clues to the identity of these industries. Blast furnaces, kilns, chemical processing towers, and large chimneys or stacks are usually visible and serve to indicate the kind of processing being carried on.

"Processing industries usually require large quantities of power; coal piles, fuel tanks, boiler houses, or transformer yards may indicate the source of power. The buildings which house processing equipment are often large and usually complex in outline and roof structure. Since processing usually includes refinement of raw materials, piles and ponds of waste are common; they have to be distinguished from stored raw materials.

"Processing industries can be subdivided according to function into mechanical processing, chemical processing, and heat processing industries. A few industries depart from the functional classification, but this departure does not interfere with the utility of the key.

"Mechanical processing industries are those engaged in sizing, sorting, separating, or otherwise changing the physical form or appearance of the raw materials. They can be identified by the presence of bulk materials stored in piles, ponds, or reservoirs, outdoor equipment such as silos, bins, bunkers, and open tanks, or handling equipment such as conveyors, launders, cranes, and railroad cars. A great deal of power is generally required, and boiler houses or transformer yards are

quite common. Buildings are likely to be large and complex. Piles or ponds of waste are also common.

"Mechanical processing industries differ from other processing industries in that they have few pipelines, closed or tall tanks or stacks except those on boiler houses. They do not have kilns.

"Typical mechanical processing industries are ore reducers, sawmills, and grain mills. Plants for hydroelectric power production, water purification, and sewage disposal also fall in this class. Aluminum refining is one of those industries whose images place them in this class although the processes are not mechanical.

"Chemical processing industries separate or rearrange the chemical constituents of the raw materials. Pressure, heat, and catalysts or other chemicals are usually employed. Closed vessels for handling liquids, gases, or suspensions of solids in liquids or gasses are typical of these industries, as is the use of fluid flow in processing. Closed tanks, pipelines, and towers for cracking or distillation are usually visible in photographs of chemical processing industries.

"Heat processing industries refine, separate, or reform the raw materials, or derive energy from them. Large quantities of coal or other fuel, chimneys, stacks, blast furnaces, and kilns are characteristic of these industries. Pipelines and tanks are sometimes used but are never abundant, and their presence, which might be taken to indicate chemical processing, is outweighed by the abundance of objects evidencing the use of heat. Industries typical of this class are thermal electric power plants, iron and copper smelters, cement plants, and clay products plants."²

Environmental Considerations. Industrial land use category (13) contains the greatest number of potential sources of pollution. Environmental problems can arise from the open storage of raw materials, the manufacturing of the products, the storage of the finished products and byproducts, and the disposal of waste materials.

The most frequent environmental impact is the deterioration of water quality and soil contamination. These conditions occur because of runoff from the raw materials, improper or careless storage practices for finished products, and improper disposal of harmful waste byproducts.

²The description of heavy processing industries is taken from the Manual of Photographic Interpretation, American Society of Photogrammetry (1960), p. 701-702.

¹Description of light industry is taken from the Land Use and Natural Resource Classification Manual (Swanson, 1972), p. 14-15.

Open storage of raw materials can lead to runoff containing heavy metals, phosphates, and other harmful substances which can find their way into surface and ground-water resources. Contamination from finished products can occur from faulty and leaking storage tanks, unrevetted storage tanks, and careless cleanup practices when a spill or leakage occurs.

The most damaging conditions which occur are the result of improper disposal of waste byproducts. Burying of drums containing toxic chemicals in unsafe landfills; directly discharging toxics into waterways or onto the ground; and unlined, poorly constructed waste lagoons all contribute to the deterioration of both ground and surface water quality.

At the local level, industries also contribute to air and noise pollution. Depending on the type of industry, the air quality in the surrounding area may deteriorate. Some of the air pollution is caused by auto emissions from employee autos and company trucks. Additional air quality problems may arise if the industry uses processes which require the emission of pollutants into the air.

Noise pollution by industry is generally confined to the plant and immediate area, effecting mostly those employed by the industry and nearby residents.

Interpretation Keys. The following examples illustrate various types of industry. These examples by no means cover all the various industrial types, but they do present a good cross section of the Industrial category.

Site No. 8 (Rolling Mills-Steel)
 Location: St. Louis
 St. Louis City, Missouri
 Geographic Coordinates: 38°37'N
 90°18'W

This site is an example of a steel rolling mill. The installation would be classified as a heavy or processing industry if compared to the definitions given in the category description. The stereogram, figure 6-77, shows the plant layout, the high-sided buildings, and the raw materials yard.

These types of mills have stacks along the sides of one of the buildings (point A, figure 6-78) which are probably soaking pits where the ingots of metal are heated to the point where the rolling process can form the required steel pieces.



Figure 6-77.--Stereogram of a steel rolling mill, St. Louis, Mo.



Figure 6-78.--Large-scale vertical photograph of building layout and stacks, St. Louis, Mo.

The identifying features of this type of installation are the long, high-sided buildings with the skylights (figure 6-79). The buildings are constructed in this manner to allow room for the heavy travelling cranes. These cranes move the steel to various processing stations within the buildings.

This installation is serviced by both truck and railroad. There is marked difference in the plant as shown in the small-scale stereogram, dated 1974, (figure 6-77) and the large-scale oblique photograph taken in 1980 (figure 6-80). In figure 6-80, tanks have been removed from A. Lack of raw materials in the

raw materials yard, point B, and absence of finished products would lead one to believe that the mill is no longer active.



Figure 6-79.--Ground photograph of high-sided building with skylights.



Figure 6-80.--Low-altitude oblique photograph of steel mill.

Site No. 9 (Barge Building)
 Location: St. Louis
 St. Louis City, Missouri
 Geographic Coordinates: 38°32'N
 90°15'W

This installation is located on the St. Louis waterfront south of mid-town (figure 6-81).



Figure 6-81.--Barge building and repair, St. Louis, Mo.

This installation is a barge-building and barge-repair or refitting operation. There are several identifying features for this installation. Among these are the number of barges in proximity to the installation. The barges are not moored in any systematic manner as they would be if they were being loaded or unloaded.

The primary identifying features of this type installation are shown in figure 6-82. Notice the shipways (marine railings) which are used to launch the vessels at A. The barge is built on the steel tracks, and when the hull is completed, it slides down the ways into the river. After the barge hull is launched, there remains a number of items to be completed, such as the decks and hatches. These jobs are generally completed while the barge is moored in the river. The travelling crane, point B, figure 6-82 and point A, figure 6-83, is used to move steel into position for welding during construction. The raw materials used in barge construction, steel, are shown in the form of rolls at point C, figure 6-82, and at point A, figure 6-84. Directly behind these rolls, at point B, figure 6-84, is a large building where fabrication of pieces of steel for the barges takes place.

In addition to the barges and tugboats moored next to the installation, there are two drydocks which are used to raise the vessel out of the water so that the hull is exposed for repair. At D, figure 6-82, is a tugboat in one drydock, being repaired or refitted.

This installation, although small in comparison to the large shipbuilding yards found in the major port cities, has the same identifying features. The size and length of the shipways will be larger in proportion to the size of the ship being constructed. The crane will be larger as will be the storage and fabrication areas. All of these identifying features will be recognized as a boat or shipbuilding area.



Figure 6-82.--Low-altitude oblique photograph showing plant components.



Figure 6-84.--Storage yard and fabrication building.

Site No. 21 (Cement Plant and Quarry)
 Location: Cape Girardeau
 Cape Girardeau County, Missouri
 Geographic Coordinates: 37°16'N
 89°32'W

Located near the southern city limits of Cape Girardeau, very near the Mississippi River, the plant shown in figures 6-85 through 6-89 has all of the recognition characteristics of a cement plant. Raw materials for the plant are obtained from the adjacent quarry shown in figure 6-85.

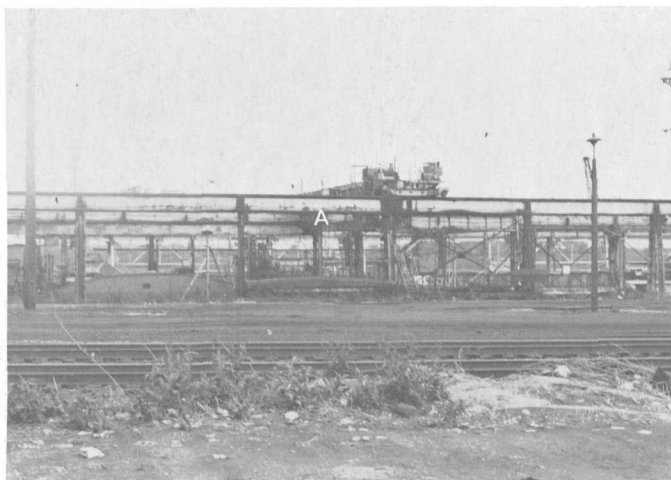


Figure 6-83.--Travelling crane.



Figure 6-85.--Cement plant with quarry, Cape Girardeau, Mo.

Since the quarry meets minimum size parameters (10 acres), it should be classified as category 75. The raw materials are transported from the quarry to a cement plant by means of a complex conveyor-belt system (figure 6-86).

Additional features associated with cement plants are identified in figures 6-87 and 6-88. Roasting kilns are shown at A in figure 6-87. Actually there are two kilns; however, one is obscured by the construction activity at C. Also shown at B in figure 6-87 are 10 large

silos. Several silos are shown in figure 6-88, as well as several cement trucks at A.

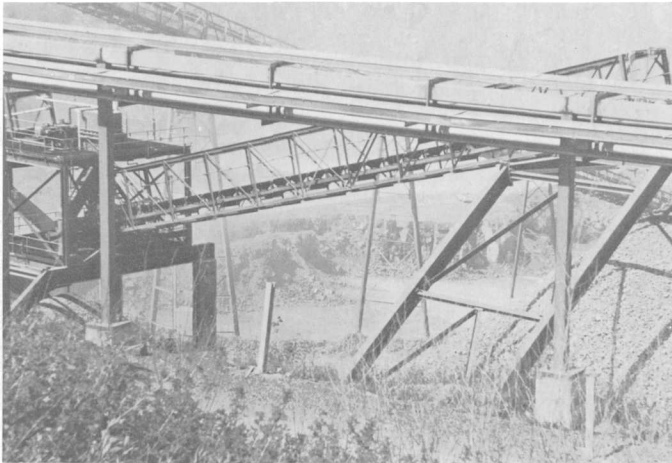


Figure 6-86.--Conveyor belts used for transporting materials to the plant area.



Figure 6-87.--Low-level photograph of cement plant.



Figure 6-88.--Ground photograph of silos and cement trucks.

Figure 6-89, presents a good view of the entire layout of the cement plant. Notice the quarry at A, the conveyor belts at B, storage silos at C, and the railroad at D. Although not shown on this photograph, port facilities are located just east of the plant area.

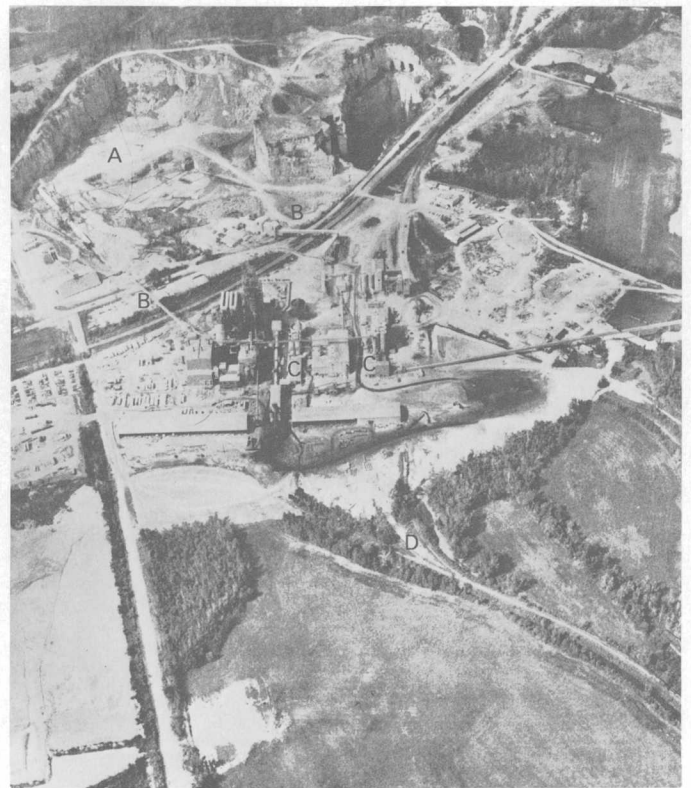


Figure 6-89.--Low-level oblique photograph of cement plant with associated features.

Site No. 35 (Mine)
 Location: Bunker
 Reynolds County, Missouri
 Geographic Coordinates: 37°32'N
 91°09'W

The primary purpose of the installation in figure 6-90 is to mine lead ore, process it, and concentrate it for smelting. This mining and the concentration processes that the ore is subjected to are generally the same for other mines in this area. Building arrangement and style of structures may be different; however, the identifying features will be the same. Identifying features of the mine are shown in figure 6-91: one or more shafts at A, an ore crusher building at B, and the concentration building at C. Since the mine uses water floatation, it has its own reservoir.

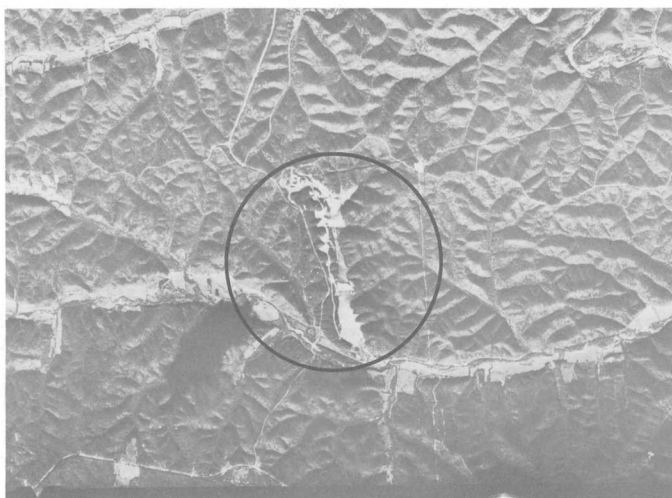


Figure 6-90.--Mapping photograph of a mining installation at Bunker, Mo.

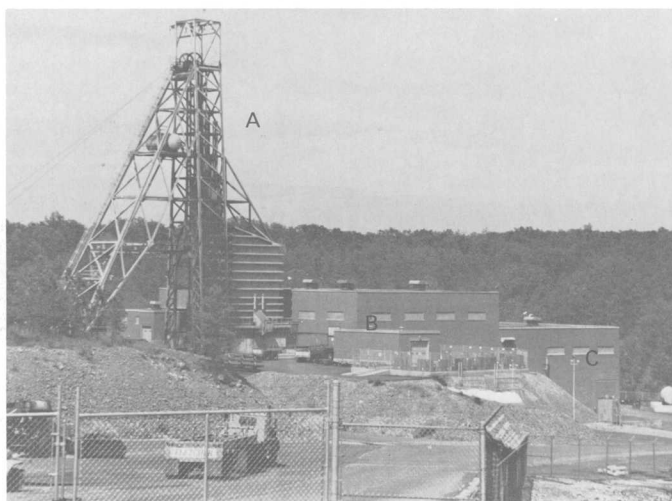


Figure 6-91.--Mine shaft and processing building.

Figure 6-92 shows the plant layout. The reservoir is at A, the mine shafts at B, the crusher and concentrating buildings at D, and dewatering tanks at C. The processing buildings, built on a hillside, allow for gravity flow throughout the processing system.

All above-ground structures and features associated with mining activity, such as the reservoir, shafts, processing buildings, and tailings pond, should be included in category 13. Figure 6-93 shows the spatial relationship of these characteristics: point A--the reservoir, point B--the mine shafts and processing buildings, and point C, the tailings pond.



Figure 6-92.--The mine area, Bunker, Mo.



Figure 6-93.--Mine layout, Bunker, Mo.

Site No. 36 (Metal Processing)
 Location: Buick
 Reynolds County, Missouri
 Geographic Coordinates: 37°34'N
 91°08'W

This is a mine and ore concentration site. The final product from this mine is the same as that at site 35. This installation is larger than site 35 and the individual operations are separated. The tailings pond is rather far removed from the mine itself, as can be seen in figure 6-94, where point A is the mine and point B is the tailings pond.

The various components of the installation are connected by conveyors. The layout of the site is shown in figure 6-95. The mine shafts (A) at this mine do not look like the shafts at site 35, however, they serve the same purpose. The primary crusher (B) has a conveyor to the secondary grinder and screener (C) also shown at this operation. Also, there is a feed back to the primary crusher from the secondary grinder. The conveyor then moves the material to the silos (D) for storage awaiting the concentration process (E). The dewatering tanks are shown at F. Since this type of mining operation requires considerable electric power, a transformer yard was constructed at G. Point H indicates the location of piles of ore concentrate.

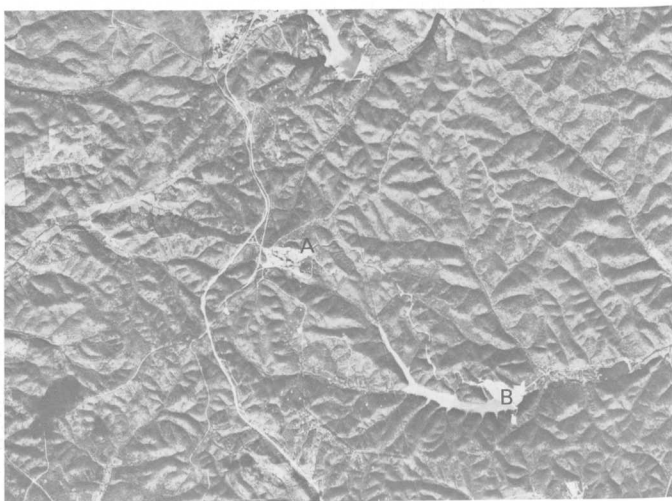


Figure 6-94.--Small-scale photograph of mine area.

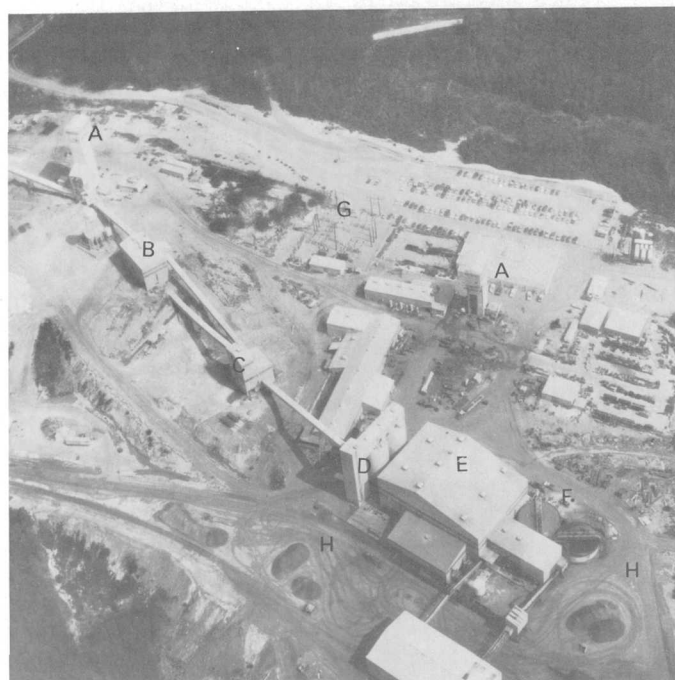


Figure 6-95.--Mine layout indicating component points.

The ground photograph (figure 6-96) shows a close view of one of the mine shafts (A), the secondary grinder and screens (B), the storage silos (C), the concentrator and processing building (D), and the transformer yard (E). This mine, like site 35, is serviced by truck and railroad.



Figure 6-96.--Ground photograph of mine area, Buick, Mo.

Site No. 37 (Mine and Smelter)
Location: Buick
Reynolds County, Missouri
Geographic Coordinates: 37°34'N
91°08'W

Shown in figure 6-97 is the area covered by the mine, smelter, and tailings pond of a large new installation near Buick, Missouri.

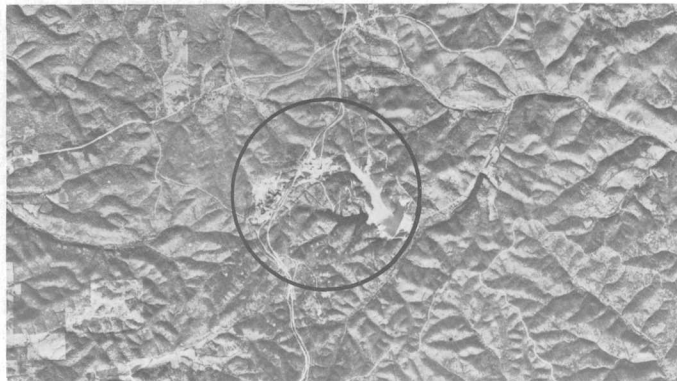


Figure 6-97.--Mapping photograph of mining and lead smelting plant at Buick, Mo.

Figure 6-98 shows a low-level oblique photograph of the mining and concentrator area at A and the smelter area at B. The mining and concentration of lead ore were previously illustrated in sites 35 and 36. Therefore, the description given here is for the smelting area only.

The smelting areas are labeled in figure 6-99. The concentrate and flux begins the smelting process at A where the ingredients for smelting are mixed together. Then, by conveyor, they are transported to B, the sintering building. Sintered material is transported to C, the blast furnace. From the blast furnace the material moves into the refinery building at D. The lead bullion awaits shipment at E. Sulfuric acid is a byproduct of the smelting process. The fumes from the smelting process are piped through the bag house (F) to the acid plant (G) where they are converted to sulfuric acid.



Figure 6-98.--Low-level photograph of the mining and smelter areas.



Figure 6-99.--Low-level photograph of lead smelter.

Figure 6-100 shows a ground-level photograph of the mixing building (A), the smelting building (B), the blast furnace building (C), the refinery (D), and the stack for the bag house (E).



Figure 6-100.--Ground photograph of the smelter area at Buick, Mo.

Site No. 50 (Stave Company)
 Location: Lebanon
 Laclede County, Missouri
 Geographic Coordinates: 37°40'N
 92°40'W

Site No. 85 (Sawmill)
 Location: Potosi
 Washington County, Missouri
 Geographic Coordinates: 37°55'N
 90°51'W

These two sites are lumber-related industries and therefore will be considered together. Site 50 is a stave mill which, in addition to producing barrel staves, also produces walnut fixtures. The stave mill is located in the town of Lebanon (figure 6-101). The sawmill (site 85) is located in a heavily forested area (see figure 6-102) and also produces pallets.



Figure 6-101.--Mapping photograph of the stave company, Lebanon, Mo.



Figure 6-102.--Mapping photograph of the lumber mill near Potosi, Mo.

Raw materials for both plants are wood. However, the sawmill uses logs while the stave company uses processed lumber. Figure 6-103 shows lumber piles stacked at A and stave processing at B. Figure 6-104 identifies the location of the storage area for logs (B) to be processed at the sawmill (A).

The logs, before processing, are shown in the ground shot at A in figure 6-105, while the finished pallets are shown at B.



Figure 6-103.--Stave factory, Lebanon, Mo.



Figure 6-104.--Sawmill, Potosi, Mo.



Figure 6-105.--Sawmill and raw materials.

The one identifying feature which is identical for both of these industries is the sawdust burner. The sawdust burners for the stave factory can be seen in figure 6-106, while the sawdust burner for the sawmill is shown in figure 6-107.

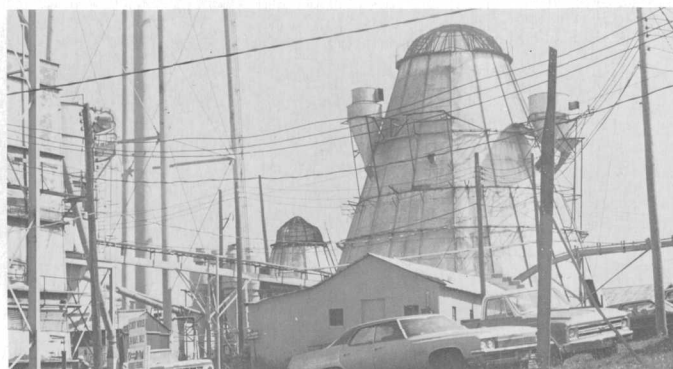


Figure 6-106.--Sawdust burners at the stave factory, Lebanon, Mo.



Figure 6-107.--Sawdust burner at the lumber mill, Potosi, Mo.

Site No. 60 (Light Industry)
 Location: Springfield
 Greene County, Missouri
 Geographic Coordinates: 37°15'N
 93°12'W

This plant is located just east of Springfield, Mo., an area surrounded by cropland and pasture (figure 6-108). The features which identify light processing industries are large expansive flat top buildings with low profiles, ventilation outlets on the roof, and silos, at C, for storage of raw materials (figure 6-109). This installation is serviced by rail (A) and by truck (B). Truck loading docks are shown at E and F. The largest concrete apron and truck loading dock (E) is probably the shipping dock, while the railroad and truck loading docks at F are most likely used for delivery of raw materials. Also note the employee parking at D.



Figure 6-108.--Mapping photograph of light processing industry east of Springfield, Mo.



Figure 6-109.--Low-level oblique photograph of light industry.

Also notice in figure 6-110 the rail tank car at A. With light industry, the silos may not always be present, but the remaining identifying features will be.

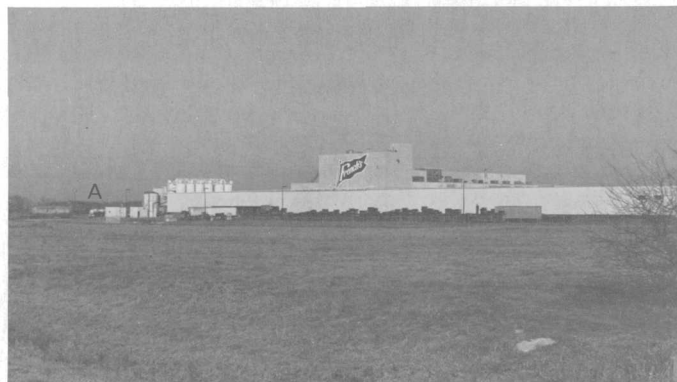


Figure 6-110.--Ground shot of light industry building shows low profile, loading docks, and storage silos.

Site No. 66 (Dam-Hydroelectric)
 Location: Table Rock Reservoir
 Taney County, Missouri
 Geographic Coordinates: 36°36'N
 93°19'W

Site No. 71 (Nuclear Power Plant)
 Location: Reform
 Callaway County, Missouri
 Geographic Coordinates: 38°45'N
 91°45'W

Site No. 96 (Thomas Hill Power Plant-Thermal)
 Location: Thomas Hill Reservoir
 Randolph County, Missouri
 Geographic Coordinates: 39°33'N
 92°38'W

Sites 66, 71, and 96 are power plants. These sites represent the three major types of power generation plants: hydroelectric, nuclear, and thermal. Some of the identifying features are the same for all (transformer yards and transmission lines), while other identification features are unique.

Site No. 66 is a hydroelectric plant. Although there is machinery and equipment associated with this plant, it is housed within the dam. The identifying features associated with this industry are shown on figure 6-111, particularly the dam (A). The electrical generator area is identified by tailraces at B. The water in the reservoir is funneled past

a set of turbines which are rotated by water pressure. The turbines are in turn attached to generators for developing electric current. The transformer yard, at C, is a starting point for transmitting the electric current. In addition to using the dam as a means of generating electric power, the reservoir provides recreational activities. At D, a fish hatchery uses cold water from a reservoir.

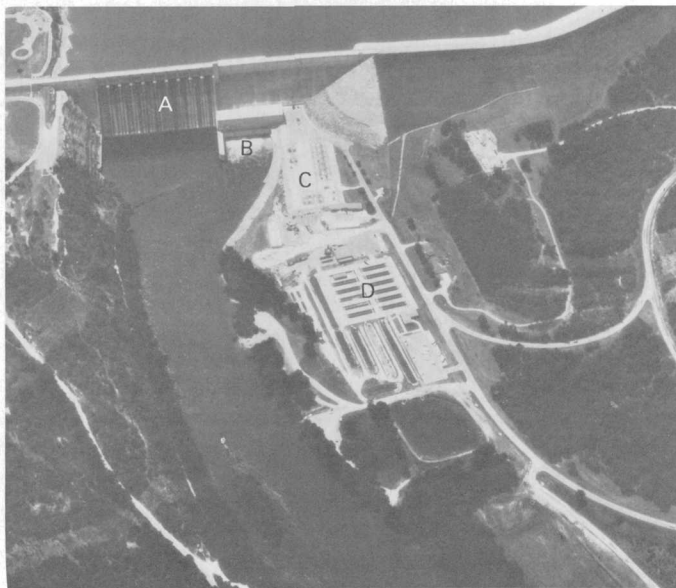


Figure 6-111.--Table Rock hydroelectric power generation dam.

Site No. 71 is a nuclear power plant under construction. Figure 6-112, photographed in July 1980, shows the plant under construction. There are many features which can be used to identify a nuclear plant. Among these features are the cooling tower (A) and the nuclear reactor building (B). In this particular photograph, because these items are under construction, they are difficult to identify. Nuclear power plants require a source of cooling water (C) as do thermal power plants (site 96). In the nuclear plant, the nuclear reactor creates the heat to convert the water to superheated steam which drives the turbines which turn the generators. Prior to discharge, water must be cooled and purified for further use. The ground photograph (figure 6-113), taken in June 1981, clearly shows the cooling tower (A) and the nuclear reactor building (B).

Site 96 is a thermal power plant. Figure 6-114, taken on April 11, 1977, shows the plant prior to recent expansion. The plant is located next to a reservoir so that water needed for cooling is readily available. Also, note that it is located in an area where there is a great deal of surface mineable coal for fuel. Features which identify the installation



Figure 6-112.--Nuclear plant under construction near Reform, Mo., July 1980.

are shown in figure 6-115: the coal pile (A) to be used for fuel and the conveyor belt which transports the coal to the main plant (B and C). In the plant, the coal is put through tube or ball mills to grind it into a fine powder. This coal powder is used to fire the boiler which heats the water and converts it to steam to turn turbines that run the generators. The water is then cooled (D). Another identifiable feature is the transformer yard (E).

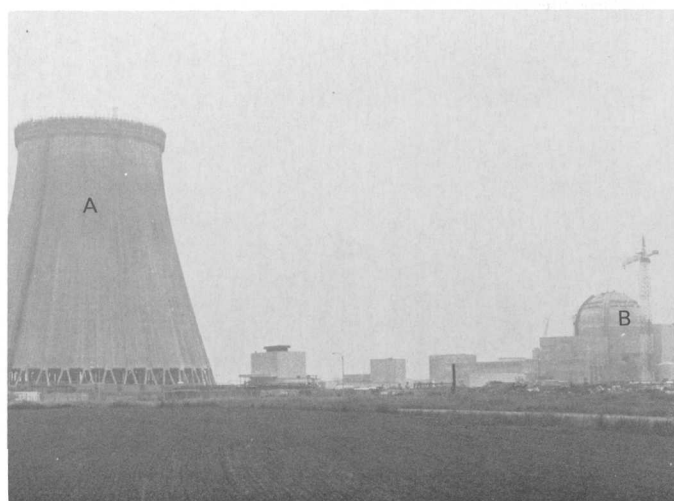


Figure 6-113.--Ground photograph of the same nuclear power plant, June 1981.



Figure 6-114.--Mapping photograph of thermal power plant at Thomas Hill Reservoir, April 1977.

The photograph in figure 6-115 was taken in 1981. Construction has produced a great deal of change since the time the photograph was acquired for figure 6-114.

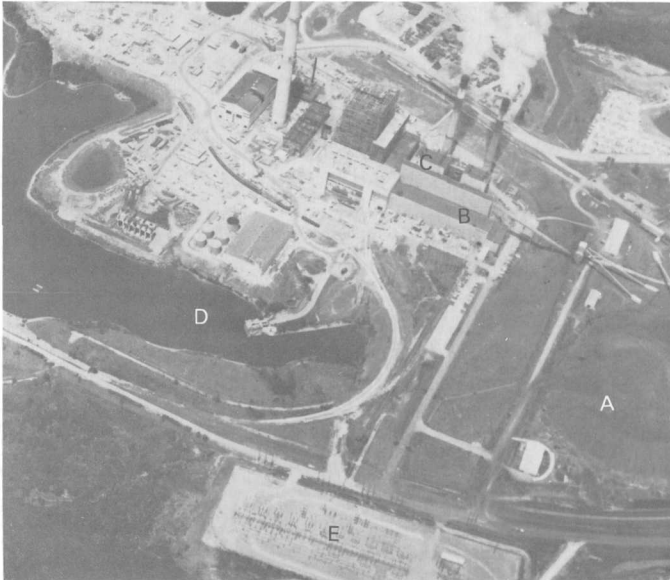


Figure 6-115.--Low-level oblique photograph of the thermal power plant, 1981.

Site No. 81 (Stockyards)
 Location: Kansas City
 Jackson County, Missouri
 Geographic Coordinates: 39°06'N,
 94°37'W

This land use type (figure 6-116) is a unique type of industrial installation which does not exist to the extent of the others previously illustrated. If the installation was in the countryside, it probably would be confused with confined feeding category 23.

The installation is served by both railroad and highway. The rectangular pattern of stock pens at A, figure 6-117, is one of its identifying features. The buildings at B are also divided into pens; this can be clearly seen only from the ground (figure 6-118).



Figure 6-116.--Mapping photograph of the stockyards in Kansas City, Mo.



Figure 6-117.--Low-altitude oblique photograph of the stockyards in Kansas City.



Figure 6-118.--Ground photograph of stockyards.

Site No. 90 (Coal Processing Plant)

Location: Hartford

Putnam County, Missouri

Geographic Coordinates: 40°29'N
92°52'W

This coal processing plant, figure 6-119, is located in the coal surface mining area of northern Missouri. Its function is to receive the coal, crush it, and grade it into specific sizes. The coal is either mined nearby or trucked in from more distant areas for processing. At this installation, the coal is



Figure 6-119.--Low-altitude oblique photograph of a coal processing plant near Hartford, Mo.



Figure 6-120.--Low-altitude vertical photograph of processing plant, Hartford, Mo.

primarily obtained from the surface mine area at point A. At the plant, the coal is moved to the crusher house (figure 6-120), and transported by conveyors to various areas of the yard where it awaits shipment (figure 6-121) to truck loading chutes (B, figure 6-120).



Figure 6-121.--Coal in bin awaiting transshipment.

Site No. 100 (Chemical Plant)

Location: Louisiana

Pike County, Missouri

Geographic Coordinates: 39°41'N
91°19'W

This chemical plant, figure 6-122, is divided into various sections which constitute different types of processing. The features which identify this installation as a chemical plant are visible on both the large-scale photograph and the ground photograph. The fractionating towers may be seen in several areas of the plant (A, figures 6-122, 6-123, and 6-124). There are also cooling towers in each area of chemical processing (B, figures 6-122, 6-123, and 6-124). The various types of storage tanks, spherical and cylindrical, are seen throughout the plant (C, figure 6-122 and 6-123). Also visible is numerous piping used for specific processing, as well as for connecting the various parts of the plant. A coal-fueled power plant is located at D, figure 6-122. The plant is served by river, truck, and railroad, as shown at E in figure 6-122.

These Industrial category illustrations are but a few of the land use classification types in the State of Missouri, and represent the categories of light and heavy industry described in U.S. Geological Survey Professional Paper 964 (Anderson and others, 1976).

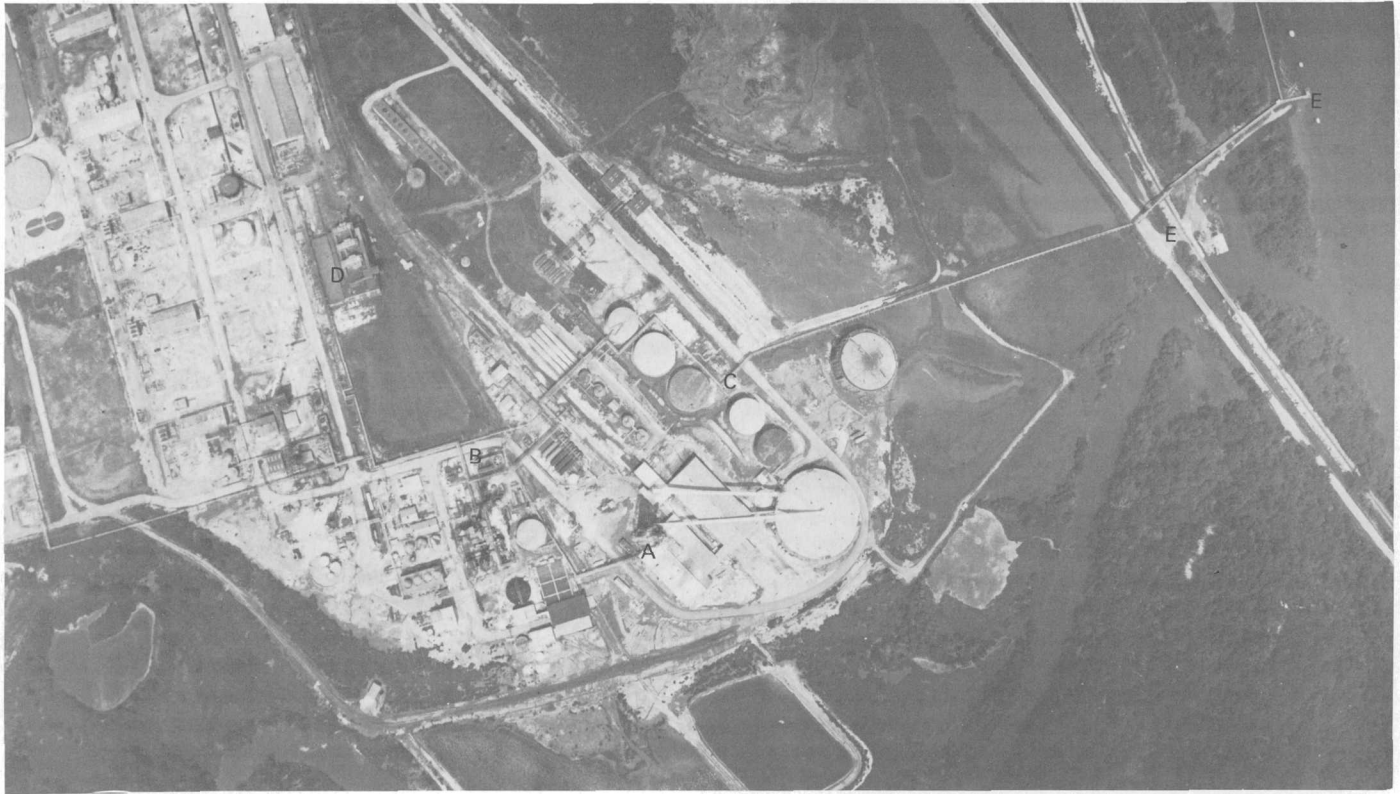


Figure 6-122.--Vertical photograph of the chemical plant at Louisiana, Mo.

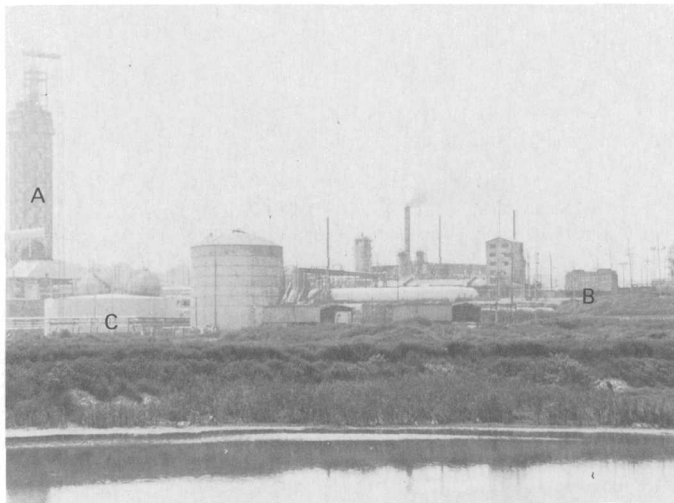


Figure 6-123.--Fractionating columns and tanks.

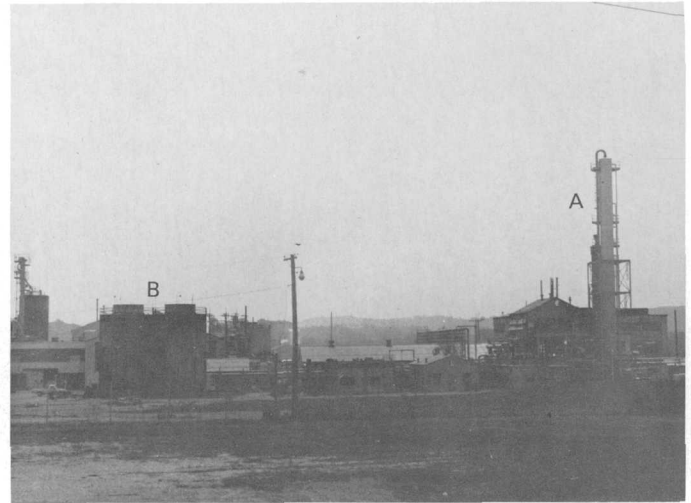


Figure 6-124.--Fractionating columns and cooling towers.

Category 14--Transportation, Communications, and Utilities

Category Description. Major transportation routes and areas greatly influence other land uses. The types and extent of routes determine the degree of access and thus affect the present and potential use of an area.

Linear areas of highways and railroads are among the land use types included in this

category. The highways include rights-of-way, interchanges, and service and terminal facilities. Rail facilities include stations, parking lots, roundhouses, repair and switching yards, and related areas. Also included are overland track and spur connections of sufficient width for delineation at mapping scale.

Airports, seaports, and major lake and river ports are also included in this category.

Airport facilities include all the runways, intervening land, terminals, service buildings, navigation aids, fuel storage, parking lots, and limited buffer zones. Port facilities include docks, shipyards, drydocks, locks, and waterway control structures.

Finally, communications and utilities areas are included in this category. Communications and utilities areas are those involved with the processing, treatment, and transportation of water, gas, oil, electricity, and areas used for airwave communications. Included are pumping stations, electric substations, and areas used for radio, radar, or television antennas.

Environmental Considerations. Transportation facilities such as highways, railroads, airports, and riverports are potential water pollution sources. The pollution occurs as a result of runoff and leakage of fossil fuels associated with these facilities. River and lake ports have a high potential for pollution. Leakage and spillage of raw chemicals, petroleum products, coal, and other cargo handled and distributed in ports can be detrimental to water quality and aquatic life, and cause health problems for adjacent communities. Toxic substances such as polychlorinated biphenyl (PCB), used in diesel locomotive transformers and motors, are often stored at railroad yards and repair shops. The land around airport facilities is often used for solid waste disposal, creating a potential for soil and water contamination. Accidental discharge of toxic chemicals in transport via highways and railways can release these poisons to the soil, water, and air. The toxin can sterilize the soil, reduce air quality, and contaminate ground water. Almost all major transportation facilities, especially those with heavy traffic, are generally associated with unacceptable levels of noise and inferior air quality.

Waste-water treatment plants can be a major source of water pollution. Obsolete, inadequate, and overloaded facilities result in the discharge of effluents that do not meet water quality standards, and at times raw sewage may be discharged into the natural drainage system.

When ecologically sensitive areas such as wetlands and forestlands are altered, the whole ecosystem may be changed. Facilities associated with the distant transport of communications and electricity have rights-of-way clearing through forest and other natural areas which can also have adverse impacts on the environment. Rights-of-way are usually sprayed with pesticides and herbicides which can have a detrimental effect on wildlife and

contribute to water pollution by surface runoff.

Interpretation Keys. The following nine sites illustrate the land use types associated with the Transportation, Communications, and Utilities category.

Site No. 10 (Highway Intersection)
Location: St. Louis
St. Louis City, Missouri
Geographic Coordinates: 38°38'N
90°17'W

Figure 6-125 shows the intersection of U.S. Highway 40 and Hampton Avenue in St. Louis, Missouri. It is an excellent example of a major urban arterial road and a controlled-access highway. The cloverleaf-type intersections, dividing medians, and the right-of-way, are all included when delineating highways. However, they must meet the minimum width requirements of the land use and land cover specifications (300 feet wide for controlled-access highways). On the aerial photograph, the highway is easily recognizable by its lighter, smooth texture and ribbonlike appearance. The dividing medians between lanes are identified by their darker tone and position. The rectangular images on the road surfaces are cars and trucks.



Figure 6-125.--A low-level photograph of a highway cloverleaf, St. Louis, Mo.

Site No. 11 (Truck Terminal)
Location: St. Louis
St. Louis City, Missouri
Geographic Coordinates: 38°31'N
90°12'W

Truck terminals generally provide maintenance and serve as a transfer point for shifting loads between trucks. They are classified as category 14 whenever they meet minimum mapping size requirements. Such a truck terminal has been circled in figure 6-126. Notice its proximity to a major transportation route--Interstate 55--to its left. The transfer building is the long, narrow, white structure in the circle on the photograph. Near the top center of the circle at A is a smaller square maintenance and repair building.



Figure 6-126.--Mapping photograph of a truck terminal, St. Louis, Mo.

Truck terminal facilities can be seen more clearly in the vertical photograph shown in figure 6-127. Notice the transfer building at A, the maintenance and repair shop at B, and parking facilities at C. The volume of business activity at this terminal is reflected by the size of its parking space and the number of trailers parked at the transfer building.



Figure 6-127.--Truck terminal, St. Louis, Mo.

Site No. 12 (Railroad Yards)
Location: St. Louis
St. Louis City, Missouri
Geographic Coordinates: 38°35'N
90°12'W

Rail facilities in this land use category include stations, roundhouses, repair shops, switching and storage yards, and related areas, as well as surface track and spur connections of sufficient width for map delineation.

Rail facilities circled in figure 6-128 are representative of those in land use category 14. Often single- and double-track railroad beds are too narrow for delineation on small-scale land use maps.



Figure 6-128.--Mapping photograph of rail facilities, St. Louis, Mo.

The southern choke-point for these yards is shown at point A in figure 6-129. The choke-point is that point in the yards where the main line branches out into the rail yards. Figure 6-129 also shows related rail facilities (switching and storage yards at B, repair shops at C, and a warehouse at D). Notice the tracks entering the repair shops. At D, notice the truck trailers backed up to the warehouse loading docks (docks not visible).



Figure 6-129.--Low-level oblique photograph of rail facilities on St. Louis waterfront.

Railroads, with their yards, tracks, and repair facilities, are easily recognized by their linear pattern. The yards all emanate from a choke-point on the main tracks, the

spurs usually parallel storage buildings, and repair shops have tracks entering or running through them.

Site No. 61 (Railroad Yards and Repair Shops)

Location: Springfield

Greene County, Missouri

Geographic Coordinates: $37^{\circ}13'N$
 $93^{\circ}20'W$

Figure 6-130 presents another view of a railroad yard with repair shops. As with site 12, this railroad facility exhibits the common photorecognition characteristics--a widening area of parallel tracks emanating from a choke-point on the main tracks, large repair buildings with tracks entering the structures, and an irregular track pattern in the repair area of the railroad yard.



Figure 6-130.--Mapping photograph of the railroad yard at Springfield, Mo.



Figure 6-131.--Low-altitude oblique photograph of the switching yard and repair shops.

Site details are seen in figure 6-131. Located at Springfield, the site is part of the Burlington Northern railroad line. Repair shops are located at A, while the main switching and car storage area is at B. Notice the irregular track pattern of the repair area. The repair shop and employee parking lot are shown from ground level in figure 6-132.



Figure 6-132.--Burlington Northern diesel repair shop.

Site No. 42 (Airport)

Location: Vichy

Maries County, Missouri

Geographic Coordinates: $38^{\circ}08'N$
 $91^{\circ}46'W$

Airports, with their runways, hangars, shops, and associated facilities, are included in land use category 14. Airports vary in size from grass landing strips to vast complexes in urban areas. The key identifying photographic feature of an airport is an area cleared of vegetation and other obstructions and with long, linear runway surfaces. If the airport is more than just a grass landing strip (which are not shown on 1:250,000-scale U.S. Geological Survey land use and land cover maps), it will normally have smaller parallel taxi strips, aircraft parking aprons, hangars, and passenger terminals. The primary runways are normally oriented into the prevailing wind.

Figure 6-133 is a stereogram of the Rolla National Airport at Vichy. This stereoscopic image illustrates level terrain of the airport.

The airport's primary function is to provide maintenance and storage facilities for general aviation aircraft. Charter flights are also common; however, at the time of this writing, there were no scheduled commercial flights. This accounts for the lack of large terminal buildings and other built-up facilities in figure 6-134. The main runways are located at A and B, the main hangars at C, and taxi strips at D.

Figure 6-135 shows three DC-3 aircraft parked in front of one of the main hangars.

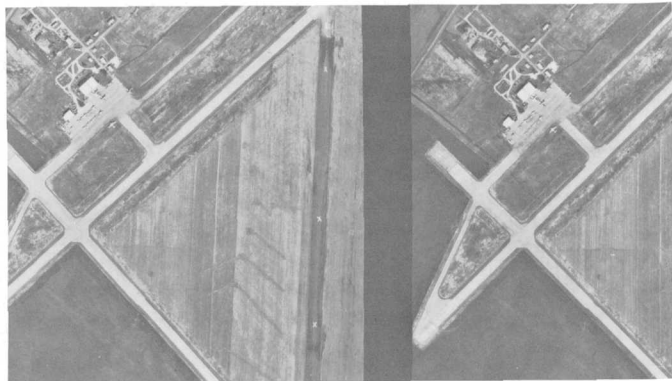


Figure 6-133.--Stereogram of airport at Vichy, Mo.

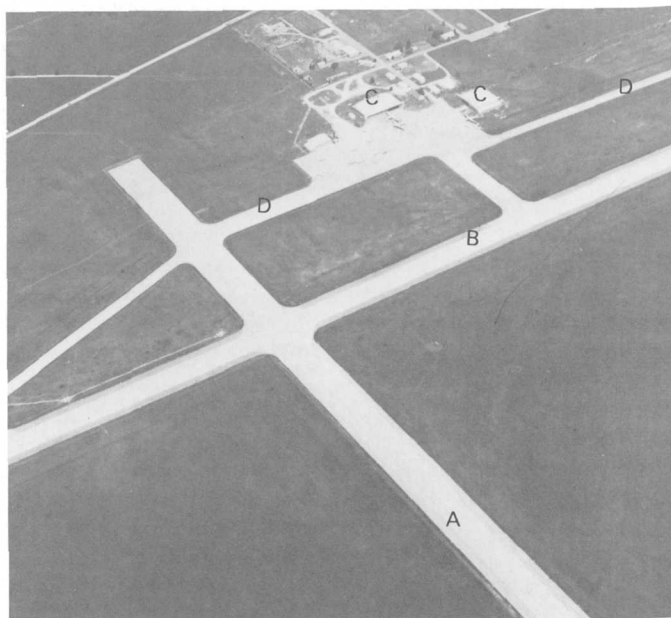


Figure 6-134.--Low-level oblique of Rolla National Airport at Vichy, Mo.



Figure 6-135.--DC-3 aircraft parked on apron at Rolla National Airport, Vichy, Mo.

Site No. 62 (Downtown Airport)
Location: Springfield
Greene County, Missouri
Geographic Coordinates: 37°13'N
93°15'W

Figure 6-136 shows the Springfield Downtown Airport. Like most downtown airports, open areas which once surrounded the facility are now occupied by residential (A) or commercial structures (B). Frequently, these airport facilities are abutted by other land use categories. As residents become more and more concerned about potential aircraft accidents, more attempts are made to close the facilities.



Figure 6-136.--Mapping photograph of Downtown Airport, Springfield, Mo.

Figure 6-137, depicts the single paved runway at A, taxi strip at B, parking aprons (grass rather than hard surface), and hangar facilities at C.



Figure 6-137.--Downtown airport, Springfield, Mo.

Site No. 14 (Municipal Water Treatment Plant)
Location: St. Louis
St. Louis City, Missouri
Geographic Coordinates: 38°45'N
90°11'W

One of the two municipal water treatment plants in St. Louis, Missouri, is pictured in figure 6-138. This plant, the Chain of Rocks Waterworks, uses the Mississippi River for its water source. The water is pumped into settling tanks where, after a period of time, heavier particulate materials and impurities settle out. Later the water is filtered, chlorinated, and then distributed to the city's water mains. The settling tanks and water treatment areas are more clearly shown in figure 6-139. The settling tanks appear as the larger rectangular tanks at A, the water treatment tanks are square tanks at B, and the treatment plant is shown at C.

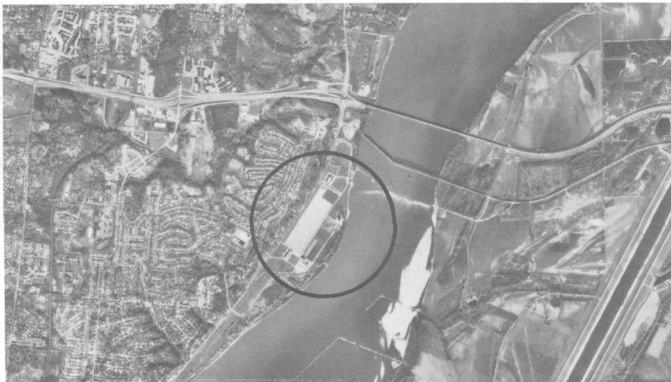


Figure 6-138.--Mapping photograph of Chain of Rocks Waterworks in St. Louis, Mo.

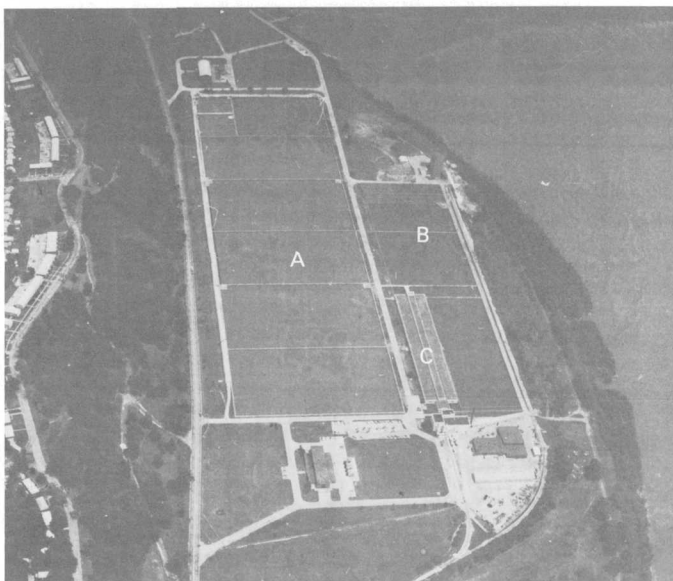


Figure 6-139.--Oblique photograph of Chain of Rocks Waterworks.

Figure 6-140 presents a ground-level photograph of the settling tanks in the foreground with the treatment plant in the background.



Figure 6-140.--Ground-level photograph of Chain of Rocks Waterworks.

Site No. 63. (Water Treatment Plant)
 Location: Springfield
 Greene County, Missouri
 Geographic Coordinates: 37°10'N
 93°13'W

This plant, just newly constructed, supplements the supply of water provided by the plant at Fullbright Spring. The water for the plant is pumped from the James River, treated, then pumped into the city's water mains. The low-level vertical photograph shown in figure 6-141 was taken in July 1980, near the final phases of construction. Notice the rectangular shape of the treatment tanks.

A visit to the site in January 1981 revealed that the plant had been placed in operation (see figure 6-142).



Figure 6-141.--Water treatment plant under construction, July 1980, Springfield Mo.

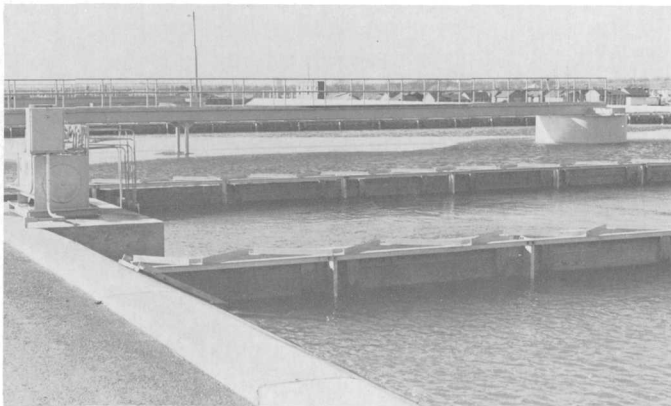


Figure 6-142.--Water treatment plant in operation, January 1981, Springfield, Mo.

Site No. 13 (Sewage Treatment Plant)
 Location: Lemay
 St. Louis County, Missouri
 Geographic Coordinates: $38^{\circ}32'N$
 $90^{\circ}17'W$

Site No. 91 (Sewage Treatment Plant)
 Location: Kirksville
 Adair County, Missouri
 Geographic Coordinates: $40^{\circ}09'N$
 $92^{\circ}34'W$

Sewage treatment plants are found in or around most medium or large cities. There are many different processes by which sewage can be treated, however, the identifiable features are nearly the same for all plants.

Site 13, figure 6-143, shows a sewage treatment plant for St. Louis City prior to expansion. The array of rectangular tanks is a typical identifying feature. The large-scale oblique photograph (figure 6-144), taken June 1980, shows the expanded plant. There are two types of tanks visible in this photograph; initial processing tanks are shown at A and



Figure 6-143.--Small-scale photograph of St. Louis sewage treatment plant, 1974.

secondary tanks are shown at B. The tanks at C are newly constructed and were not in operation at the time of the photograph (June 1981).

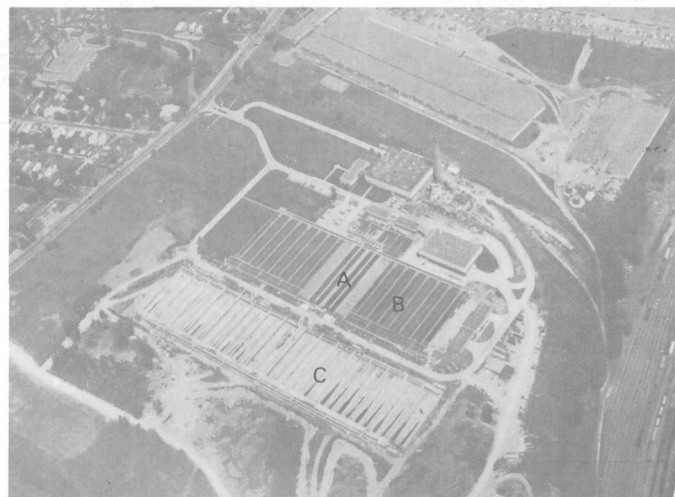


Figure 6-144.--Low-altitude oblique photograph (1980) of sewage treatment plant undergoing additional construction, St. Louis, Mo.

Site 91 is a small sewage treatment plant just south of Kirksville, Missouri. The plant has circular tanks, as opposed to the rectangular tanks at site 13. Figure 6-145 shows the plant layout and several identifying features. Point A is the area of initial processing where the screening and grinding of raw sewage occurs. At B are two primary settling tanks. The tone of the liquid in the tanks is a clue to the process flow. The darker tanks at C contain water which has been treated, while the lighter tanks at B hold raw sewage. The two circular white tanks at D are probably digester tanks where the material that settles out by the settling process is converted to sludge. Point E is the outlet where the treated effluent flows into a nearby stream.

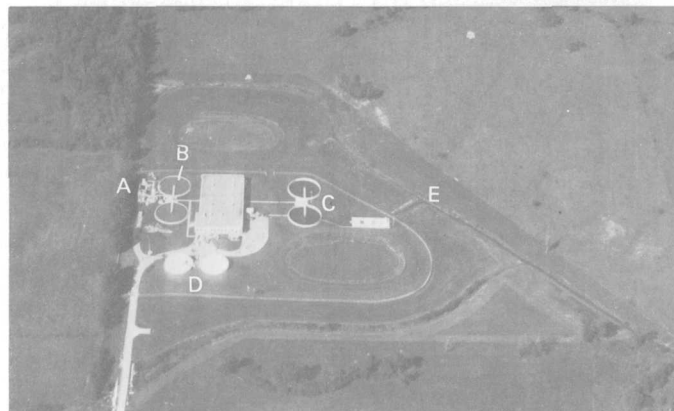


Figure 6-145.--Low-altitude oblique photograph of sewage treatment plant, Kirksville, Mo.

Category 15--Industrial and Commercial Complexes

Category Description. The Industrial and Commercial Complexes category includes those industrial and commercial land uses that typically occur together or in close functional proximity. These areas are commonly referred to as "Industrial Parks." The major types of business establishments located in these planned industrial parks are light manufacturing, printing, distributing, research and development facilities, and computer systems companies, in addition to warehousing, wholesaling, and retailing.

Environmental Considerations. Industrial and Commercial Complexes are a minimum source of pollutants. The clean industries and commercial establishments in these "parks" generally are nonpolluting types. However, improper disposal of wastes and spillage of working materials will produce adverse environmental effects. Excessive surface water runoff from buildings and hard-surfaced parking areas creates the potential for flash flooding.

Interpretation Keys. Areas which meet specifications for Industrial and Commercial Complexes are not widespread. The following example, however, is representative of land use category 15.

Site No. 15 (Industrial and Commercial Complexes)

Location: Robertson
St. Louis County, Missouri.

Geographic Coordinates: 38°46'N
90°23'W

The photograph at figure 6-146 shows an industrial/commercial area just north of Lambert-St. Louis Airport. The buildings are modern in design with ample parking for employees. The warehouse and manufacturing buildings are serviced by railroad for transportation of raw materials and finished products. The ground photograph, figure 6-147, provides a closeup of one of the buildings and the well-kept grounds.

Industrial and Commercial Complexes are usually located in suburban or rural areas. The key identifying feature is the planned layout of buildings exhibiting the same or very similar construction. The lack of smokestacks, storage tanks, raw materials or finished products, and wastes signifies that no heavy industries are present.

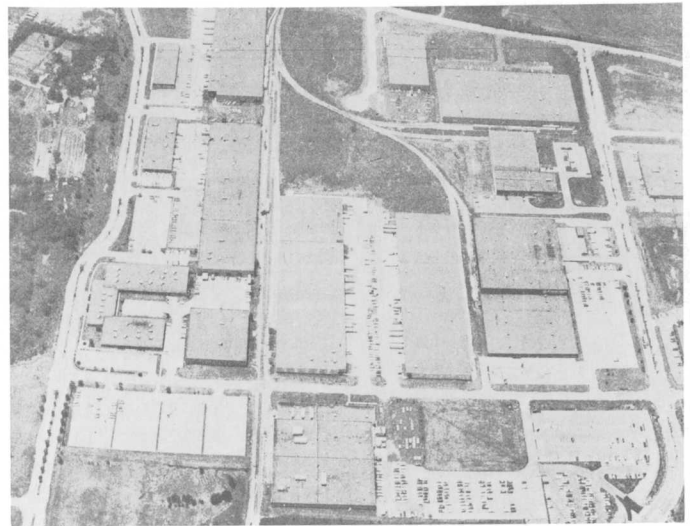


Figure 6-146.--Low-altitude oblique photograph of an Industrial and Commercial Complex, St. Louis County, Mo.

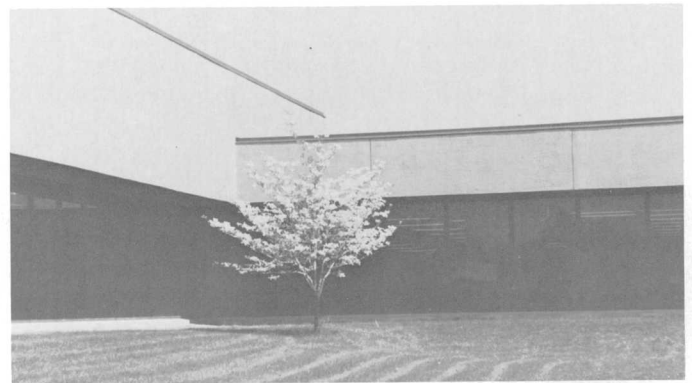


Figure 6-147.--Ground photograph of Industrial and Commercial Complex.

Category 16--Mixed Urban or Built-up Land

Category Description. The Mixed Urban or Built-up Land category is used when a mixture of urban uses cannot be separated into individual categories at mapping scales. Where more than one-third intermixture of another use or uses occurs in a specific area, it is classified as Mixed Urban or Built-up Land. This category includes developments along transportation routes and in cities, towns, and built-up areas where separate land uses cannot be mapped individually at map scale.

Environmental Considerations. This category, a mixture of urban land uses, such as residential, industrial, and commercial has the same potential for pollution as the land use categories which comprise it. Excessive runoff can affect water quality and produce a potential for flooding during heavy rainfalls.

Air quality and noise levels can be affected by this land use category as well.

Interpretation Keys. The following are examples of Mixed Urban or Built-up Land category 16.

Site No. 16 (Mixed Urban or Built-up Land)
Location: St. Louis
St. Louis City, Missouri
Geographic Coordinates: 38°38'N
90°15'W

Figure 6-148, an urban area east of Forest Park is an excellent example of Mixed Urban or Built-up Land. This site has several hotels and motels, apartments, duplexes, hospitals, schools, churches, office buildings, and other commercial activities. The main land uses are commercial and residential, but in areas where more than one-third is mixed, it is classified as Mixed Urban or Built-up Land.

The oblique photograph in figure 6-149 shows height of the buildings, irregular building pattern, rectangular streets, and various sizes and shapes of the buildings. The key identifying feature of Mixed Urban or



Figure 6-148.--Mapping photograph of Mixed Urban or Built-up Land area, St. Louis, Mo.



Figure 6-149.--Low-altitude oblique photograph of Mixed Urban or Built-up Land area.

Built-up Land is its combination of both residential and commercial structures.

Site No. 64 (Mixed Urban or Built-up Land)
Location: Springfield
Greene County, Missouri
Geographic Coordinates: 37°12'N
93°17'W

Figure 6-150 shows an example of the Mixed Urban or Built-up Land in Springfield. This area is adjacent to the central business district; the small lighter tones and images are single-family residences or duplexes. The residential and commercial categories are too small to separate at the mapping scale; therefore, the area should be classified as a "mixed" category. On the small-scale mapping photograph (figure 6-150) it is evident that the "mixed" category is a transitional category between residential and commercial.



Figure 6-150.--Mapping photograph of a Mixed Urban and Built-up Land area, Springfield, Mo.

The large-scale photograph (figure 6-151) shows the complex intermixture of the various sizes and shapes of the buildings which make up this category.



Figure 6-151.--Large-scale photograph of Mixed Urban and Built-up Land area.

Category 17--Other Urban or Built-up Land

Category Description. Other Urban or Built-up Land consists of such land uses as parks, cemeteries, waste dumps, water control structures and spillways, golf courses and driving ranges, and undeveloped land within the urban area.

Environmental Considerations. Landfills are the main potential pollution sources in this category. Uncontrolled waste dumps are becoming obsolete since most communities dispose of waste in sanitary landfills or recycle it. (Note that sanitary landfills are classified as land use category 76 rather than 17.) Parks, public lands, golf courses, zoos, and undeveloped land all provide open areas which for the most part are nonpolluting.

Interpretation Keys. The next four sites are land use examples included in category 17.

Site No. 17 (Forest Park)

Location: St. Louis

St. Louis City, Missouri

Geographic Coordinates: 38°38'N
90°17'W

Key recognition features of parks are irregular road patterns, the coarse photographic texture which results from tree cover, and various athletic fields. Larger parks usually have a pond or lake, while others have museums and bandstands. Urban parks are usually surrounded by residential or commercial areas.

Figure 6-152, Forest Park in St. Louis, illustrates a large urban park in a metropolitan area. It is a good example of this category. There is a diversity of activity visible within the confines of the park. In this photograph are parking lots (A), ball diamonds (B), tennis courts (C), golf courses (D), a zoo (E), and the Muny Opera (F) with its separate parking lot and seating area.

This site is indicative of the larger metropolitan parks. There are, however, smaller parks throughout the State in the medium and small towns which do not have all of the activities associated with them that the larger parks have. Many times without auxiliary source material, the park area may appear as a grove of trees and not be discernible as a park. Since most parks are generally surrounded by built-up area, by definition, they will generally fall in this category.



Figure 6-152.--Mapping photograph of Forest Park in St. Louis, Mo.

In the vertical photograph of figure 6-153 can be seen the zoo with its animal shelters, enclosures, aquatic animal ponds, and walkways between the different exhibits.



Figure 6-153.--Large-scale photograph of the St. Louis Zoo.

Site No. 47 (Golf Course)

Location: Fort Leonard Wood

Pulaski County, Missouri

Geographic Coordinates: 37°44'N
92°05'W

Golf courses are also included in the Other Urban or Built-up Land category. Often they are located within urban areas, in parks, and on outskirts of suburban residential areas.

If the golf course is part of an athletic complex, the built-up area consists of the clubhouse, swimming pool, and parking lots, and if these facilities meet minimum size requirements, they are mapped as category 12. If they are not large enough, they are included in category 17.

Figure 6-154, a small-scale photograph, shows the layout of the Fort Leonard Wood golf course. With proper magnification, the fairways, bunkers, and greens can be identified. However, in this photograph, all that can be detected is the general cleared fairways and white spots--sand traps.

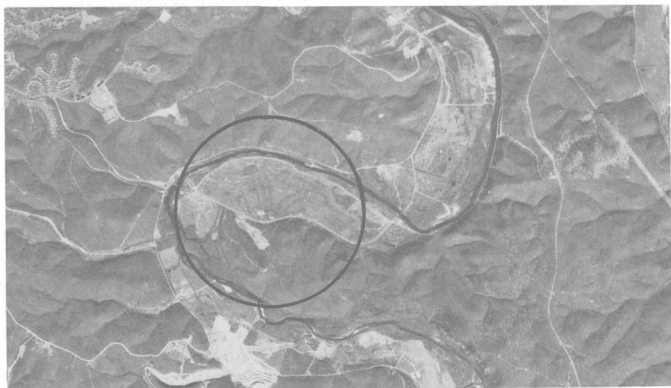


Figure 6-154.--Mapping photograph of the golf course at Fort Leonard Wood, Mo.

The fairways, darker in tone and smoother in texture than the "rough", are clearly visible on the large-scale photograph (figure 6-155). At the end of each fairway, the greens, with their associated light-toned sand traps, are easily identified. The fairways are cleared of trees or when retained, line the fairways on one or both sides.



Figure 6-155.--Large-scale photograph of Fort Leonard Wood golf course.

Site No. 18 (Cemetery)

Location: Mehlville

St. Louis County, Missouri

Geographic Coordinates: 38°30'N
90°17'W

Cemeteries are likewise included in category 17. Most larger cemeteries are within or close to an urban area. Many of the smaller rural cemeteries are too small to delineate at land use mapping scales. Cemeteries may have regular or irregular road patterns with the area generally open with shade trees bordering the roads. Figure 6-156 is a mapping photograph of the National Cemetery at Jefferson Barracks in south St. Louis County.



Figure 6-156.--Mapping photograph of National Cemetery near Mehlville, Mo.

Under magnification, figure 6-157 illustrates symmetrical patterns of the gravestones.



Figure 6-157.--Large-scale photograph of road pattern and gravestones.

Site No. 92 (Cemetery)
Location: Kirksville
Adair County, Missouri
Geographic Coordinates: 40°10'N
92°34'W

Figure 6-158 is a smaller cemetery near Kirksville, Missouri, located in the northern part of the State. The light-toned road pattern, the scattered shade trees, and lack of buildings help identify this site as a cemetery. In the vertical photograph, figure 6-158, the light-toned dot-shaped images are gravestones. Notice the linear arrangement of the graves.

The ground photograph, figure 6-159, shows the well-kept grounds and regular spacing of the grave markers.

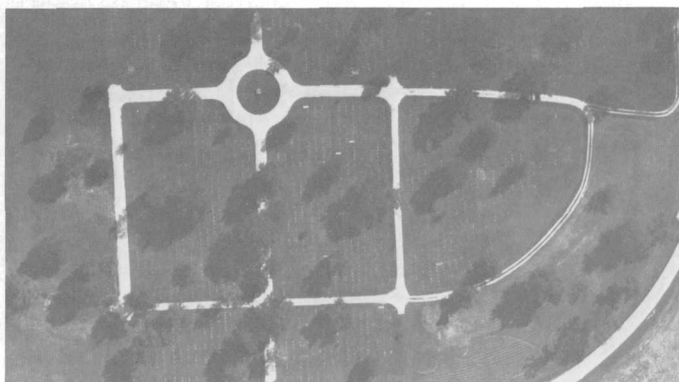


Figure 6-158.--Large-scale photograph of the cemetery layout at Kirksville, Mo.



Figure 6-159.--Ground photograph of cemetery.

LEVEL I, CATEGORY 2 - AGRICULTURAL LAND

Agricultural Land may be defined broadly as land used primarily for production of food and fiber, or, as in the case of farmsteads, built-up service areas associated with

agricultural practices. In Missouri, approximately 63 percent of the land is used for agriculture--most of which is either cropland or pasture.

On aerial photographs, particularly high-altitude photographs, the primary recognition characteristics of agricultural activity are the distinctive geometric field and road patterns on the landscape, the traces produced by livestock or mechanized equipment, and the variations in photographic tones (gray levels) of the adjacent land parcels. Compared with the Urban or Built-up Land categories previously discussed, the number of building complexes is less and the density of the road and highway network is much lower in Agricultural Land areas. Finally, there is a marked deficiency of woodland vegetation.

The Level II categories of Agricultural Land are: Cropland and Pasture; Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas; Confined Feeding Operations; and Other Agricultural Land.

Category 21--Cropland and Pasture

Category Description. The Cropland and Pasture category includes harvested croplands, summer-fallow and idle croplands, croplands in soil-improvement grasses and legumes, croplands used for pasture in rotating crops, and improved as well as idle pasture. Approximately 62 percent (28 million acres) of Missouri is used as cropland or pasture. Of this amount, roughly two-thirds is cropland. The majority of Missouri's croplands are located in northern Missouri--north of the Missouri River. The remaining croplands are located in the bootheel area of the State and along alluvial flood plains.

It is also important to note that the U.S. Geological Survey's classification system does not separate cropland from pasture in the Level II land use and land cover mapping. Even at Level III, it is difficult to separate the two categories. Generally, a Level III differentiation between cropland and pasture areas required excessive field validation.

Concerning the separation of cropland from pasture, most croplands exist where the slopes are less than 10 percent. However, with certain conservation management practices, such as terracing, croplands may occur on slopes slightly greater than 10 percent. In the latter case, the terracing practices help to identify the areas as croplands. Accordingly, as the slope of the land increases beyond 10 percent, one finds less cropland and more pasture.

Environmental Considerations. Cropland and Pasture areas are most frequently associated with nonpoint pollution. Since the farmer must first prepare the land for planting, fertilize it, and then use pesticides to protect the crops, there are many pollution possibilities.

If tillage farming is used, loosened soil particles become prime candidates for transport to nearby water bodies. If medium to heavy precipitation follows shortly after a field has been plowed, numerous particles of soil can be transported to nearby water bodies as part of the surface runoff. The term used to refer to the condition of soil particles suspended in water is "sediment load." When a farmer does not take precautions to lessen the amount of surface soil loss which can occur with surface runoff, the number of soil particles entering nearby water bodies may increase significantly. When the sediment load becomes 1,000 parts per million or higher, there is a greater probability that aquatic plant and animal life may be adversely affected. The increase in sediment load reduces sunlight penetration, thereby reducing plant growth. Reduced plant growth reduces the level of oxygen plant production which affects the ability of certain fish species to survive in these waters.

In addition to soil erosion from plowed areas, pasture areas may also become a source for transportable soil particles, particularly where livestock overgrazing has denuded the landscape. However, the extent of soil particle contribution from overgrazing is much less than that which occurs from plowing.

In Missouri, soil loss and the subsequent increase of sediment load is by far the greatest surface water quality contaminant.

Besides the potential for increased sediment loads in nearby streams, cropland areas are also a source for such chemical pollutants as fertilizers and pesticides. As with loose soil particles, any residues from fertilizer or pesticide applications may be carried to nearby streams with surface runoff. Accordingly, the farmer must exercise care in the application of such materials to reduce the potential for water quality degradation.

Interpretation Keys. Cropland and Pasture areas are depicted in several examples which follow.

Site No. 93 (Cropland)
Location: Plymouth
Livingston County, Missouri
Geographic Coordinates: 39°37'N
93°43'W

Figure 6-160 illustrates the characteristic checkerboard pattern of cropland areas in northwestern Missouri near Plymouth. The checkerboard pattern results from different crop stages (exhibited by varying gray tones) and differences in tillage directions. Cropland areas, generally devoid of trees, possess a smoother texture than pasture land areas. A small pasture area lies just south of the east-west road to the west of a small farmstead in figure 6-160 at point A. Note the mottled texture of this area. The oblique photograph (figure 6-161) shows more clearly the characteristic checkerboard cropland pattern and the general lack of trees in cropland areas.



Figure 6-160.--Mapping photograph of cropland near Plymouth, Mo.



Figure 6-161.--Low-level photograph of cropland near Plymouth, Mo.

Site No. 44 (Pasture)
Location: Jerome
Phelps County, Missouri
Geographic Coordinates: 37°58'N
91°59'W

Figure 6-162, along the Gasconade River, presents an interesting pasture land photographic image. The white dots (or small circles) identify former locations of hay bales. Figure 6-163, of the same area but taken in winter, does not exhibit the dot pattern. Notice also the differences in gray values for the two figures. The winter scene in figure 6-163, shows the pasture area as a much lighter gray than in figure 6-162. Although the area may be in pasture at the time of figure 6-162 (June 1980), chances are that it will revert to cropland in the near future. This highlights another important point--using aerial photography, one must delineate the land use of an area according to its use at time of photographic acquisition.



Figure 6-162.--Low-level photograph of pasture land near Jerome, Mo., June 1980.



Figure 6-163.--Mapping photograph of pasture land near Jerome, January 1976.

Site No. 68 (Cropland)
Location: Chamois
Osage County, Missouri
Geographic Coordinates: 38°40'N
91°45'W

Figure 6-164 shows another cropland area near Chamois along the Missouri River. The linear pattern of cropping techniques is easily recognized and the fact that the area is devoid of trees supports classification as cropland. Figure 6-165 provides a better illustration.

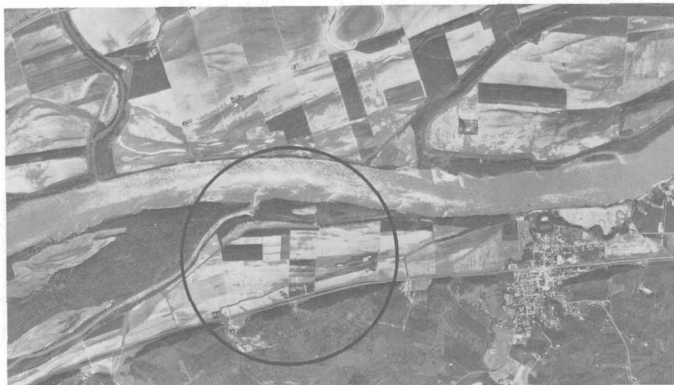


Figure 6-164.--Mapping photograph of cropland near Chamois, Mo.



Figure 6-165.--Oblique photograph of cropland near Chamois, Mo.

Category 22--Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas

Category Description. Category 22 includes orchards, groves, vineyards, nurseries, and ornamental horticultural areas which produce various fruit and nut crops; nurseries and horticultural areas are used permanently for such purposes. Included in these land use categories are floricultural and seed-and-sod areas, and some greenhouses. Tree nurseries, which provide seedlings for plantation forestry, are also included in category 22 when they meet the minimum acreage requirements.

Orchards and groves are some of the more easily recognized land use types on aerial photographs, particularly during the growing season. The primary recognition feature is the grid pattern exhibited by the equally spaced rows of trees or bushes. Although the grid pattern is more easily identified on large-scale photographs, it is also discernible on high-altitude aerial photographs when they are appropriately magnified.

Environmental Considerations. Potential environment impacts from orchards, groves, and vineyards are very similar to those associated with cropland areas. Surface runoff can transport loose soil particles and various residual fertilizers, pesticides, and herbicides to nearby water bodies. To a lesser extent, nursery areas may also yield the same type of pollutants. Except for a possibility of pollution contaminants associated with the improper disposal of waste, ornamental horticultural areas are seldom a source of pollution.

Interpretation Keys. Presented below are three examples of orchards and a vineyard.

Site No. 23 (Orchard)
Location: Kelso
Scott County, Missouri
Geographic Coordinates: 37°11'N
89°33'W

Circled in figure 6-166, just south of Kelso, is an apple orchard. Because of the small scale of the photograph, one would have to view the area under magnification to clearly discern the orchard grid pattern. The orchard is seen more clearly in the oblique photograph (figure 6-167). Note the open spaces in the orchard. Apparently, the owner has lost some of the trees to disease or severe weather.

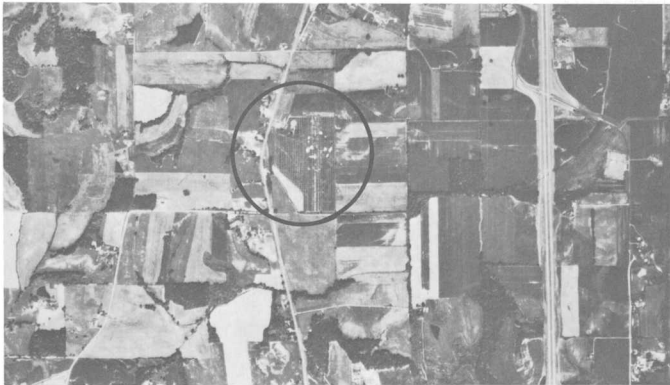


Figure 6-166.--Mapping photograph of an apple orchard south of Kelso, Mo.



Figure 6-167.--Low-level photograph of an apple orchard south of Kelso, Mo.

Site No. 41 (Orchard)
Location: Bonne Terre
St. Francois County, Missouri
Geographic Coordinates: 37°55'N
90°32'W

Another orchard is shown in figure 6-168 near Bonne Terre. This oblique photograph illustrates well the equally spaced rows common to orchards. Notice the various tones exhibited by the orchard. This is caused by growth stage differences and by differences in the crop types. The area just to the right of the pond (A) is an area of more mature apple trees. Just to the west of the pond are younger apple trees (B). The four rows just above the younger apple trees, the lighter gray area, are peach trees. The next four rows are vineyards.

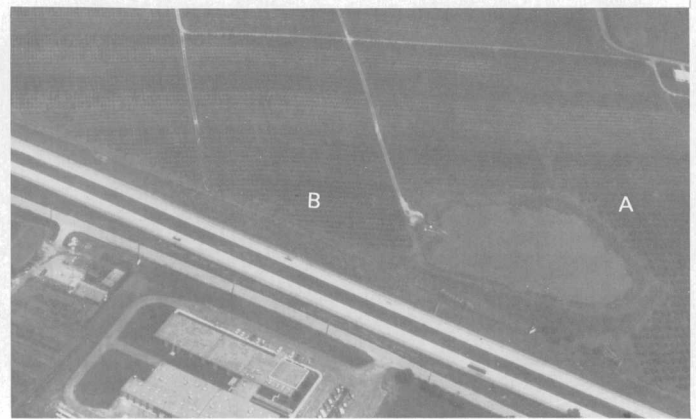


Figure 6-168.--Low-level photograph of orchard at Bonne Terre, Mo.

Figure 6-169, a ground photograph of the orchard, shows three rows of apple trees to the right of the pickup (with camper), and four rows each of peach trees and grapevines.



Figure 6-169.--Orchards at Bonne Terre, Mo.

Site No. 73 (Orchard)
Location: New Franklin
Howard County, Missouri
Geographic Coordinates: 39°02'N
92°43'W

The equal spacing of orchard rows is also illustrated by this orchard near New Franklin. However, notice in this low-level photograph (figure 6-170) the gentle curved pattern of the rows. These patterns result when orchards are planted in hilly areas as opposed to the linear pattern exhibited by orchards planted on flatter terrain (see figure 6-168).



Figure 6-170.--Oblique photograph of an orchard northeast of New Franklin, Mo.

Site No. 43 (Vineyard)
Location: St. James
Phelps County, Missouri
Geographic Coordinates: 38°02'N
91°34'W

Finally, just east of St. James, large vineyards are shown in figure 6-171. It is difficult to identify vineyards on small-scale aerial photography after the frost season. Even with large-scale imagery, positive identification is difficult. The photointerpreter must be aware of the existence of vineyards in an area, and even then, must take advantage of ancillary data such as topographic maps to identify these areas.

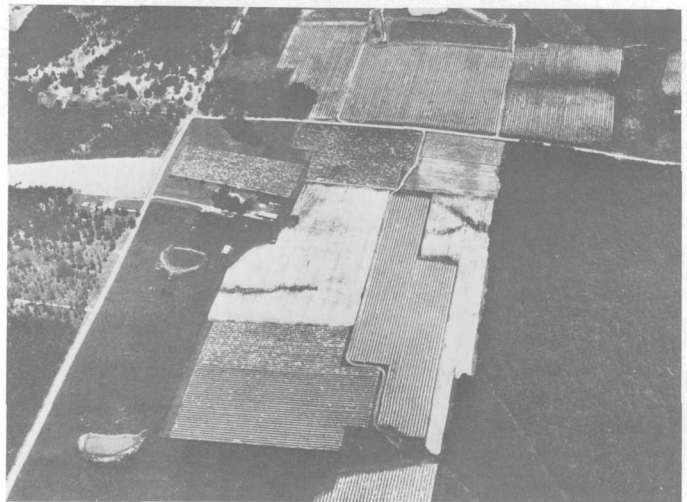


Figure 6-171.--Oblique photograph of vineyard northeast of St. James, Mo., June 1980.

Category 23--Confined Feeding Operations

Category Description. Confined Feeding Operations are large, specialized livestock production enterprises; chiefly beef cattle feedlots, dairy operations with confined feeding, large poultry farms, and hog feedlots. Confined Feeding operations have large animal populations restricted to relatively small areas. Confined Feeding Operations exhibit a built-up appearance, chiefly composed of animal shelter buildings, fencing, access paths, and waste-disposal areas.

Environmental Considerations. Confined Feeding Operations, as noted above, tend toward large animal populations restricted to relatively small areas. If not properly maintained they can become a source for air and/or

water pollution. If animal waste is allowed to accumulate beyond acceptable levels, foul odors and various insects can become windborne. Areas downwind, such as urban residential, are subjected to high levels of air pollution.

In addition to the potential for air pollution, Confined Feeding Operations are often a source of water pollution. Since the ground surface is often denuded, periods of moderate to heavy precipitation can produce intense surface runoff which can transport such organic nutrients as phosphates and nitrates and/or loose soil particles to nearby water bodies. If the magnitude of the nutrients reaching nearby water bodies, particularly lakes or reservoirs, is significant, eutrophication can be greatly accelerated.

In some cases the trophic state of some of these water bodies is enhanced so much that they are overtaken by decaying aquatic plants to the extent that they fill up and become Nonforested Wetland areas.

In those instances where significant amounts of soil particles are transported to nearby water bodies, the increase in sediment load will often lessen the amount of sunlight penetration and thereby reduce aquatic plant production. A reduction in plant production results in a reduction in dissolved oxygen levels which may then cause these water bodies to become less suited as habitats for certain fish species.

Interpretation Keys. A cattle Confined Feeding Operation, a combination hog/cattle operation, a chicken operation, and a turkey farm are shown in the following illustrations.

Site No. 29 (Chicken Houses)
Location: Bloomfield
Stoddard County, Missouri
Geographic Coordinates: 36°53'N
89°55'W

Perhaps one of the more easily recognized types of confined feeding operations are chicken houses. Chicken houses are long, narrow wood or metal structures and most frequently occur in groups of three. Even on high-altitude photographs (figure 6-172), this characteristic pattern can be easily detected. The pattern is even more easily discerned from the oblique photograph shown in figure 6-173. Whitish tones of the chicken house roofs result from use of corrugated metal roofs which reflect a great deal of the Sun's rays.

Figure 6-174 provides a ground-level photograph of two of the three chicken houses shown in the center portion of figure 6-173.

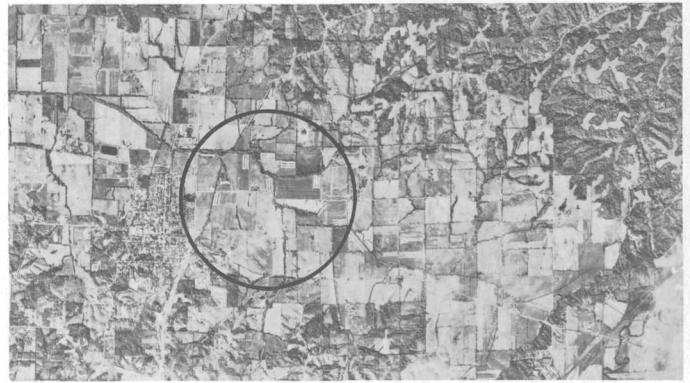


Figure 6-172.--Mapping photograph of chicken houses east of Bloomfield, Mo.



Figure 6-173.--Low-level photograph of chicken houses east of Bloomfield, Mo.



Figure 6-174.--Chicken house east of Bloomfield, Mo.

Site No. 87 (Confined Cattle Feeding)

Location: Spickard

Grundy County, Missouri

Geographic Coordinates: 40°15'N
93°13'W

Another type of confined feeding which is easily recognized is that of confined cattle feeding. Circled in figure 6-175 is a confined cattle feeding operation at Spickard, Missouri. Lack of vegetation is shown clearly on the vertical photograph of figure 6-176. Note the whitish areas near the animal shelter buildings. These areas are devoid of vegetation. Also notice the rectangular shape of the fenced feedlots. Just to the northwest of the larger animal shelter buildings are a series of smaller buildings and narrower feedlots. The feedlots at A are not presently in use. Examination of the smaller feedlots reveals that a distinct texture difference exists. The smooth-textured area lots are used more frequently. The less frequently used lots (A) have grown up with vegetation and therefore, exhibit a coarser texture.



Figure 6-175.--Mapping photograph of confined cattle feeding near Spickard, Mo.



Figure 6-176.--Low-level photograph of confined cattle feeding operation near Spickard, Mo.

Site No. 86 (Confined Hog and Cattle Feeding)

Location: Ravenwood

Nodaway County, Missouri

Geographic Coordinates: 40°25'N
94°40'W

Another example of confined feeding is illustrated in the oblique and vertical photographs shown in figures 6-177 and 6-178. Two types of confined feeding operations are apparent. In figure 6-178, eight rather large rectangular feedlots are shown in the middle of the photograph. They are very similar in appearance to the feedlots shown earlier in figure 6-176; therefore, one would expect to find cattle here. However, when the imagery was enlarged, it appeared as though the eastern feedlots were also being used for hogs. To the west of these feedlots, just north of a small pond, are located 12 smaller hog feedlots. The whitish area leading away from the feedlots to the pond is used during cleanup operations. The pond serves as a settling pond.

The differences in tone and texture can be used to identify the various stages of use for the larger feedlots. The fourth feedlot from the north at A in figure 6-178, as shown by its courser texture and spotted tone, has not been used recently. However, note that the second feedlot from the north has a smoother texture and more even gray tones. Under appropriate magnification, more than a dozen hogs are visible in the second feedlot. Another item commonly associated with confined feeding operations, in addition to the animal shelter buildings, are feed storage tanks. Located at the extreme top of figure 6-178, at B, can be seen five feed storage tanks.



Figure 6-177.--Low-level oblique photograph of confined feeding operation north of Ravenwood.



Figure 6-178.--Low-level vertical photograph of confined feeding operation north of Ravenwood.

Site No. 95 (Turkey Farm)
 Location: Winigan
 Sullivan County, Missouri
 Geographic Coordinates: 40°02'N
 92°56'W

Also included in land use category 23 are turkey farms. Turkey farms are rather difficult to identify on high-altitude aerial photographs. Therefore, prior knowledge of their existence in an area is normally required to increase the probability of correct photographic identification. Four turkey farm areas are shown in the oblique photograph of figure 6-179. The turkey farms are located just west of Winigan, Missouri. Two of the areas are active (A and B), two are inactive (C and D). The inactive areas appear whitish in tone with small, darker squares indicating the former locations of portable range shelters now located at A and B.

Although open range feeding of turkeys is an identification feature of this category, the areas in which the birds feed would not be delineated as confined feeding. The brooder houses themselves and auxillary structures would be the only area to be delineated.



Figure 6-179.--Low-level oblique photograph of a turkey farm near Winigan, Mo.

The vertical photograph of figure 6-180 clearly illustrates the practice of relocating turkey farm areas once an area has been denuded of vegetation. Note the small darker gray rectangular spots paralleling the road (A). These spots mark the former positions of the range shelters. The range shelters, as well as most of the turkey feeders, have been moved to a new position just to the south of their old location (B). The range shelters, without sides, are constructed to allow the turkeys to get out of the sun during the hot summer months. During winter, the turkeys are housed in large, long poultry houses such as those seen in the ground-level photograph of figure 6-181 just east of the area shown in figure 6-180.

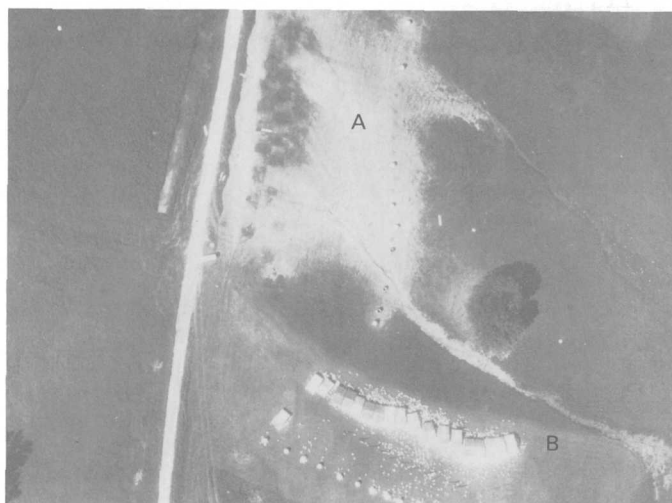


Figure 6-180.--Low-level photograph of turkey farm area near Winigan, Mo.

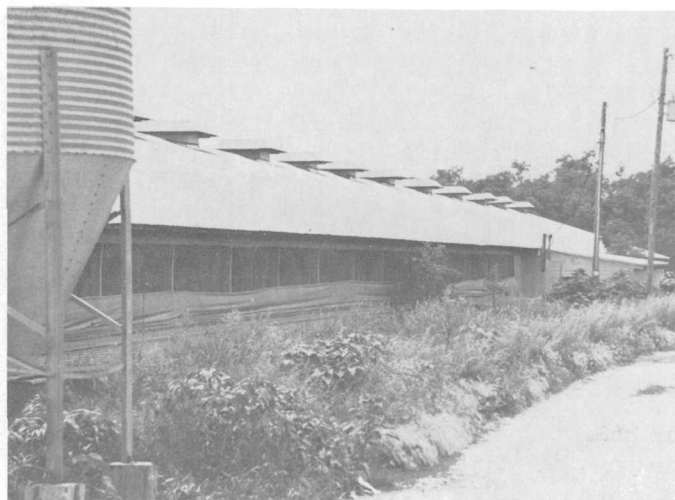


Figure 6-181.--Turkey brooder house near Winigan, Mo.

Category 24--Other Agricultural Land

Category Description. The Other
Agricultural Land category includes farmsteads, holding areas for livestock such as corrals, farm lanes and roads, ditches and canals, small farm ponds, fish farms and hatcheries, horse farms, and other similar associated built-up features adjacent to and closely associated with agricultural resource management.

Environmental Considerations. The pollution potential from Other Agricultural Land areas is very similar to the other Level II categories of Agricultural land previously discussed; that is, Other Agricultural Land areas may become sources for nonpoint water pollution. However, primarily because of their relatively small areal extent, the pollution potential from these areas is less than that from the more extensive Agricultural Land Level II categories.

Also included in the Other Agricultural Land category are fish hatchery operations. After a period of time, fish hatchery ponds may become saturated with waste (such as phosphates and nitrates) and various disease organisms. If there is a discharge of fish pond waters due to flooding, breaching, leaching, or a deliberate release, several conditions may ensue: eutrophication of nearby water bodies may occur; disease organisms may spread; or the escape of non-native fish species into nearby water bodies may lead to the depletion of natural stocks by predation or competitive exclusion.

Fish hatchery operations may also generate foul odors, particularly from a fish kill which will attract insects and cause diseases

to spread. Abandoned fish ponds, left filled with water, are also possible insect breeding areas.

Interpretation Keys. The Other
Agricultural Land category is illustrated by a fish farm and farmstead.

Site No. 38 (Fish Farm)

Location: Montreal

Camden County, Missouri

Geographic Coordinates: 37°53'N
92°31'W

Fish farms are shallow manmade water bodies maintained for the purpose of raising fish for wholesale trade. Quite often, due to differences in water depths or sediment loads and algae concentrations, the adjoining irregularly shaped water bodies exhibit a variety of shades from gray to black. Figure 6-182 illustrates this well. The differences in the shades of gray are illustrated even more clearly in the oblique photograph (figure 6-183) of the southernmost fish farm ponds shown in figure 6-182. A ground-level photograph (figure 6-184) further illustrates the shape of the individual fish farm ponds and provides the reader with an appreciation for the widths of the holding levees separating the ponds. The levees provide the owners access to the ponds for maintenance and harvesting.



Figure 6-182.--Mapping photograph of a fish farm southeast of Montreal, Mo.

Most fish farms will be found in stream valleys. The stream water will flow directly through or be directed into the ponding areas. In southeast Missouri in rice production areas, reservoirs used to store water for the fields are used part of the year for fish production. These types of fish ponds are impossible to delineate without ground observation.

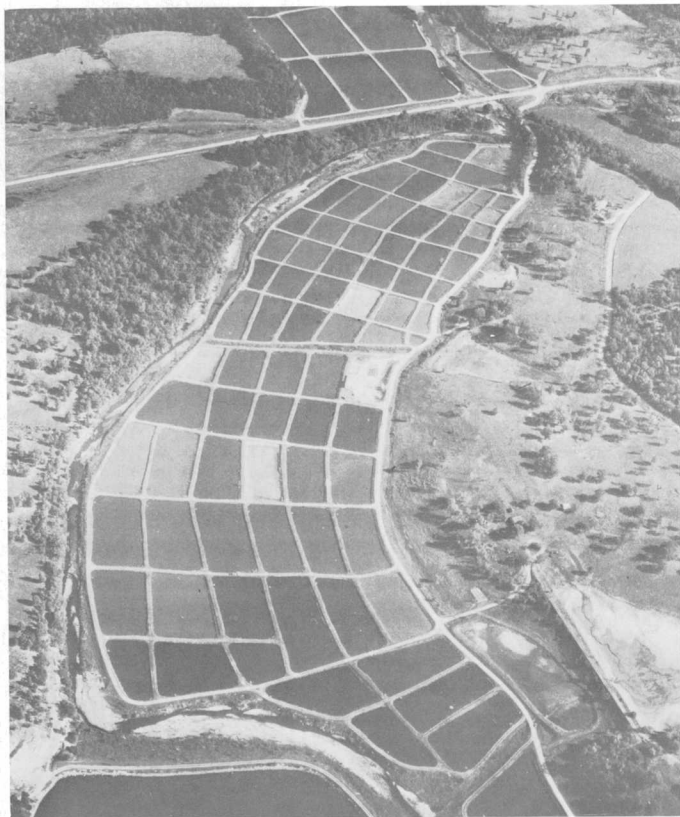


Figure 6-183.--Low-level photograph of fish farm ponds southeast of Montreal, Mo.



Figure 6-184.--Fish farm ponds near Montreal, Mo.

Site No. 99 (Farmstead)
 Location: Maitland
 Holt County, Missouri
 Geographic Coordinates: 40°07'N
 95°04'W

Farmsteads are built-up service areas associated with agricultural practices. In order for farmsteads to be shown on a land use map, they must meet the minimum mapping size requirements for the scale of the map. On land use maps at a publication scale of 1:250,000, farmsteads must be at least 10 acres in size to be shown. Circled in figure 6-185 is a farmstead approximately 6 miles south of Maitland, Missouri. The built-up photographic signature of the farmstead, surrounded by cropland and pasture, is easily identified. The oblique photograph (figure 6-186) further illustrates the extent of the built-up features associated with this farmstead. Noted on the photograph are residential structures at A, B, and C; feed storage tanks at D; tractors at E; and several rectangular shelter/storage buildings at F. In addition to the built-up signature displayed by the farmstead, the lighter gray tone of the farmstead draws the attention to the site.



Figure 6-185.--Mapping photograph of a farmstead south of Maitland, Mo.

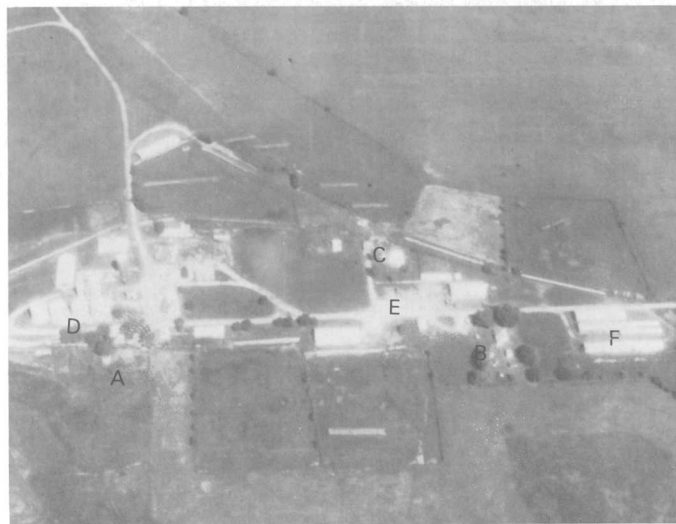


Figure 6-186.--Low-level oblique photograph of the farmstead near Maitland, Mo.

LEVEL I, CATEGORY 3 - RANGELAND

Historically, Rangeland has been defined as land on which the potential natural vegetation is predominately grasses, grasslike plants, forbs, or shrubs and where natural herbivory was an important influence in its precivilization state. Generally, management practices do not include fertilization, cultivation, or irrigation. Instead, Rangeland management practices follow ecological principles of resource management.

In Missouri, what little Herbaceous Rangeland there is, primarily is located in the west-central and southwest portions of the State. Shrub and Brush Rangeland, specifically eastern brushland vegetation, is found in the same areas as Cropland and Pasture; namely, north of the Missouri River and along the Mississippi River floodplain.

Category 31--Herbaceous Rangeland

Category Description. Herbaceous Rangeland encompasses lands dominated by naturally occurring grasses and forbs as well as those areas of natural rangeland which have been modified to include grasses and forbs as their principal cover, when managed for rangeland purposes and not managed using typical pastureland practices.

As noted earlier, the Herbaceous Rangeland areas of Missouri occur in the west-central and southwestern portions of the State. Unlike the more expansive Herbaceous Rangeland areas found from the Texas Panhandle northward to the Dakotas, Missouri Herbaceous Rangeland areas are boxed in by Cropland and Pasture; Therefore, it is difficult to accurately identify Herbaceous Rangeland areas on high-altitude photographs. The boxed-in shape of these areas robs the photointerpreter of one of the most important photorecognition characteristics of the more expansive Herbaceous Rangeland areas--the irregularly shaped natural landscape. Not only are there so few areas of Herbaceous Rangeland in Missouri, but add to this the fact that these areas are difficult to identify on high-altitude aerial photographs, and it can be realized why there is a high potential for an understatement of the total Herbaceous Rangeland acres in the State.

Environmental Considerations. Herbaceous Rangeland areas are, by definition, areas which are managed by ecological resource management principles rather than by fertilizing, cultivating, or irrigation. Therefore, such areas are not a potential pollution source.

Interpretation Keys. Since Herbaceous Rangeland areas are of limited extent in Missouri, there are few good examples of this land use category. However, the forb prairie just west of Kingdom City, Missouri, provides an excellent example.

Site No. 102 (Forb Prairie)

Location: Kingdom City

Callaway County, Missouri

Geographic Coordinates: 39°57'N

92°00'W

Most of the Herbaceous Rangeland that exists in Missouri is owned and/or protected by the Missouri Department of Conservation. As of 1978, the State had 23 public prairies totaling over 6,000 acres. These prairies were owned by either the Missouri Department of Conservation, the Missouri Prairie Foundation, the Nature Conservancy, the University of Missouri, or a combination of the above. One of these sites, Tucker Prairie, is circled in figure 6-187. Under appropriate magnification, one can discern a difference in the Cropland fields surrounding the prairie and the prairie itself. The Cropland fields retain signs of tillage, while the prairie areas do not. Had the surrounding areas been Pasture rather than Cropland, it would have been more difficult to identify prairie areas.

Even the use of low-level imagery adds little to assisting the photointerpreter in identifying the area as Herbaceous Rangeland (see figure 6-188). Only when verified by ground observations can one be confident of an accurate classification of Herbaceous Rangeland in Missouri (see figure 6-189). This photograph illustrates a field of black-eyed Susans, a typical forb vegetation.



Figure 6-187.--Mapping photograph of forb prairie west of Kingdom City, Mo.



Figure 6-188.--Oblique photograph of forb prairie west of Kingdom City, Mo.



Figure 6-189.--Tucker (forb) Prairie west of Kingdom City--ground observation.

Category 32--Shrub and Brush Rangeland

Category Description. Shrub or scrub vegetation, characteristic of arid or semiarid regions, is not found in Missouri. Eastern brushland areas, however, do occur primarily north of the Missouri River and adjacent to the Mississippi River north of Cape Girardeau.

Eastern brushlands are typically former croplands or pasture lands (cleared from original forest lands) which are being allowed to revert to their natural state. Accordingly, these areas, grown up in brush, are in transition back to forest land to the extent that they are no longer identifiable as cropland or pasture. Many of these areas are extensively grazed by livestock and provide wildlife

habitat. More often, they are retained as part of the farm, but are not used at their former levels of intensity. Traditionally, botanists have not included eastern brushland areas in the Rangeland category because of their original forested state prior to clearing for cropland or pasture; therefore, they have been summarized statistically with pasture land. However, since they primarily function as grazing land, they are included in the U.S. Geological Survey's classification system's Rangeland category. Following sufficient reforestation, these areas should be classified as Forest Land.

Environmental Considerations. Eastern brushland areas, particularly in their early stages of development, may reduce water quality as surface runoff transports loose soil particles to nearby water bodies. However, as these areas mature and are retained in Rangeland, there are few, if any, contaminant sources associated with eastern brushland areas.

Interpretation Keys. Examples of eastern brushland can be found in many areas of the State. The following example, near New Hampton, is illustrative of this land use category.

Site No. 84 (Eastern Brushland)

Location: New Hampton

Harrison County, Missouri

Geographic Coordinates: 40°16'N

94°10'W

Circled in figure 6-190, just east of New Hampton, is an example of eastern brushland as it appears on mapping photographs. Notice the slightly darker gray tone and coarser texture exhibited by the presence of the brushland

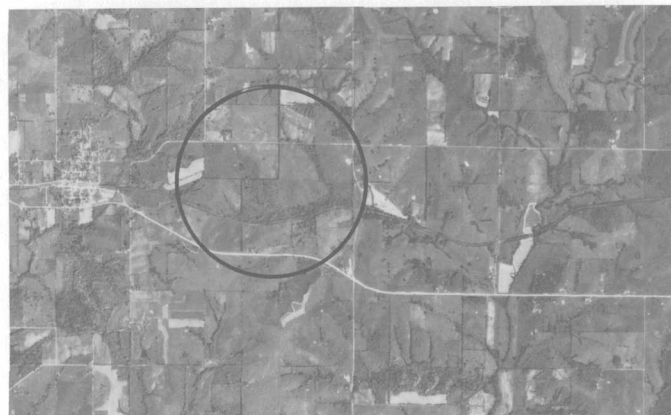


Figure 6-190.--Mapping photograph of eastern brushland area near New Hampton, Mo.

vegetation. Vegetation nearest the railroad (the southern boundary of the area) is actually too dense to be classified as eastern brushland. However, because the strip does not meet minimum mapping width criteria at the 1:250,000 scale, this more heavily vegetated strip should be combined with the eastern brushland to the north and shown as eastern brushland.

Figure 6-191 illustrates more clearly the characteristic vegetation pattern of eastern brushland. Notice the denser strip of trees near the bottom of the photograph.



Figure 6-191.--Oblique photograph of eastern brushland area near New Hampton, Mo.

LEVEL I, CATEGORY 4 - FOREST LAND

Areas of trees capable of producing timber and other wood products, which exhibit a tree-crown areal density (crown closure percentage) of 10 percent or more, and exert an influence on the climate or water regime, are classified as Forest Land. Although the precise boundary between Forest Land and other categories of land use may be difficult to delineate, generally Forest Land areas can be identified rather easily on high-altitude aerial photographs. The majority of the Forest Land in Missouri is located south of a line extending from Joplin in the southwest through Columbia to Hannibal in the northeast. Statewide, over 15 million acres of Forest Land cover Missouri.

Also included in the Forest Land category are lands from which trees have been removed to less than 10 percent crown closure but which have not been developed for other uses. These areas often have been clear cut and are scheduled for blockplanting. This practice is commonplace in our national forest lands.

Not included in the Forest Land category are those areas which would otherwise be

classified as Forest land if it were not for the fact that the water table was at or near the ground surface. Since the wetland condition is of much interest to land managers and planning groups, such lands are classified as Forested Wetland.

At Level II, Forest Land is separated into three categories: Deciduous, Evergreen, and Mixed. From small-scale aerial photographs, the photointerpreter must rely on site association knowledge, tone, and texture analysis to differentiate these cover categories. In addition, the availability of photographs obtained during the period when deciduous trees are bare can be very helpful in separating Deciduous and Evergreen Forest cover types.

Prior to initiating Forest Land photointerpretation, the photointerpreter should be familiar with the various tree species known to exist in the area. This task can be facilitated by consulting silviculture handbooks normally available from State or Federal service agencies for the area.

Photographic tone can also be used to help identify forest cover types. Generally, evergreen trees exhibit a darker tone (dark green) than deciduous trees. On color-infrared winter photographs, evergreen trees are generally magenta in color.

Concerning photographic texture, even-aged coniferous trees generally exhibit a smooth, carpetlike texture. Deciduous trees, on the other hand, exhibit a rougher texture as a result of their varying heights and rounded crowns, particularly when the stands are of an uneven-aged nature.

Category 41--Deciduous Forest Land

Category Description. Deciduous Forest Lands include all forested areas with a predominance of trees that lose their leaves at the end of the frost-free season or at the beginning of the dry season. Nearly 94 percent of Missouri's 15 million acres of Forest Land is of the deciduous cover type--mostly oak.

The geographic extent of the Deciduous Forest Land parallels that of Missouri's Forest Land; that is, the majority of the Deciduous Forest Land occurs south of a line extending from Joplin to Columbia to Hannibal.

Environmental Considerations. Deciduous Forest Land areas exert a strong influence on local water supplies and microclimatic conditions. Silvicultural management practices may effect both the quantity and quality of nearby water bodies. Since the types of pollution which may occur from Deciduous Forest Lands

would be the same for Evergreen Forest Lands and Mixed Forest Lands, a detailed description of environmental considerations is presented only for the Deciduous Forest Land category rather than each Level II Forest Land category.

Thinning and harvesting operations may increase water quantity by reducing existing transpirational surface areas and decrease water quality as a consequence of the transport of chemical (primarily herbicides, insecticides, and fertilizers) and physical (loose soil particles) contaminants to nearby water bodies with surface runoff.

The use of herbicides for plantation clearing, site preparation, right-of-way maintenance, and other uses may contaminate the soil, wildlife, and surface or ground-water supplies. Insecticides, used to check the spread of harmful pests, can cause both air and water pollution--not to mention the possibility of adversely affecting certain beneficial species such as honey bees.

Forest fertilization, if improperly administered, can increase the nutrient load of nearby water bodies and thereby increase existing trophic states. Logging road construction and maintenance activities can lead to erosion and increase nearby water course sediment loads. Repeated passes of logging equipment over the area can result in soil compaction, reduce percolation rates, and as a consequence, intensify surface runoff rates--even to the extent that it may cause minor flooding and the loss of tree vigor.

Interpretation Keys. The Deciduous Forest Land areas at Windsor (west-central Missouri) and Kirksville (northeast Missouri) illustrate land use category 41.

Site No. 74 (Reforested Strip Mine)
Location: Windsor
Henry County, Missouri
Geographic Coordinates: 38°34'N
93°35'W

A number of areas in the State which have been strip mined have been allowed to return to Forest Land vegetation. One such area, approximately 6 miles west of Windsor, is circled in figure 6-192. Notice the alternating rows of white (ridges) and dark (forested troughs) in the upper left portion of the circle. Figure 6-193, an oblique photograph of the same area, reveals the extent to which additional deciduous tree growth has occurred between 1972 and 1980. Just to the southwest of the strip mines shown in figure 6-192 is an excellent example of a larger strip mined area



Figure 6-192.--Mapping photograph of strip mine area west of Windsor, Mo., undergoing natural reforestation, 1972.

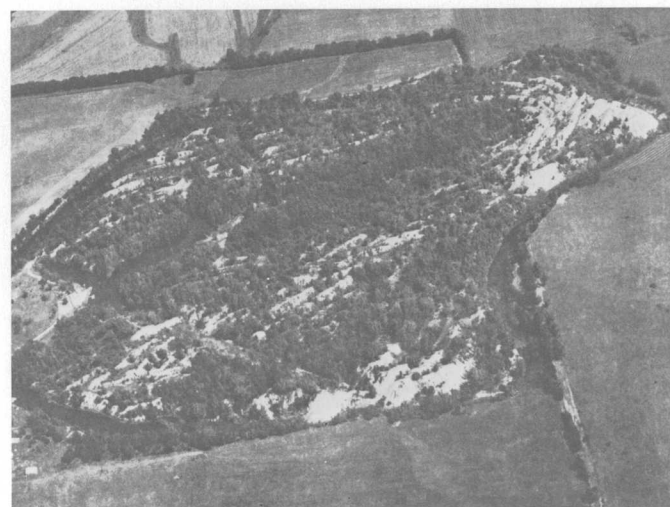


Figure 6-193.--Low-level oblique photograph of reforested strip mine area, 1980.

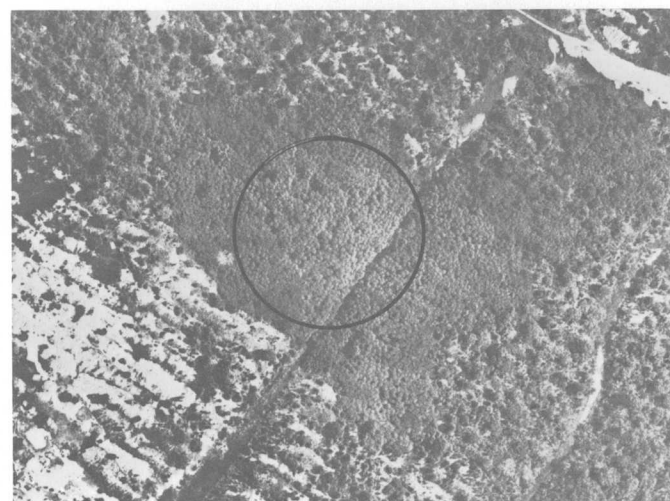


Figure 6-194.--Low-level vertical photograph of mature, natural reforestation of former strip mine area southwest of Windsor.

after more than 30 years of natural reforestation. Notice the two types of forest cover shown in figure 6-194. The smoother textured, area, circled, is an area of coniferous forest cover. The remaining area is covered by deciduous trees.

Site No. 94 (Deciduous Trees)
Location: Kirksville
Adair County, Missouri
Geographic Coordinates: 40°11'N
92°38'W

Another example of Deciduous Forest is shown in figure 6-195. This site, at Thousand Hills State Park just west of Kirksville, Missouri, also provides an excellent example of coniferous evergreen trees adjacent to deciduous trees. Although coniferous trees are not native to the area, Boy Scouts voluntarily planted some scotch pines in several places in the park about 25 years ago. The coniferous trees stand out as the darker tone areas in figure 6-195.

Figure 6-196, an oblique photograph taken 6 years later, shows an area of defoliated trees at A. A recent forest fire has destroyed some of the scotch pines. To the east of the defoliated area are the deciduous trees with their characteristic, more rounded tree crowns (B). Notice that the deciduous trees generally have a lighter tone on black-and-white photographs. Had frost-season photography been available, it would have also been helpful in separating the deciduous from the evergreen trees.



Figure 6-195.--Mapping photograph of deciduous and evergreen forest cover in Thousand Hills State Park, 1974.



Figure 6-196.--Low-level 1980 oblique photograph of a portion of the area shown in figure 6-195.

Category 42--Evergreen Forest Land

Category Description. Forest areas in which the trees are predominately those which remain green throughout the year are classified as Evergreen Forest Lands. Included in this category are both coniferous and broadleaved evergreens. Evergreen species commonly associated with Wetland areas are not included in this category.

The two most common species of evergreens occurring in Missouri are the shortleaf pine (*pinus echinata*) and the eastern redcedar (*juniperus virginiana*). The former is found primarily in the southeastern part of the State while the latter can be found in extreme east-central Missouri and in some east-central counties.

Environmental Considerations. The environmental description presented earlier for land use category 41, Deciduous Forest Land, applies to Evergreen Forest Land areas as well; therefore, refer to land use category 41 for information on the potential pollution contaminants most likely to be associated with Evergreen Forest Land.

Interpretation Keys. Presented below are examples of planted pine at New Madrid and eastern redcedar near Bradleyville (south-central Missouri).

Site No. 25 (Plantation Pine)
 Location: New Madrid
 New Madrid County, Missouri
 Geographic Coordinates: 36°32'N
 89°26'W

Located about 3 miles southeast of New Madrid is a rectangular area of planted short-leaf pine. Photographed in 1974, notice the height differences between the planted pine and the adjacent deciduous trees in figure 6-197. Figure 6-198, an oblique photograph of the same area in 1980, illustrates both the rapid rate of tree growth exhibited by this species in southeast Missouri and the characteristic carpetlike texture common to even-aged coniferous tree cover. Although not the case with this particular pine plantation, many pine plantations are actually planted in rows. When viewed from the air, or on an aerial photographs, row pine plantations are easily identified.

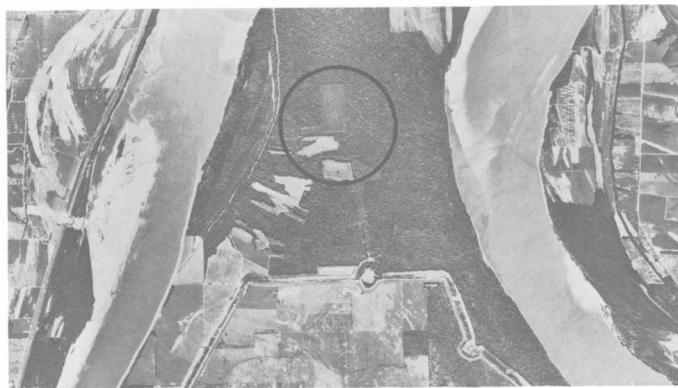


Figure 6-197.--Mapping photograph of planted pine near New Madrid, Mo., 1974.

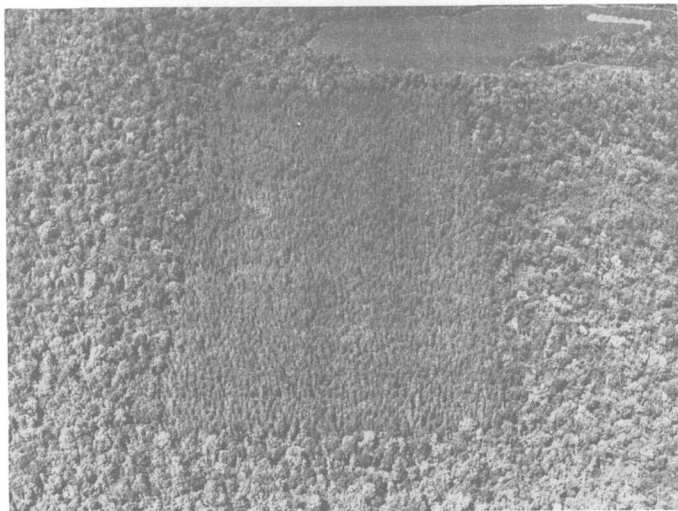


Figure 6-198.--Low-level oblique photograph of planted pine near New Madrid, 1980.

Site No. 65 (Eastern Redcedar)
 Location: Bradleyville
 Taney County, Missouri
 Geographic Coordinates: 36°46'N
 92°57'W

The second most prevalent type of Evergreen Forest Land, eastern redcedar, is shown in figure 6-199 at A. This area barely meets the minimum mapping size of 40 acres required for 1:250,000-scale land use and land cover mapping. The photograph, taken on January 23, 1976, allows the photointerpreter to easily separate deciduous and evergreen trees. The darker tone areas are eastern redcedars (evergreens) while the lighter tone areas, particularly on the right side of figure 6-199 at B, are deciduous trees which have lost their leaves. In the upper-left portion of figure 6-199 is an area of Mixed Forest Land; that is, an area of evergreen and deciduous trees where neither predominates. Figure 6-200, an oblique photograph, illustrates the darker tone of the cedar trees. Notice how the cedar trees parallel the limestone bedding plains as they curve around the hillsides. The areas devoid of tree cover have been cleared for pasture. A comparison between figure 6-199 and figure 6-200 reveals the extent of additional clearing that occurred at A between 1976 and 1980.



Figure 6-199.--Mapping photograph of eastern redcedar forest cover southwest of Bradleyville, January 1976.



Figure 6-200.--Low-level oblique photograph of eastern redcedar forest cover near Bradleyville, July 1980.

Category 43--Mixed Forest Land

Category Description. A Forest Land area is classified as Mixed Forest when more than one-third intermixture of either evergreen or deciduous tree species occurs in a specific area. In actuality, this division of the Forest Land category is a function of the land use and land cover mapping specifications and, therefore, will be less often used at some mapping scales than others, particularly at larger mapping scales.

Environmental Considerations. The environmental description presented earlier for land use category 41, Deciduous Forest Land, applies to Mixed Forest Land areas as well; therefore refer to land use category 41 for information on the potential pollution contaminants most likely to be associated with Mixed Forest Land.

Interpretation Keys. Site 39, near Edgehill, presents an example of Mixed Forest Land.

Site No. 39 (Mixed Deciduous and
Evergreen Forest Cover)
Location: Edgehill
Iron County, Missouri
Geographic Coordinates: 37°37'N
90°54'W

An example of Mixed Forest Land is illustrated by figure 6-201. This area, approximately 3 miles north-northeast of Edgehill, has varying degrees of deciduous (lighter tone areas) and evergreen (darker tone areas) trees. Notice the small, but more homogeneous, stands of darker tone evergreen trees (circled on the photograph) surrounded by deciduous trees. Because this photograph was taken during the frost season (photo date March 9, 1980), the deciduous trees exhibit an even lighter tone than had the photo been taken during the frost-free season. Quite often, frost season (leaf-off) photographs are not available. In such cases, if color-infrared photographs are available, the task of separating deciduous and evergreen trees or delineating Mixed Forest Land areas is facilitated. Figure 6-202, a black-and-white reproduction of a high-altitude color-infrared (CIR) photograph taken in September 1974, illustrates the benefits to be gained from the use of CIR photographs--even when they are reproduced in black-and-white. The evergreen trees appear as darker tones on the photograph. Notice the dark tone of the purer stands of evergreen trees at A. The deciduous trees are lighter in tone. Also notice, particularly along stream segments, the lighter tone of the deciduous trees which have begun to lose their leaves. In such cases these linear areas appear whitish to gray in tone. The lighter, almost white, areas in the photograph are rock outcroppings.



Figure 6-201.--Black-and-white reproduction of a mapping photograph of mixed forest cover near Edgehill, March 1980.

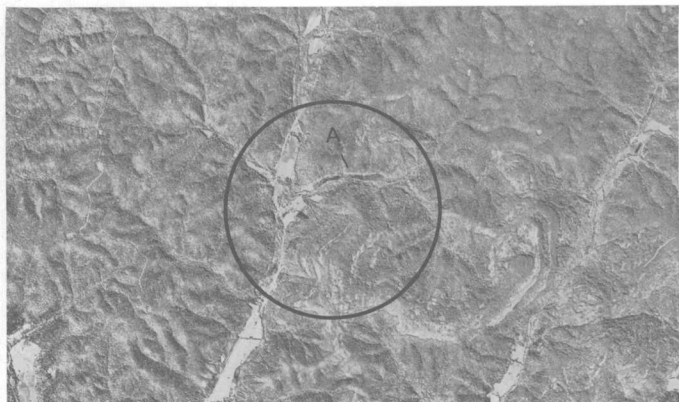


Figure 6-202.--Black-and-white reproduction of a color-infrared mapping photograph of mixed forest cover near Edgehill, September 1974.

LEVEL I, CATEGORY 5--WATER

Water areas, as defined by the Bureau of the Census, include all areas within the land mass of the United States that are persistently covered by water, at least 40 acres in size, and if linear, are at least 1/8 mile wide. However, for most purposes, agencies require the identification of water bodies smaller than 40 acres. The U.S. Geological Survey land use and land cover maps include all water bodies greater than 10 acres which are at least 300 feet wide and shown as double-line streams on the 1:250,000-scale base map. Water included in this category are streams and canals, lakes, reservoirs, and bays and estuaries.

At the 1:250,000-scale land use and land cover mapping for Missouri, only major rivers, such as the Mississippi, Missouri, and Osage, and major canals, such as those near Kennett in southeast Missouri, are shown. Natural lakes are rare with less than 17 square miles of this land use type in the State. More common are the State's many reservoirs. Reservoirs such as Clearwater, Pomme de Terre, Stockton, and Table Rock account for over 232,000 acres of State's reservoirs. Bays and estuaries are not found in Missouri.

The above acreage figures reflect water area totals based on Level II land use and land cover mapping at the 1:250,000 scale. At a larger mapping scale and a greater level of land use detail, these acreage totals increase somewhat.

It is important to note that all water bodies should be delineated as they exist at the date (time) of the photography, except areas in an obvious state of flood.

Category 51--Streams and Canals

Category Description. Included in the Streams and Canals category are rivers, creeks, canals, and other linear water bodies. Where the water course is interrupted by a control structure, the impounded area is placed in the Reservoir category.

Environmental Considerations. Streams and canals are not in themselves pollution sources. Instead, it is the discharge from point sources and surface runoff from nonpoint pollution sources, such as agricultural and silvicultural areas, which reduce stream and canal water quality. Perhaps flooding is the most serious detrimental effect which can occur from streams. When streams overflow their banks they can, and have, caused significant damage to manmade structures and crops.

Interpretation Keys. Two sites, site 70 and 26, follow which depict rivers and canals.

Site No. 70 (Missouri River)
Location: Jefferson City
Cole County, Missouri
Geographic Coordinates: 38°35'N
92°11'W

Rivers and streams are easily recognized on aerial photographs. As shown in figure 6-203, natural water courses consist of somewhat parallel land/water interface boundaries which quite often vary in width as a function of normal fluvial processes. Water bodies are most often characterized by medium gray tones on aerial photographs. Figure 6-204 is an oblique photograph of the same section of the Missouri River at Jefferson City. Notice the bridge over the river and the barges docked on the northern shore.



Figure 6-203.--Mapping photograph of Missouri River at Jefferson City, Mo.

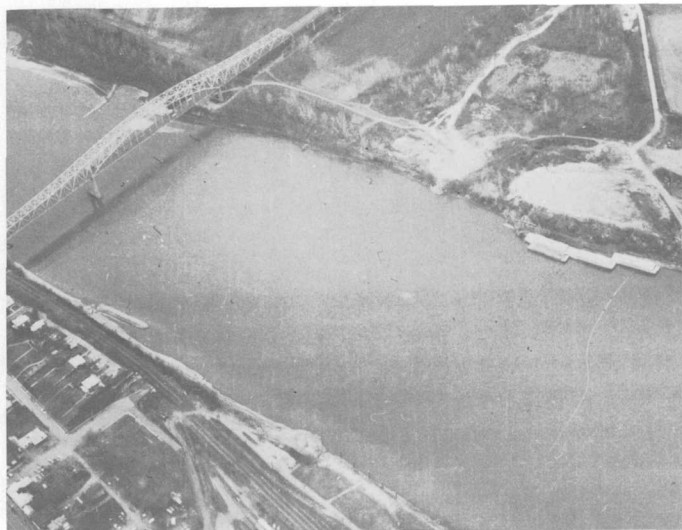


Figure 6-204.--Oblique photograph of Missouri River at Jefferson City, Mo.

Site No. 26 (Canals)

Location: Kennett

Dunklin County, Missouri

Geographic Coordinates: 36°10'N

90°01'W

Canals, or ditches, are constructed for one of two purposes: to drain or to irrigate an area. Around the turn of the century, a number of drainage ditches were constructed in southeast Missouri extending from south of Cape Girardeau to across the Missouri/Arkansas State line. This area, once swampy and marshy, is now very productive cropland. From a weblike network of ditches north of Gideon, many of the smaller ditches finally enter one of five main ditches about 3 miles southeast of Gideon where the five ditches extend southwest for almost 35 miles. Pictured in figure 6-205 is a segment of the five main drainage ditches about 4.5 miles southeast of Kennett. Unlike natural linear water courses (streams and rivers), canals and ditches have parallel land/water interface boundaries of nearly constant separation. Three of the ditches in the photograph appear medium gray in tone--the two westernmost ditches and the easternmost one. The two other ditches are lighter gray, almost white. The difference in tone can be explained by slight differences in water levels, camera angles, and subsequent Sun reflections. The lighter gray tone ditches are reflecting more sunlight and therefore show up as light gray in the photograph.

Figure 6-206, an oblique photograph of the same area, also shows differences in gray tone values for the ditches; however, in this case, only one ditch reflects more sunlight.



Figure 6-205.--Mapping photograph of canals near Kennett, Mo.



Figure 6-206.--Oblique photograph of canals near Kennett, Mo.

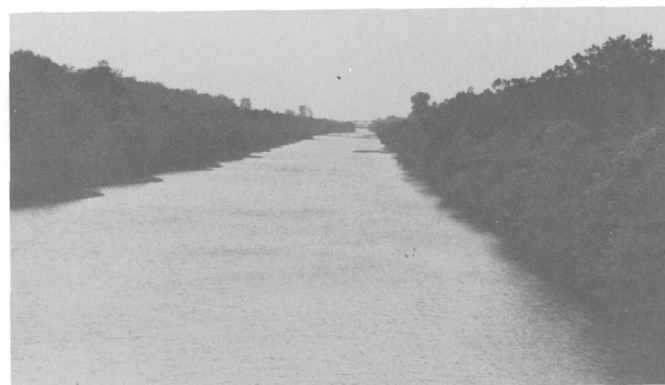


Figure 6-207.--Ground shot of drainage canal near Kennett, Mo.

Figure 6-207 is a ground-level photograph of one of the ditches taken from a bridge 6 miles northwest of the location shown in figures 6-205 and 6-206. Notice how straight the water course is and its constant width.

Category 52--Lakes

Category Description. Lakes are naturally enclosed standing water bodies, including regulated natural lakes but excluding reservoirs. Only lakes 10 acres or greater at the time of photoacquisition are delineated on the U.S. Geological Survey 1:250,000-scale land use and land cover maps. If the photointerpreter has source material which provides the name of a water body, he should not necessarily classify the water body from this information because many reservoirs in Missouri have lake names. Accordingly, the majority of Missouri's nonlinear water bodies are reservoirs and not lakes. It is important to remember that lake water levels are maintained by the seepage of ground water and the direct surface runoff of precipitation, whereas reservoir water levels are the result of manmade impoundments and the subsequent accumulation of surface runoff, primarily by contributing linear water courses.

For the most part, Missouri lakes are found in the flood plains of the State's two largest rivers--the Mississippi and the Missouri. These lakes, called oxbow lakes, are formed by sealing off the meanders of alluvial streams. As alluvial streams mature, their meanders (snake-like patterns) grow until the channels bend to meet themselves, causing the meander loops to be pinched (sealed) off and abandoned--therefore, oxbow lakes can be found all along the Missouri and Mississippi Rivers.

Environmental Considerations. Like streams and canals, lakes are not in themselves pollution sources. The same types of point and nonpoint pollution sources which affect linear water bodies also affect lakes. However, unlike linear water bodies, lakes do not possess the same flood hazard potential. Therefore, one is more likely to find manmade construction, namely houses and businesses, closer to the land/water interface boundaries of lakes than streams or rivers.

Interpretation Keys. Site 83, an oxbow lake west of Fortescue, Missouri, characterizes Missouri lakes.

Site No. 83 (Oxbow Lake)

Location: Fortescue

Holt County, Missouri

Geographic Coordinates: 40°05'N
95°21'W

Located west of Fortescue, Big Lake is one of Missouri's many oxbow lakes. In figure 6-208, it appears as a crescent shape with the crescent ends pointing west toward the Missouri River. Close inspection of the photograph reveals a series of meander scars to the east. Figure 6-209, an oblique photograph of the northern half of the lake, shows the extent to which resort-type residential structures rim the land/water interface boundary.



Figure 6-208.--Mapping photograph of an oxbow lake west of Fortescue, Mo.



Figure 6-209.--Oblique photograph of a portion of Big Lake west of Fortescue.

Category 53--Reservoirs

Category Description. Manmade impoundments of water used for such purposes as irrigation, flood control, municipal water supplies, recreation, and hydroelectric power generation are classified as reservoirs. On aerial photographs, reservoirs are identified by their overall nonlinear shape and associated manmade water-control structures--such as dams or levees. It is the manmade water-control structures which key the photointerpreter to classify a nonlinear water body as a reservoir. As with land use category 52 (Lakes), only reservoirs 10 acres or greater at the time of photoacquisition are delineated on 1:250,000-scale land use and land cover maps. Accordingly, many farm ponds in Missouri are not included in the acreage figures for reservoirs presented in Section 7. Of the State's 377,022 acres of water, 232,559 acres (61 percent) are represented by the Reservoir category. This category includes reservoirs such as Table Rock Lake, Stockton Lake, Lake of the Ozarks, Clearwater Lake, Clarence Cannon Lake, and many more smaller reservoirs around the State.

Environmental Considerations. Comments previously presented as environmental considerations for lakes hold true for reservoirs. Concerning flood hazard potential, the most dreaded occurrence would be a dam break. Fortunately however, such occurrences are rare.

Interpretation Keys. The Clearwater Lake Reservoir exemplifies many Missouri reservoirs.

Site No. 33 (Clearwater Lake Reservoir)

Location: Piedmont

Wayne County, Missouri

Geographic Coordinates: 37°08'N
90°46'W

Located approximately 4 miles west of Piedmont, Clearwater Lake Reservoir is one of Missouri's excellent recreational areas. Around the reservoir's perimeter are a number of public access points and use areas. Some of these areas are identified in figure 6-210 at A, B, and C; also shown is the dam at D. Note the straight land/water interface formed by the dam and the water.

Figure 6-211 shows more clearly the back side of the dam and some of the recreational/camping facilities. In figure 6-212, several campers and trailers can be seen parked at the site. Also shown in figure 6-211, at A, is a boat ramp. Figure 6-213 shows a ground photograph of the boat ramp area.



Figure 6-210.--Mapping photograph of Clearwater Lake Reservoir near Piedmont, Mo.



Figure 6-211.--Oblique photograph of Clearwater Dam near Piedmont, Mo.



Figure 6-212.--Camping area at Clearwater Dam near Piedmont, Mo.



Figure 6-213.--Public use area and boat ramp at Clearwater Lake Reservoir near Piedmont, Mo.

LEVEL I, CATEGORY 6--WETLAND

Wetland areas are areas where the water table is at, near, or above the land surface for a significant part of most years. The hydrologic regime is such that aquatic or hydrophytic vegetation is established, however, alluvial and tidal flats may be nonvegetated. Examples of wetlands include swamps, marshes, mudflats, and portions of streams, lakes, reservoirs, and bays which exhibit surface aquatic or hydrophytic vegetation. Shallow water areas where aquatic vegetation is submerged are classified as open water and not included in the Wetland category.

Extensive parts of some river flood plains qualify as Wetland, as do regularly

flooded irrigation overflow areas. Not included in the Wetland category are agricultural lands where seasonal wetness or short-term flooding provides an important component of the total annual soil moisture necessary for crop production; for example, flooded fields associated with rice production or developed cranberry bogs.

Uncultivated Wetland, from which wild rice, cattails, or wood products, and other crops are harvested, or Wetland grazed by livestock, are placed in the Wetland category.

Wetland areas drained for any purpose belong to the land use and land cover category for which they are being used. If, however, drainage is discontinued and such use ceases, classification may revert to the Wetland category. Wetland managed for wildlife purposes may exhibit short-term land use changes as different management practices are used; however, such areas should be classified as Wetland.

With regard to the delineation of Wetland areas, two separate boundaries are important: the upper wetland boundary above which almost any non-wetland category of land use or land cover may exist, and the boundary between wetland and open water beyond which the appropriate Water category should be utilized.

Wetland areas in Missouri occur primarily along the Mississippi and Missouri River flood plains, the upper reaches of reservoirs, and in the Missouri bootheel counties of Wayne, Stoddard, Bollinger, Mississippi, and Dunklin. These five counties account for slightly more than one-third of all of Missouri's 66,862 acres of Wetland.

The Level II categories of Wetland are Forested Wetland and Nonforested Wetland. Approximately two-thirds (46,585 acres) of Missouri's Wetland areas are Forested Wetland.

Category 61--Forested Wetland

Category Description. Wetlands dominated by woody vegetation are classified as Forested Wetland. In Missouri, the Forested Wetland category is primarily represented by bottomland oaks such as pine; swamp, white, and shingle oaks; and tupelo, blackgum, sweetgum, and cypress species.

Extensive Forested Wetland areas are usually more easily identified on color-infrared (CIR) photography than on color or black-and-white photography. These areas exhibit a bluish cast on CIR imagery as opposed to the red colors of deciduous trees and magenta colors of the evergreens.

If available, ground surveys of soil types or the duration of flooding can provide supplemental information to assist the photointerpreter in delineating Forested Wetland areas. Many times photographs acquired with low Sun angles will aid in detecting standing water areas where tree crown closure values are not too great.

Environmental Considerations. Like water, Forested Wetland areas do not cause pollution. These areas, however, can become victims of a range of man's activities which can ruin an otherwise balanced ecosystem. In Missouri, the greatest potential pollution source for Forested Wetland areas is nonpoint pollution, primarily runoff from adjacent agricultural areas. If proper precautions are not taken, agricultural areas may introduce such pollutants as livestock manure, fertilizers, and pesticides.

Interpretation Keys. Two sites, both in southeast Missouri, are described below to illustrate Forested Wetland areas.

Site No. 31 (Swamp)
Location: Puxico
Stoddard County, Missouri
Geographic Coordinates: 37°01'N
90°10'W

Figure 6-214, a black-and-white reproduction of a color-infrared photograph of a portion of the Mingo National Wildlife Refuge (approximately 3 miles north of Puxico), depicts both land use categories 61 (Forested Wetland), at A, and 62 (Nonforested Wetland), at B. Notice the dark areas as opposed to the lighter area just above A. The dark areas are wetter areas of woody vegetation, while the lighter areas are higher, drier areas of forest land. The lighter area at B, Nonforested Wetland, is discussed later.

On color-infrared photography, the Forested Wetland areas appear bluish in color while the drier deciduous forest areas appear red in summer. During the frost season, deciduous trees appear as blue-green when the leaves are brown, yellow when the leaves are red, and white when the leaves are yellow. The photograph shown in figure 6-214 was taken in November 1974, when the leaves had already turned brown; therefore, on the color-infrared photography, the trees at C appeared blue-green.

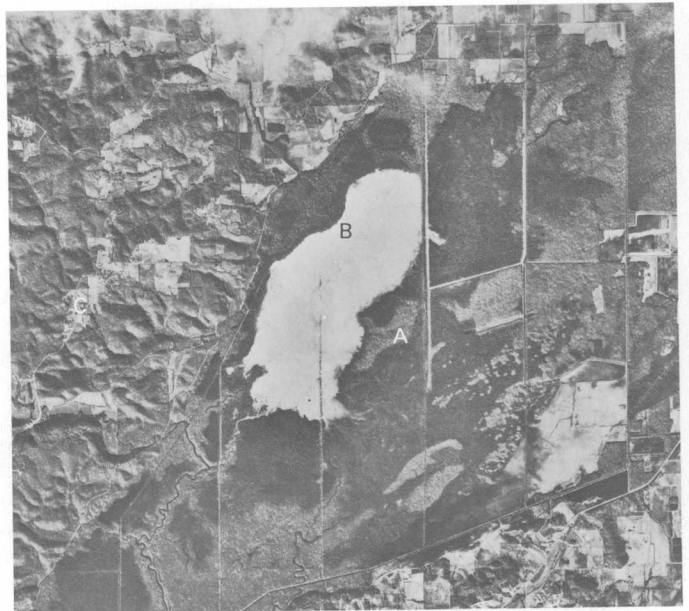


Figure 6-214.--A black-and-white reproduction of a color-infrared mapping photograph of swamp and marsh areas in Mingo National Wildlife Refuge near Puxico, Mo.

Figure 6-215, a forward oblique photograph of the same area, also suggests slight differences in moisture levels. Notice the slightly lighter tone exhibited in the area just to the right of A. Apparently there has been an increase in water levels since 1974 when the photograph shown in figure 6-214 was obtained. The increased water levels have increased the size of the wetland area which existed in 1974.

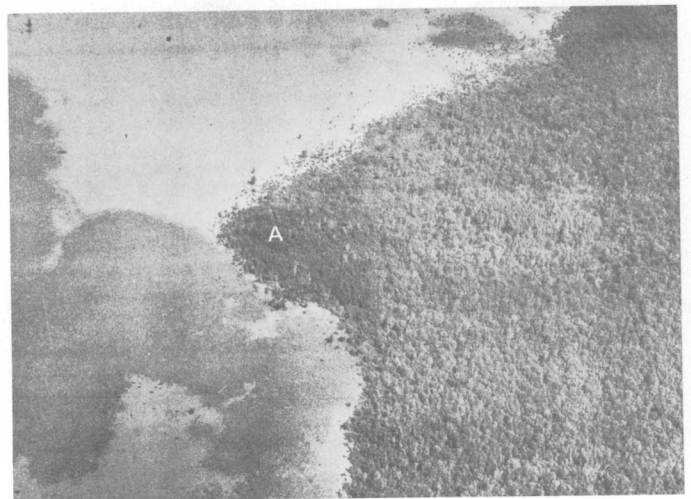


Figure 6-215.--Low-level photograph of swamp area in Mingo National Wildlife Refuge near Puxico, Mo.

Site No. 32 (Swamp and Marsh)
 Location: Wappapello
 Wayne County, Missouri
 Geographic Coordinates: 36°58'N
 90°23'W

Located approximately 6 miles west of the Mingo National Wildlife Refuge lies Wappapello Lake--actually it is a reservoir since this water body was formed following the construction of a dam on the St. Francis River near Wappapello in 1941. Many of the upper reaches of the reservoir now exist as Forested and Nonforested Wetland areas. Site 32, noted by the circle on figure 6-216, illustrates the wetland nature of just one of these areas. Notice the dark gray tone of the Forested Wetlands area in the southwest quadrant of the circle. Also notice the lighter gray tones of adjacent deciduous trees.

Figure 6-217 provides a closer view of the area. Note the difference between the Forested Wetland vegetation at A and B as compared to the Nonforested Wetland area at C.

At the time of this photograph, September 1980, water level of the reservoir was down somewhat. Accordingly, some of the areas, such as just above the B and below the A in the photograph, were not water covered. Although they can be seen more clearly on the original large-scale color photograph, these areas can be identified as the lighter gray areas on this photograph. Marsh areas, at C, appear as even lighter gray areas on the photograph.

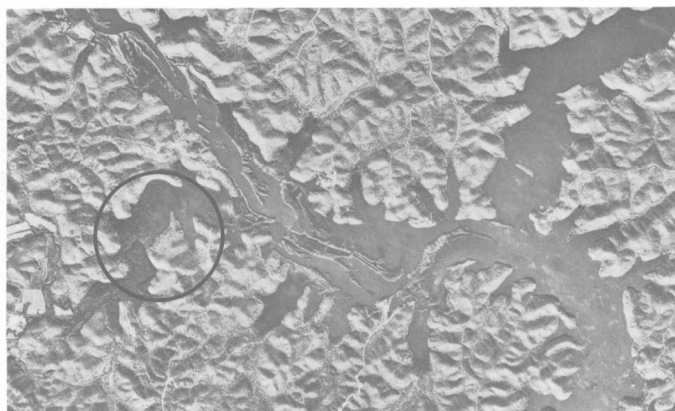


Figure 6-216.--Forested Wetlands on upper reaches of Lake Wappapello reservoir west of Wappapello.



Figure 6-217.--Oblique photograph of forested wetlands near Wappapello.

Category 62--Nonforested Wetland

Category	Description.	Nonforested
Wetlands	are areas dominated by herbaceous wetland vegetation or are nonvegetated. In Missouri, these areas include fresh marshes and nonvegetated flats. As suggested in the introductory comments, the Nonforested Wetland category accounts for only one-third of the State's 66,862 acres of wetland. Of this amount, approximately 20,000 acres, almost half is situated in numerous reservoir hollows. The remainder occurs mostly in alluvial flood plains of the Mississippi and Missouri Rivers.	

Environmental Considerations. As with Forested Wetlands, Nonforested Wetland areas are not pollution sources. Likewise, since Nonforested Wetland areas are often situated adjacent to Forested Wetland areas, the environmental consideration comments presented earlier for Forested Wetlands hold for Nonforested Wetlands as well. Therefore, no further comments are presented here.

Interpretation Keys. Site 31, in southeast Missouri, and site 82, in northwest Missouri, illustrate the types of Nonforested Wetland areas found in the State.

Site 31 (Marsh)
 Location: Puxico
 Stoddard County, Missouri
 Geographic Coordinates: 36°59'N
 90°10'W

Figure 6-214, presented earlier in the descriptions for Forested Wetland, identifies the area of the Mingo National Wildlife Refuge to be described here. Water levels have increased since 1974 and, consequently, the area immediately below point A in figure 6-214 now exists as Nonforested Wetland. Figure 6-218, a 1980 photograph of the same area, illustrates the surface appearance of a Nonforested Wetland area. Note the overall mottled tone of the area. The lighter areas at A and B are small water areas, the darker areas at C and D are Forested Wetlands. The remaining nonvegetated area is Nonforested Wetland.



Figure 6-218.--Oblique photograph of Nonforested Wetland in Mingo National Wildlife Refuge near Puxico, Mo.

Site No. 82 (Nonforested Wetland)
Location: Mound City
Holt County, Missouri
Geographic Coordinates: 40°04'N
95°15'W

Site 82, located approximately 4 miles south of Mound City, is located near the southern end of the Squaw Creek National Wildlife Refuge. Figure 6-219, taken in 1975, shows the area at a time of relatively high water levels. Notice the light gray tone of the water area. In contrast, figure 6-220, taken in September 1980, was obtained near the end of a prolonged drought. Notice how aquatic vegetation has replaced much of the water area that existed in 1975. Also note the overall mottled appearance of the area. The mottled

appearance results from differences in algal growth and herbaceous vegetation. The complete lack of woody vegetation in the area should also be noted since this rarely occurs in Missouri.



Figure 6-219.--Mapping photograph of Nonforested Wetland area near Mound City, Mo.



Figure 6-220.--1980 Oblique photograph of Nonforested Wetland area near Mound City, Mo.

LEVEL I, CATEGORY 7--BARREN LAND

Barren Land is land with limited ability to support plant life with less than one-third of the area in vegetation or other cover. In general, it is an area of thin soil, sand,

or rocks. Vegetation, if present, is widely spaced and scrubby. Barren Land is more often found in nature; however, land also may become barren because of man's activities. The Level II categories of Barren Land are: Dry Salt Flats; Beaches; Sandy Areas Other Than Beaches; Bare Exposed Rock; Strip Mines; Quarries and Gravel Pits; Transitional Areas; and Mixed Barren Land. Barren Land categories found in Missouri are Sandy Areas Other Than Beaches (mostly islands and sand bars created by the currents in the larger rivers of the State), Strip Mines, Quarries and Gravel Pits, and Transitional Areas.

The geologic structure of Missouri allows mining of coal in the northern portion of the State, while Quarries and Gravel Pits occur throughout the State.

When land clearing occurs, either in rural or urban areas of the State, and the former or future use of the land cannot be discerned, the area is said to be in transition. Accordingly, in order to avoid inferential errors in classification, it is considered to be a Transitional Area. This transitional classification is also used when forest land is cleared for agriculture, wetland is drained for development, or where areas become temporarily bare, such as construction for highways, residences, shopping centers, industrial sites, or suburban and rural residential subdivisions. Land areas altered by filling, such as sanitary landfills, are also included in the Transitional Area category. These areas in Missouri are mostly forest lands converted for agriculture purposes and areas cleared for new construction.

Category 73--Sandy Areas Other Than Beaches

Category Description. There are approximately 4,000 acres of Sandy Areas Other Than Beaches in Missouri. Most of these sandy areas occur in the channels and banks of the Missouri and Mississippi Rivers, and are formed by sand deposited by their currents. These sandbar islands and tow heads are in a constant state of change--every time the current increases, they are subject to being washed away, and the sand deposited in another location. Because of this instability, vegetation does not have a chance to become established.

Environmental Considerations. Sandy Areas Other Than Beaches, formed by natural process, are not a source of pollution.

Interpretation Keys. The following site indicates the types of areas to be delineated under this category.

Site No. 24 (Sandbar)

Location: 10 miles northeast of Hayti
Pemiscot County, Missouri

Geographic Coordinates: 36°20'N
89°36'W

Figure 6-221, a mapping photograph taken in 1974, shows an area in the Mississippi River channel which would be delineated under this category. Because of their inherent instability, the size and shape of the islands, sandbars, and tow heads are in a constant state of change. Since vegetation hasn't had a chance



Figure 6-221.--Sandy area along the Mississippi River.



Figure 6-222.--Low-altitude oblique photograph of unstable sandy area in Mississippi River.

to become established, these areas are much lighter in tone than the surrounding areas. The instability of this feature is shown in figure 6-222, a low-altitude oblique photograph taken in 1980 of the same area shown in figure 6-221. The photograph shows the light-toned sandy areas in the river and adjacent to the dark-toned shoreline.

Category 75--Strip Mines, Quarries, and Gravel Pits

Category Description. Surface mining activities that have significant surface expressions are included in this category. Vegetative cover and overburden are removed to expose deposits of extractive material such as coal, limestone, iron ore, or copper. Quarrying of stone and the recovery of sand and gravel also result in large open pits. All surface expressions of this type of mining, including active, inactive, and unreclaimed quarries and gravel pits, are included in this category. When other land use or land cover types have been established, these areas are no longer included in this category. Missouri contains approximately 75,177 acres of land in category 75.

Environmental Considerations. Strip mines, quarries, and gravel pits are often a source of significant pollution. Extraction of minerals is often accompanied by careless disposal of spoil materials containing heavy metals and toxic chemicals. Runoff from these waste products may sterilize local soils and contaminate surface and ground water. Surface runoff can collect large concentrations of sulfur and iron resulting in "acid drainage."

Strip mining activities and their associated removal of topsoil increase the erosional potential of an area and may result in increased sediment loads in nearby streams.

Quarries and gravel extraction activities can create excessive noise levels and lower air quality. The use of heavy machinery, vehicles, and intermittent blasting results in increased local noise levels. Dust and debris, caused by heavy machinery and crushing operations, affect local air quality and can create health hazards to nearby residents.

Improper reclamation methods, or the lack of them, can create a site which continually affects the environment. These sites, especially quarries, have been used as landfill sites for both residential and industrial wastes, which if not properly controlled may lead to ground-water contamination. Land collapse, subsidence, and increased erosion result in increased loss of land. The drainage

pattern and hydrology of large regions may also be altered, as well as water quality. Removal or burying of topsoil under spoil material also affects the future productivity of extraction sites.

Interpretation Keys. Presented below are examples of a strip mine, quarry, and gravel pit.

Site No. 97 (Coal Strip Mine)
Location: Thomas Hill Reservoir
Randolph County, Missouri
Geographic Coordinates: 39°32'N
92°38'W

Identification features for strip mining are the spoil banks of overburden, the lack of vegetation on active mines, and deep trenches. The last trench in a sequence of strips is usually water filled. The outer edge of the mining area is called the highwall or headwall. Active strip mines use power shovels for stripping overburden or mining.

This strip mine is just south of the Thomas Hill Reservoir in Randolph County, Missouri. The mapping photograph, figure 6-223, shows the layout of the mined area. New mining is occurring at A, a newly reclaimed mine is at B, and an older reclaimed area at C.



Figure 6-223.--Mined area near Thomas Hill Reservoir, Mo.

Figure 6-224 shows mounds of overburden, newly mined coal, and a power shovel removing overburden. The overburden is removed, the coal removed, and the trench where the coal

was extracted then filled with overburden. This process is repeated until the coal deposits are depleted. The ground photograph, figure 6-225, shows a mining shovel in the process of stripping coal. This photograph provides insight into the size of the shovel and the depth of the trenches and excavation.



Figure 6-224.--Strip mining in progress.



Figure 6-225.--Ground photograph of stripping process.

Site No. 22 (Quarries)
 Location: Cape Girardeau
 Cape Girardeau County, Missouri
 Geographic Coordinates: 37°16'N
 89°34'W

The key identifying photographic features of quarries is the large open pits, usually lighter in tone than adjacent areas, with steep walls. An active quarry will have roads to the pit and loading and crushing facilities.

Quarries are open pits where building stone such as slate, granite, marble, and limestone are extracted. The mapping photograph in figure 6-226, shows two quarries used in producing cement at points A and B. These limestone quarries, south of Cape Girardeau, are owned and operated by a cement company. The limestone is removed and transported to a cement plant nearby. The oblique photograph in figure 6-227 shows the layout of the quarry and the roads leading into the quarry area. The ground photograph, figure 6-228, shows the nearly vertical walls and provides an appreciation for the depth of the quarry.



Figure 6-226.--Mapping photograph of two limestone quarries south of Cape Girardeau, Mo.



Figure 6-227.--Low-altitude oblique photograph of quarry area.



Figure 6-228.--Ground photograph of quarry.

Site No. 30 (Gravel Pit)
 Location: Dexter
 Stoddard County, Missouri
 Geographic Coordinates: 36°49'N
 89°58'W

Key identifying features of gravel pits are the light tones and rough-textured areas where gravel is being excavated, lack of vegetation in the areas being worked, and the presence of access roads leading to the area.

The gravel pit shown in figure 6-229 is a mile and a half northwest of Dexter, in south-east Missouri. Topsoil and overburden are removed and the gravel scooped up by shovels and loaded on trucks for hauling to its destination. Many times, gravel pits are only operated during road construction. The absence of vegetation and the rough texture of the excavation area is exhibited on the photograph shown in figure 6-230. This ground photograph also shows the active gravel pit and the depth of the excavation.



Figure 6-229.--Low-altitude oblique photograph of a gravel pit near Dexter, Mo.

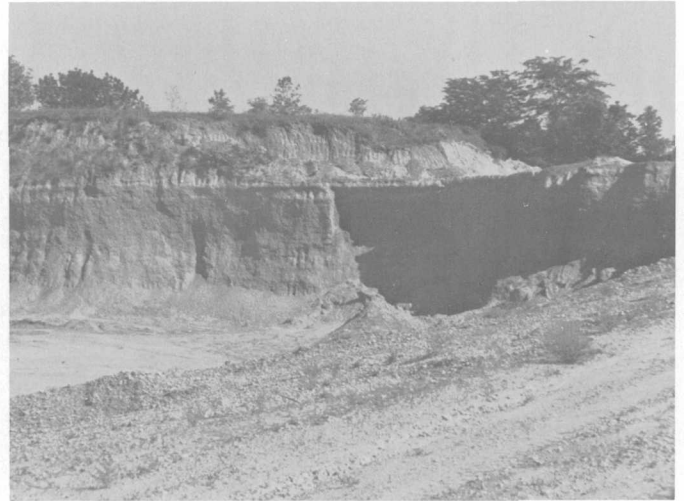


Figure 6-230.--Ground photograph of gravel pit near Dexter, Mo.

Category 76--Transitional Areas

Category Description. The Transitional Area category is used for those areas which are in transition from one land use activity to another. This transitional phase occurs when forest lands are cleared for agriculture, wetlands are drained for development, or when any type of land use ceases as areas become temporarily bare preceding construction for future uses such as residences, shopping centers, industrial sites, or suburban residential subdivisions. Land altered by filling, such as sanitary landfills, is also included in the Transitional category.

Environmental Considerations. The Transitional land use and land cover category in urban areas has the same potential pollution sources as the category to which it belongs. Urban, suburban, and rural areas undergoing conversion to residential and commercial uses exhibit the potential pollution sources associated with construction--excessive noise, dust, and debris, and runoff and erosional possibilities. Following completion of construction, the main environmental concern will be surface runoff and possible localized flooding.

A forested area being cleared for agriculture will exhibit pollution potentials similar to a forested area being harvested or a right-of-way being cleared.

Forested areas undergoing conversion to agriculture are usually sprayed with herbicides to kill trees and brush. Effects of these herbicides on wildlife are controversial, and immediately after spraying, runoff can carry these herbicides into nearby streams and other surface water bodies.

Landfills and spoil dumps are also potentially dangerous sources of water pollution. Landfills are often situated in abandoned pits or quarries. If the geologic structure is unfavorable, or the bedrock permeable, ground water can be contaminated by the disposed wastes. Dust, debris, and noxious fumes from decaying waste can lower air quality in these areas and in adjacent communities.

Interpretation Keys. Two sites, one urban and one rural, are presented to illustrate Transitional Areas.

Site No. 20 (Urban Renewal)

Location: St. Louis

St. Louis City, Missouri

Geographic Coordinates: $38^{\circ}39'N$

$90^{\circ}12'W$

The oblique photograph in figure 6-231 shows an urban renewal area in "inner city" St. Louis. Buildings have been removed and future use is unknown, so the area is classified as a Transitional Area. In many urban renewal projects, deteriorating buildings are torn down and modern apartments or civic buildings constructed.



Figure 6-231.--Urban renewal in St. Louis, Mo.

Figure 6-232, a ground photograph, shows some of the buildings in an urban renewal area. These buildings will be removed, and until another land use can be identified, the area is considered Transitional.



Figure 6-232.--Buildings slated for removal in a urban renewal area, St. Louis, Mo.

Site No. 28 (Rural Transition)

Location: Piedmont

Wayne County, Missouri

Geographic Coordinates: $37^{\circ}13'N$

$90^{\circ}30'W$

Site No. 28, four and a half miles north-east of Piedmont, is a Rural Transition area. The trees were sprayed with a herbicide and bulldozed into windrows. The larger trees were used for firewood and the remaining debris either burned or left to rot. The cleared areas are then tilled, fertilized, planted in grass, and used for pasture.

Figure 6-233 illustrates various phases of the transition: forested area at A, cleared area at B, and land already in pasture at C.

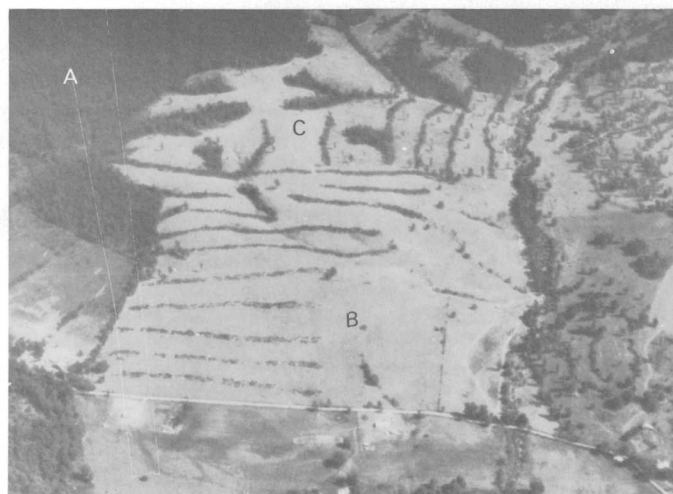


Figure 6-233.--Low-level photograph of forest clearing near Piedmont, Mo.

The ground photograph in figure 6-234 shows the pasture, the windrows, and a few scattered trees in the background.



Figure 6-234.--Ground photograph of forest clearing process.

Site No. 19 (Sanitary Landfill)
Location: Peerless Park
St. Louis County, Missouri
Geographic Coordinates: 38°32'N
90°36'W

Landfills are usually located on the periphery of urban areas in abandoned pits, in low-lying areas, or in other areas of low economic importance. The photographic signatures of landfills can be as varied as the landscape itself. A key identifier of landfills is the lack of trees. The landfills are lighter in tone than the adjacent landscape and tend to have a rough texture (because of the constant repositioning of the waste materials and overburden).

Landfills are included in category 76, Transitional. The mapping photograph, figure 6-235, shows a landfill area at A with lighter tones exhibited in the area of disturbed earth. Also shown, at B, is a drive-in theater which should be placed in land use category 12.

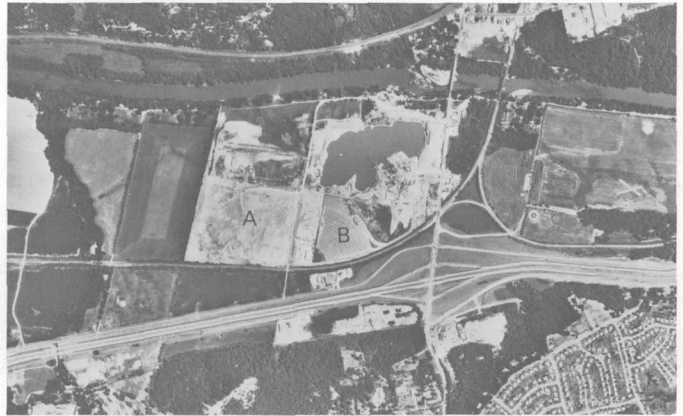


Figure 6-235.--Landfill area, St. Louis County, Mo.

Figure 6-236 shows the inverted "L-shaped" landfill area with its various gray tones and rough texture. When the area is filled to capacity, it will be leveled and developed for another land use such as commercial or residential.



Figure 6-236.--Low-altitude photograph of landfill area near Peerless Park, Mo.

SECTION 7: LAND USE AND LAND COVER TABULATIONS FOR MISSOURI

The graphic maps of land use and land cover, and associated maps, can be used to tabulate the distribution of land use and land cover categories for various regions of concern (e.g., land use by county). Manual methods of computing acreage statistics from maps (e.g., random dot grid counting) are often effective for small project areas, but cannot be used economically over large regions.

In order to meet the need for acreage statistics of large regions, computer methods are used to calculate and cross-tabulate map data. To do this, lines from the maps representing boundaries which separate adjacent polygons must be converted into a computer-readable or digital form. Specialized computer equipment, referred to collectively as digitizers, have been developed to facilitate the conversion of data from graphic to digital form.

There are many varieties of digitizers and methods of representing the map data in a computer. Very often, lines on the map are approximated by line segments defined as a series of x,y coordinates. A group of line segments, or vectors, define closed polygon areas corresponding to polygons on the maps. While polygons on the political units outline counties, polygons on the land use and land cover map outline areas with homogenous land use or cover characteristics. Associated with each polygon is an attribute code. For example, the land use and land cover attribute code "11" describes a homogeneous area of residential land use. Together, the x,y coordinates and associated attributes form a basic unit for computer processing. Once the map information is digitized, the data are processed and edited by a computer system developed by the U.S. Geological Survey. The system, the Geographic Information Retrieval and Analysis System (GIRAS), is utilized to convert and edit the digital x,y-coordinate data (Mitchell, 1977). To compare digital data between maps, the x,y-coordinate data defining the polygon boundaries are converted into uniform sized grid cells. Once gridded, the maps are registered for orientation and alignment (Guptil, 1978).

The land use and land cover maps use a square grid size of 200 meters. This size (4 hectares, approximately 10 acres) is the same as the minimum-sized polygon portrayed on the land use and land cover maps at a scale of 1:250,000.

After the data are converted from x,y coordinates to a regular matrix of grid cells,

subsequent programs merge the grid cells of the individual maps into a single computer file, then count and cross-tabulate the coincidence of attribute codes from two of the maps for each grid cell. In this manner, acreage statistics of land use by county or land use by hydrologic units (or any other associated maps) can be obtained.

The land use and land cover and associated maps for the State of Missouri have been processed through the GIRAS programs and statistical tabulations generated. A listing of the preliminary land use and land cover acreage data by county cross-tabulations follows. The county codes are standard FIPS (Federal Information Processing Standards) codes which are utilized by all Federal agencies. The five digits in these codes consists of a State code (i.e., the leftmost two digits) and a county code (odd numbers only such as 001, 003, 005, etc.). The complete list of codes in ascending order correspond to an alphabetized list of county names for the State (e.g., 29001=Adair county, 29229=Wright county).

Care should be taken in comparing figures from the land use and land cover inventories with other inventories of resources or areal statistical figures. The classification system and methods employed in land use and land cover mapping are explained in this and other documents and it is essential that users understand and critically evaluate the methodologies and data sources used in the various inventories being compared. For example, often-quoted areas of counties may or may not include internal water bodies less than 40 acres, while the land use and land cover maps provide a complete enumeration of all land and water surfaces 10 acres or larger. Estimated areas may be based on manual computations or by more accurate methods employing digitizing. Methodologically, some inventories are based on sampling methods utilizing air photos supplemented with selected field-checks. The land use and land cover maps, by comparison, are based upon precompilation field-checks and interpretation of high-altitude aerial photographs. Basically, differences in inventory results are usually attributable to definable differences for map categories and criteria used in classifying and/or mapping the land surface. Other frequently contributing factors are the dates, scales, and types of photographs used in resource inventory and the scale, methods, and specifications employed in mapping the data. A major objective of this publication has been to aid users in their understanding of the land use and land cover mapping compiled by the U.S. Geological Survey. A better

understanding of land use classification schemes and compilation methods should help users better understand land use and land cover maps and products derived from these maps, such as the areal statistics. Statistical acreage data for the counties and the State of Missouri follow.

State of Missouri Statistical Data--
Land Use By Counties

The following pages present land use acreage values by land use type for each of Missouri's 114 counties and St. Louis City. The number shown beneath each county and St. Louis City is the Bureau of the Census' geographic identification code.

Presented below are the land use codes and their respective explanations. Please note that categories for tundra and perennial ice and snow have been omitted from this list since they do not occur in Missouri. For a more complete listing of the Anderson classification system, refer to table 1-1 in this publication.

- 10 Urban or Built-up Land
- 11 Residential
- 12 Commercial and Services
- 13 Industrial
- 14 Transportation, Communications,
and Utilities
- 15 Industrial and Commercial
Complexes

10 Urban or Built-up Land--cont.

- 16 Mixed Urban or Built-up Land
- 17 Other Urban or Built-up Land
- 20 Agricultural Land
 - 21 Cropland and Pasture
 - 22 Orchards, Groves, etc.
 - 23 Confined Feeding Operations
 - 24 Other Agricultural Land
- 30 Rangeland
 - 31 Herbaceous Rangeland
 - 32 Shrub and Brush Rangeland
 - 33 Mixed Rangeland
- 40 Forest Land
 - 41 Deciduous Forest Land
 - 42 Evergreen Forest Land
 - 43 Mixed Forest Land
- 50 Water
 - 51 Streams and Canals
 - 52 Lakes
 - 53 Reservoirs
 - 54 Bays and Estuaries
- 60 Wetland
 - 61 Forested Wetland
 - 62 Nonforested Wetland
- 70 Barren Land
 - 71 Dry Salt Flats
 - 72 Beaches
 - 73 Sandy Areas Other Than Beaches
 - 74 Bare Exposed Rock
 - 75 Strip Mines, Quarries, and
Gravel Pits
 - 76 Transitional Areas
 - 77 Mixed Barren Land

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Adair 29001	Andrew 29003	Atchison 29005	Audrain 29007	Barry 29009	Barton 29011	Bates 29013	Benton 29015
10	3814	3518	2581	5506	4389	2707	6059	2769
11	2471	1275	998	3074	2768	1364	2165	2501
12	771	366	297	959	583	366	672	198
13	59	0	40	850	208	138	0	0
14	385	1087	1107	119	158	49	2165	40
15	0	0	0	0	0	0	0	0
16	0	316	109	79	504	573	830	10
17	128	474	30	425	168	217	227	20
20	24339	257236	336171	413337	263562	340155	494962	201479
21	243319	256732	335855	412744	262899	340076	494645	201262
22	0	316	0	0	386	0	40	0
23	0	10	128	148	70	49	119	0
24	20	178	188	445	207	30	158	217
30	0	0	306	801	415	0	3034	603
31	0	0	0	0	0	0	1670	0
32	0	0	306	801	415	0	1364	603
33	0	0	0	0	0	0	0	0
40	115606	18918	11614	24009	22870	27112	33388	267101
41	115606	18918	11614	24009	190083	26964	32222	256999
42	0	0	0	0	583	0	0	79
43	0	0	0	0	38104	148	1166	10023
50	731	257	1414	1136	6909	899	712	7709
51	0	148	1305	0	0	0	0	0
52	0	10	0	0	0	0	168	405
53	731	99	109	1136	6909	899	544	7304
54	0	0	0	0	0	0	0	0
60	208	0	267	0	0	0	1681	247
61	0	0	267	0	0	0	880	0
62	208	0	0	0	0	0	801	247
70	168	485	30	909	1483	10892	5328	732
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	109	485	0	850	89	10032	5308	99
76	59	0	30	59	1394	860	20	633
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Boilinger 29017	Boone 29019	Buchanan 29021	Butler 29023	Caldwell 29025	Callaway 29027	Camden 29029	Cape Girardeau 29031
10	979	14975	19363	7294	1781	6137	4516	10348
11	484	7581	11149	5258	1008	2224	2817	5446
12	129	3874	2026	1305	178	781	543	1334
13	109	178	1819	0	0	217	49	563
14	30	1938	2945	198	70	1987	198	2135
15	0	0	0	69	0	10	0	0
16	217	297	20	217	475	543	277	89
17	10	1107	1404	247	50	375	632	781
20	194393	311333	219153	282816	258806	323441	75416	286800
21	194264	311135	218866	282599	258471	323174	74645	286316
22	0	0	158	0	49	0	0	306
23	30	128	20	49	59	59	0	30
24	99	70	109	168	227	208	771	148
30	128	0	0	0	119	227	0	198
31	0	0	0	0	0	0	0	0
32	128	0	0	0	119	227	0	198
33	0	0	0	0	0	0	0	0
40	195125	104545	23979	155715	14066	202954	340432	73677
41	194600	103132	23979	137993	14066	193217	339077	73677
42	30	49	0	7907	0	1246	366	0
43	495	1364	0	9815	0	8491	989	0
50	603	3361	3391	1008	149	4092	31284	3894
51	0	2303	1908	346	0	3064	0	3400
52	10	0	0	0	20	0	0	0
53	593	1058	1483	662	129	1028	31284	494
54	0	0	0	0	0	0	0	0
60	2906	0	1236	247	0	0	0	59
61	2501	0	257	247	0	0	0	59
62	405	0	979	0	0	0	0	0
70	0	5604	257	712	276	2106	1116	563
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	5209	178	178	276	1750	69	405
76	0	395	79	534	0	356	1047	158
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Carroll 29033	Carter 29035	Cass 29037	Cedar 29039	Chariton 29041	Christian 29043	Clark 29045	Clay 29047
10	2649	771	12513	4044	2560	3054	960	30068
11	1720	435	6474	1196	1334	2036	811	19630
12	237	59	1473	287	336	494	109	1799
13	336	0	316	139	163	20	10	1670
14	0	69	2916	208	119	49	0	4211
15	0	0	59	0	0	0	0	0
16	287	208	544	163	484	158	0	1048
17	69	0	731	2046	119	297	30	1710
20	416036	21784	413455	201311	437415	192712	258235	208724
21	415611	21784	413080	201252	437257	192594	258136	208655
22	0	0	128	0	0	59	0	49
23	0	0	0	0	30	0	10	0
24	425	0	247	59	123	59	89	20
30	198	0	1680	0	346	0	0	0
31	0	0	0	0	0	0	0	0
32	198	0	1680	0	346	0	0	0
33	0	0	0	0	0	0	0	0
40	24552	303444	20411	99000	42443	163770	66343	18197
41	24552	292572	20411	97300	42443	157603	65661	18197
42	0	5229	0	356	0	593	247	0
43	0	5643	0	1344	0	5574	435	0
50	4675	70	1206	13403	6099	20	1729	3183
51	4181	0	0	0	1700	0	316	2412
52	336	0	10	0	1216	0	0	30
53	158	70	1196	13403	3183	20	1413	741
54	0	0	0	0	0	0	0	0
60	1028	0	79	59	1957	0	0	0
61	929	0	79	59	593	0	0	0
62	99	0	0	0	1364	0	0	0
70	128	0	1463	464	623	356	306	1403
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	128	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	662	158	0	119	148	227
76	0	0	801	306	623	237	158	1176
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Clinton 29049	Cole 29051	Cooper 29053	Crawford 29055	Dade 29057	Dallas 29059	Davies 29061	De Kalb 29063
10	3844	7532	4260	3530	3569	2264	3717	3173
11	2115	4616	1097	2343	1295	1127	1819	1166
12	494	1423	415	119	188	356	148	99
13	0	79	20	89	0	0	0	0
14	1166	119	2115	415	59	198	731	1443
15	0	0	0	0	0	0	0	0
16	0	771	435	495	208	455	307	287
17	69	524	178	69	1819	128	712	178
20	256060	158453	312587	111919	249369	176383	322166	258433
21	255912	158394	312034	111751	249309	176097	322027	258383
22	0	0	415	0	0	59	0	20
23	79	0	0	30	20	59	0	0
24	69	59	138	138	40	168	139	30
30	0	0	0	356	0	0	168	0
31	0	0	0	0	0	0	0	0
32	0	0	0	356	0	0	168	0
33	0	0	0	0	0	0	0	0
40	9469	83580	43649	359766	62122	168891	35158	10685
41	9469	67568	40318	351186	60313	166124	35158	10685
42	0	1285	0	1058	59	148	0	0
43	0	14727	3331	7522	1750	2619	0	0
50	425	4221	2589	583	8006	30	663	731
51	0	3855	2342	0	0	0	0	0
52	0	20	10	0	0	0	69	0
53	425	346	237	583	8006	30	594	731
54	0	0	0	0	0	0	0	0
60	138	0	0	0	79	0	40	0
61	0	0	0	0	79	0	0	0
62	138	0	0	0	0	0	40	0
70	880	989	50	514	424	99	781	129
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	267	99	40	0	365	30	346	119
76	613	890	10	514	59	69	435	10
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Dent 29065	Douglas 29067	Dunklin 29069	Franklin 29071	Gasconade 29073	Gentry 29075	Greene 29077	Grundy 29079
10	2184	1383	8571	11298	2085	1720	37125	2539
11	1344	692	5140	5911	1394	1354	22002	1522
12	109	158	1433	2125	148	168	6247	366
13	326	49	248	465	49	0	761	49
14	69	89	732	484	0	40	4942	316
15	0	0	0	0	0	0	0	0
16	198	267	563	1285	425	109	336	158
17	138	128	455	1028	69	49	2837	128
20	141304	169544	317293	280574	116535	290556	305570	251109
21	140879	169317	314900	280168	116535	290487	304344	250871
22	0	0	2234	89	0	0	109	0
23	0	10	40	40	0	0	168	30
24	425	217	119	277	0	69	949	208
30	0	0	0	178	109	1858	0	237
31	0	0	0	0	0	0	0	0
32	0	0	0	178	109	1858	0	237
33	0	0	0	0	0	0	0	0
40	334620	349141	15410	293175	213222	20342	87406	24453
41	321622	344781	15281	265855	205819	20233	81179	24453
42	2303	80	20	1117	395	0	504	0
43	10695	4280	109	26203	7008	109	5723	0
50	2699	40	3311	5189	1750	168	1245	386
51	0	0	3054	3983	1315	0	0	0
52	10	0	0	0	0	0	0	10
53	2689	40	257	1206	435	168	1245	376
54	0	0	0	0	0	0	0	0
60	0	0	1344	820	0	0	30	69
61	0	0	1255	820	0	0	0	0
62	0	0	89	0	0	0	30	69
70	1097	316	248	3529	425	208	1720	297
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	59
74	0	0	0	0	0	0	0	0
75	49	79	109	801	119	208	633	208
76	1048	237	139	2728	306	0	1087	30
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Harrison 29081	Henry 29083	Hickory 29085	Holt 29087	Howard 29089	Howell 29091	Iron 29093	Jackson 29095
10	3756	4342	4152	1957	1780	4212	1819	108222
11	1789	3272	2689	1008	1127	2462	801	62784
12	355	485	247	178	178	1009	306	14589
13	0	99	0	0	30	109	395	5110
14	1463	40	109	653	138	227	10	10161
15	0	0	0	0	0	0	0	751
16	60	248	178	49	198	257	287	1176
17	89	198	929	69	109	148	20	13651
20	417074	383903	107847	272636	239326	258995	48097	234531
21	416787	383774	107758	272497	238397	258916	48047	233553
22	30	0	0	0	613	0	0	810
23	20	40	0	20	267	0	20	0
24	237	89	89	119	49	79	30	168
30	1631	188	0	69	356	59	0	128
31	0	30	0	0	0	59	0	0
32	1631	158	0	69	356	0	0	0
33	0	0	0	0	0	0	0	128
40	40792	60363	145002	18206	57556	332090	304048	40841
41	40792	60056	133427	18206	57556	323313	298167	40841
42	0	208	1483	0	0	4636	1443	0
43	0	99	10092	0	0	4141	4438	0
50	415	3025	5852	4666	2719	425	801	5396
51	0	0	0	2204	2274	0	0	2323
52	0	633	0	2175	0	0	0	69
53	415	2392	5852	287	445	425	801	3004
54	0	0	0	0	0	0	0	0
60	0	287	0	3044	287	0	0	198
61	0	0	0	0	287	0	0	158
62	0	287	0	3044	0	0	0	40
70	1147	14480	346	385	59	286	217	3361
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	40	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	237	14391	79	237	59	138	128	949
76	870	89	267	148	0	148	89	2412
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Jasper 29097	Jefferson 29099	Johnson 29101	Knox 29103	Laclede 29105	Lafayette 29107	Lawrence 29109	Lewis 29111
10	22011	23851	8412	1375	7423	6543	7255	2116
11	12256	14945	3954	959	2916	2896	3637	1256
12	2787	2352	3459	138	890	909	741	237
13	1888	1097	20	0	79	109	80	49
14	1779	1631	702	30	3262	2155	2332	386
15	474	0	0	0	0	0	0	0
16	890	2768	99	159	128	158	297	99
17	1937	1058	178	89	148	316	168	89
20	320298	98723	484534	278072	216316	378931	329294	266963
21	320189	98466	484148	277924	215693	377319	328482	266824
22	0	0	109	0	0	1305	376	0
23	89	0	30	0	0	40	60	30
24	20	257	247	148	623	267	376	109
30	0	0	267	0	0	0	79	0
31	0	0	0	0	0	0	0	0
32	0	0	267	0	0	0	79	0
33	0	0	0	0	0	0	0	0
40	56834	294223	38242	41099	267022	13837	54234	53939
41	56834	244110	37797	41099	260281	13679	54185	53682
42	0	959	0	0	1364	99	0	0
43	0	49154	445	0	5377	59	49	257
50	880	6237	652	326	49	5180	89	2480
51	0	4557	0	0	0	3657	0	0
52	0	89	0	0	0	198	0	59
53	880	1591	652	326	49	1325	89	2421
54	0	0	0	0	0	0	0	0
60	0	218	0	0	0	197	20	0
61	0	208	0	0	0	49	20	0
62	0	0	0	0	0	148	0	0
70	7986	2649	988	267	149	761	297	1018
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	20
74	0	0	0	0	0	0	0	0
75	7393	741	870	267	30	227	277	227
76	593	1908	118	0	119	534	20	771
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Lincoln 29113	Linn 29115	Livingston 29117	McDonald 29119	Macon 29121	Madison 29123	Maries 29125	Marion 29127
10	4982	3252	3084	2392	3066	1642	1306	5575
11	2639	2116	2016	1067	1967	969	327	3687
12	1631	306	346	524	376	188	0	860
13	80	0	59	208	99	148	0	376
14	20	158	148	30	40	109	682	405
15	0	0	109	0	0	0	0	0
16	484	623	198	484	287	119	297	158
17	128	49	208	79	297	109	0	89
20	284962	369145	301636	147897	419397	80062	124719	232665
21	283341	369135	301349	147225	419367	80062	124699	232358
22	722	0	188	49	0	0	0	119
23	316	0	0	366	0	0	0	40
24	583	10	99	257	30	0	20	148
30	524	0	514	0	119	0	0	0
31	0	0	0	0	0	0	0	0
32	524	0	514	0	119	0	0	0
33	0	0	0	0	0	0	0	0
40	107856	24562	34456	195213	91113	237458	213628	42670
41	107698	24562	34456	194363	91113	233336	205829	42670
42	79	0	0	593	0	494	702	0
43	79	0	0	257	0	3628	7097	0
50	6632	455	504	89	2452	415	80	2590
51	0	0	0	0	0	0	0	0
52	731	119	267	0	0	0	0	0
53	5901	336	237	89	2452	415	80	2590
54	0	0	0	0	0	0	0	0
60	2659	830	2600	0	0	0	0	0
61	2659	0	267	0	0	0	0	0
62	0	830	2333	0	0	0	0	0
70	534	148	435	188	3568	791	0	286
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	158	0	336	20	3563	603	0	59
76	376	148	99	168	0	188	0	257
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Mercer 29129	Miller 29131	Mississippi 29133	Moniteau 29135	Monroe 29137	Montgomery 29139	Morgan 29141	New Madrid 29143
10	989	2718	3103	2134	1662	3804	1791	7611
11	791	1631	1759	1186	999	1611	1147	2639
12	49	494	445	415	267	197	297	820
13	0	0	109	79	0	138	0	771
14	40	198	543	0	10	1275	40	2857
15	0	0	0	0	0	0	0	0
16	69	217	79	306	326	465	267	326
17	40	178	168	148	60	118	40	198
20	249833	147699	248924	217394	363521	228621	162427	407151
21	249754	147472	248785	217186	363442	228196	161231	407012
22	0	0	0	0	0	59	227	0
23	0	0	20	0	20	109	99	40
24	79	227	119	208	59	257	870	99
30	336	0	0	0	306	89	89	336
31	0	0	0	0	0	0	0	0
32	336	0	0	0	306	89	89	336
33	0	0	0	0	0	0	0	0
40	38113	230766	7433	47938	61914	110743	218144	16754
41	38113	224470	7433	46011	61914	107441	216009	16744
42	0	820	0	59	0	297	138	0
43	0	5476	0	1868	0	3005	1997	10
50	524	4458	9755	1196	139	1909	8708	13048
51	0	2333	9676	1147	0	1147	0	12474
52	0	0	0	0	0	30	0	534
53	524	2125	79	49	139	732	8708	40
54	0	0	0	0	0	0	0	0
60	0	0	4903	0	0	30	0	0
61	0	0	4903	0	0	30	0	0
62	0	0	0	0	0	0	0	0
70	415	69	810	50	228	633	336	1404
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	69	0	751	0	0	0	0	1315
74	0	0	0	0	0	0	0	0
75	237	59	0	20	119	406	20	20
76	109	10	59	30	109	227	316	69
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Newton 29145	Nodaway 29147	Oregon 29149	Osage 29151	Ozark 29153	Pemiscot 29155	Perry 29157	Pettis 29159
10	9578	3459	1167	1246	1315	7454	4141	5891
11	5871	2283	820	573	534	2718	2006	4003
12	1404	890	267	109	178	890	257	870
13	603	0	0	20	20	198	89	148
14	830	59	30	0	79	3104	1542	208
15	20	0	0	0	0	0	0	0
16	386	128	10	544	455	267	168	227
17	464	99	40	0	49	277	79	435
20	284152	544975	162487	144666	148174	301014	207944	400171
21	282678	544609	162457	144626	148075	300895	207667	399865
22	198	0	0	0	0	10	40	69
23	158	158	0	0	20	0	59	10
24	1018	208	30	40	79	109	178	227
30	0	870	0	40	0	0	148	138
31	0	0	0	0	0	0	0	0
32	0	870	0	40	0	0	148	138
33	0	0	0	0	0	0	0	0
40	106157	10349	342478	242044	327483	4438	90232	31995
41	106127	10349	324538	219854	273199	2876	85023	23969
42	30	0	4161	2283	12266	0	0	0
43	0	0	13779	19907	42018	1562	5209	8026
50	79	406	69	2917	5199	13976	4458	445
51	0	0	0	2857	30	13660	3766	0
52	0	40	0	0	0	0	109	10
53	79	366	69	60	5169	316	583	435
54	0	0	0	0	0	0	0	0
60	0	139	0	0	277	188	386	0
61	0	119	0	0	0	188	99	0
62	0	20	0	0	277	0	287	0
70	1819	287	59	69	1898	1196	1077	257
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	1196	385	0
74	0	0	0	0	0	0	0	0
75	643	287	59	0	40	0	49	257
76	1176	0	0	69	1858	0	643	0
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Phelps 29161	Pike 29163	Platte 29165	Polk 29167	Pulaski 29169	Putnam 29171	Ralis 29173	Randolph 29175
10	7068	3567	12770	3776	20046	1057	2284	4832
11	3074	2194	7136	2580	5427	890	890	2777
12	771	613	563	712	11100	59	277	939
13	148	257	297	20	0	49	524	89
14	2066	148	4161	128	2679	0	79	346
15	0	0	0	0	0	0	0	158
16	495	217	356	69	316	10	297	306
17	514	138	257	267	524	49	217	217
20	142461	320672	220625	284912	85162	246334	239790	235255
21	142372	310101	220358	284467	84945	246304	239494	235195
22	0	731	188	0	0	0	148	0
23	20	356	30	20	0	0	89	20
24	69	484	49	425	217	30	59	40
30	0	89	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	89	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
40	278972	106651	32361	120380	247332	83077	65454	64386
41	273407	106651	32361	110772	242291	83077	64564	64386
42	2718	0	0	534	534	0	79	0
43	2847	0	0	9074	4507	0	811	0
50	593	5199	2975	2471	168	1097	1275	3331
51	267	0	1730	0	0	0	0	0
52	0	198	128	0	0	0	0	0
53	326	5001	1117	2471	168	1097	1275	3331
54	0	0	0	0	0	0	0	0
60	0	722	455	0	0	0	0	0
61	0	633	257	0	0	0	0	0
62	0	89	198	0	0	0	0	0
70	790	811	1848	247	840	1641	1087	4043
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	178	811	751	158	89	1028	1087	4043
76	612	0	1097	89	751	613	0	0
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Ray 29177	Reynolds 20179	Ripley 20181	St. Charles 20183	St. Clair 29185	St. Francois 29187	St. Louis 29189	St. Genevieve 29193
10	4557	989	1721	19937	1938	7372	158572	3320
11	3005	306	1315	10151	1473	5268	101530	1097
12	306	30	267	4596	227	820	20243	267
13	40	99	0	554	20	247	6563	188
14	217	109	20	2204	109	237	7542	1571
15	0	0	0	0	0	0	2184	0
16	445	445	20	1127	89	454	3875	148
17	544	0	99	1305	20	346	16635	49
20	303307	48887	109557	244417	254814	117750	76870	126182
21	302457	48828	109557	244071	254745	117602	76840	126043
22	0	0	20	0	0	0	0	0
23	0	0	0	0	10	10	0	30
24	850	59	10	346	59	138	30	109
30	247	0	277	0	158	79	0	0
31	0	0	277	0	0	0	0	0
32	247	0	0	0	158	79	0	0
33	0	0	0	0	0	0	0	0
40	54225	468215	291950	80567	186742	157387	83275	189273
41	54176	456838	279120	79825	185319	150438	81110	164632
42	49	1661	4992	188	267	2412	0	1285
43	0	9716	7838	554	1156	4537	2165	23356
50	1957	2225	109	20667	316	1493	7888	5200
51	978	0	0	9014	0	0	6761	4270
52	544	0	0	850	99	30	109	69
53	435	2224	109	10803	217	1463	1018	861
54	0	0	0	0	0	0	0	0
60	741	0	0	12791	1631	0	2738	870
61	642	0	0	8916	1295	0	2530	870
62	99	0	0	3875	336	0	208	0
70	1136	722	0	1315	2304	7285	5861	1177
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	20	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	415	79	0	366	2304	2313	2194	386
76	721	623	0	949	0	4972	3667	791
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Saline 20195	Schuyler 29197	Scotland 29199	Scott 29201	Shannon 29203	Shelby 20295	Stoddard 29207	Stone 20209
10	6207	970	1305	8787	1068	1770	4922	4102
11	2758	890	880	4498	761	1098	3114	2857
12	415	40	227	1196	99	326	800	484
13	79	0	0	326	30	30	109	20
14	2184	0	59	2303	0	0	415	79
15	0	0	0	0	0	0	0	0
16	741	20	99	89	119	227	187	474
17	30	20	40	375	59	89	297	188
20	450403	163514	248035	246393	75506	280869	486292	117286
21	449662	163504	247837	246186	75298	280810	485610	117266
22	178	0	0	49	0	0	99	0
23	49	0	0	30	0	0	168	0
24	514	10	198	128	208	59	415	20
30	198	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	198	0	0	0	0	0	0	49
33	0	0	0	0	0	0	0	0
40	25492	32885	30700	14470	563429	37293	28220	174081
41	23900	32885	30700	14470	534241	37293	27162	143143
42	30	0	0	0	682	0	544	722
43	1562	0	0	0	28506	0	514	30216
50	5317	89	188	2501	109	534	1373	28862
51	4754	0	0	2244	0	0	158	0
52	99	0	0	119	0	0	89	0
53	464	89	188	138	109	534	1126	28862
54	0	0	0	0	0	0	0	0
60	484	0	0	347	128	0	9558	0
61	257	0	0	139	128	0	8362	0
62	227	0	0	208	0	0	1196	0
70	277	49	89	267	367	128	633	2412
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	20	0	0	0
74	0	0	0	0	0	0	0	0
75	277	0	89	257	60	128	445	40
76	0	49	0	10	287	0	188	2372
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Sullivan 29211	Taney 29213	Texas 29215	Vernon 29217	Warren 29219	Washington 29221	Wayne 29223	Webster 29225
10	1156	4499	3104	5476	3094	1818	2452	4714
11	840	2748	1601	1789	1008	1018	1394	1838
12	49	633	504	1117	178	69	119	573
13	0	40	228	346	109	168	99	59
14	30	208	168	732	1147	69	99	2036
15	0	0	0	0	79	0	0	40
16	217	534	425	1334	524	494	306	0
17	20	336	178	158	49	0	435	168
20	348042	75505	276828	437228	122465	79361	94967	218036
21	347963	75505	276531	437139	122386	79301	94947	217650
22	0	0	0	0	0	0	0	178
23	0	0	20	0	0	20	0	99
24	79	0	277	89	79	40	20	109
30	376	198	158	237	0	0	0	0
31	0	0	0	237	0	0	0	0
32	376	198	158	0	0	0	0	0
33	0	0	0	0	0	0	0	0
40	64435	320585	471733	83383	151159	394320	383023	156200
41	64435	176364	427956	83343	142520	311036	363433	147393
42	0	16922	1967	0	524	6513	5683	376
43	0	127299	41810	40	8115	76771	13907	8431
50	316	11901	109	978	3083	2422	9430	49
51	0	0	0	0	2352	0	0	0
52	0	0	0	197	0	20	1374	0
53	316	11901	109	781	731	2402	8056	49
54	0	0	0	0	0	0	0	0
60	0	0	0	2432	316	0	4902	0
61	0	0	0	356	316	0	4872	0
62	0	0	0	2076	0	0	30	0
70	257	3222	266	3380	721	10003	790	554
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	89	138	79	3380	138	9963	217	89
76	168	3084	187	0	583	40	573	465
77	0	0	0	0	0	0	0	0

State of Missouri Statistical Data--Land Use By Counties in Acres

LUCODE	Worth 29227	Wright 29229	St. Louis City 29510
10	652	2659	38756
11	455	1720	8629
12	128	494	10724
13	0	30	3746
14	0	99	2402
15	0	0	0
16	59	237	9242
17	10	79	4013
20	160331	203011	257
21	160272	202606	257
22	0	69	0
23	0	217	0
24	59	119	0
30	672	0	0
31	0	0	0
32	672	0	0
33	0	0	0
40	9667	230588	0
41	9667	217541	0
42	0	840	0
43	0	12207	0
50	109	69	2955
51	0	0	2886
52	0	0	0
53	109	69	69
54	0	0	0
60	0	0	0
61	0	0	0
62	0	0	0
70	148	119	415
71	0	0	0
72	0	0	0
73	0	0	0
74	0	0	0
75	148	99	306
76	0	20	109
77	0	0	0

Total Area, in Acres, by Land Use
For Missouri

Land Use Code	Area (Acres)
11	494275
12	134077
13	35748
14	106232
15	3953
16	51690
17	70079
21	27990118
22	11001
23	4634
24	20573
31	2273
32	17584
33	128
41	14143510
42	105290
43	771635
51	133151
52	11312
53	232559
54	0
61	46585
62	20277
71	0
72	0
73	4003
74	0
75	95177
76	54087
77	0
Level I Totals	
10	896054
20	28026326
30	19985
40	15020435
50	377022
60	66862
70	153267
Nonresidential	280010
Agriculture	28001119
Forest Land	15067020
TOTAL	44559951

Selected References

- American Society of Photogrammetry, 1960, Manual of photographic interpretation: Menasha, Wis., George Banta Company, 868 p.
- Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.
- Anderson, J. R., Hardy, E. E., and Roach, J. T., 1971, A land-use classification system for use with remote-sensor data: U.S. Geological Survey Circular 671, 16 p., refs.
- Avery, T. E., 1977, Interpretation of aerial photographs (3rd ed.): Minneapolis, Burgess Publishing Company, 392 p.
- _____, 1978, Forester's guide to aerial photo-interpretation, revised, U.S. Department of Agriculture Handbook 308: U.S. Department of Agriculture, Forest Service, 41 p.
- Coleman, A., and Maggs, K. R. A., 1968, "An explanation of the second land use survey of Britain on the scale of 1:25,000," Land use survey handbook: London.
- Cook, E. A., 1980, Development and application of a geographic information system (GIS) for Missouri conservation lands: a preliminary investigation: Missouri Department of Conservation, 35 p.
- Fenneman, N. M., 1928, Physiographic divisions of the United States: Annals Assoc. Amer. Geographers, v. 18, p. 261-353, with map.
- Florida Department of Administration, 1976, The Florida land use and land cover classification system: a technical report: Tallahassee, Fla., Department of Administration, Division of State Planning, 50 p.
- General Electric Space Division, no date, Earth resources technology satellite reference manual: Philadelphia, General Electric Space Division, 201 p.
- Guptill, S. C., 1978, The impact of computer graphics, data manipulation software, and computing equipment on spatial data structures, in Dutton, G., ed., First International Advanced Study Symposium on Topological Data Structures for Geographic Information Systems: Cambridge, Mass., Harvard Papers on Geographic Information Systems, v. 2, p. 71-80.
- Hammond, E. H., 1964, Classes of land surface form in the forty-eight States, U.S.A.: Annals Assoc. Amer. Geographers, v. 54, No. 1, map supp. No. 4, 1:500,000.
- James, T. H., 1977, The theory of the photographic process (4th ed.): New York, MacMillan, 714 p.
- Kuchler, A. W., 1964, Potential natural vegetation of the conterminous United States: Amer. Geog. Soc., Special Publication No. 36, 116 p.
- Lintz, J. L., Jr., and Simonett, D. S., eds., 1976, Remote sensing of environment: Reading, Mass., Addison-Wesley Publishing Company, 694 p.
- Lobeck, A. K., 1932, Physiographic diagram of the United States (rev.): Madison, Wis. Geog. Press, small-scale ed., 8 folio pages, 1:34,000,000.
- Loelkes, G. L., Jr., 1977, Specifications for land use and land cover and associated maps: U.S. Geological Survey Open-File Report No. 77-555, 115 p.
- Mitchell, W. B., Guptill, S. C., Anderson, K. E., Fegeas, R. G., and Pallam, C. A., 1977, GIRAS: A geographic information retrieval and analysis system for handling land use and land cover data: U.S. Geological Survey Professional Paper 1059, 16 p.

- National Aeronautics and Space Administration, 1974, Skylab earth resources data catalog, JSC 09016: Wash., D.C., U.S. Government Printing Office (Stock No. 3300-00586), 359 p.
- National Research Council, 1970, Remote sensing with special reference to agriculture and forestry: Wash., D.C., National Academy of Sciences, 424 p.
- Reeves, R. G., ed., 1975, Manual of remote sensing, 2 volumes: Falls Church, Va., American Society of Photogrammetry, 2144 p.
- Richason, B. J., Jr., ed., 1978, Introduction to remote sensing of the environment: Dubuque, Iowa, Kendall/Hunt Publishing Company, 496 p.
- Robinson, A., Sale, R., and Morrison, J., 1978, Elements of cartography (4th ed.): New York, John Wiley and Sons, 448 p.
- Rudd, R. D., 1974, Remote sensing: a better view: North Scituate, Mass., Duxbury Press, 135 p.
- Sabins, F. F., Jr., 1978, Remote sensing principles and interpretation: San Francisco, W. H. Freeman and Company, 426 p.
- Scherz, J. P., and Stevens, A. R., 1970, An introduction to remote sensing for environmental monitoring: Madison, Wis., Remote Sensing Program, University of Wisconsin, 80 p.
- Slama, C. C., 1980, Manual of photogrammetry (4th ed.): Falls Church, Va., American Society of Photogrammetry, 1056 p.
- Sosinski, T., 1980, Kansas City, Kans., land use test and demonstration project. Kansas City, Kans., Water Pollution Control Department, 53 p.
- Swanson, R. A., 1972, Land use and natural resource classification manual, land use and natural resources inventory of New York State: Albany, New York State Office of Planning Coordination, 33 p.
- Texas Office of the Governor, 1972, Housing report: results of comprehensive survey of Texas housing conditions and occupant attitudes: Austin, Office of the Governor of Texas and Texas Department of Community Affairs, 79 p.
- Thomas, W., Jr., ed., 1973, S.P.S.E. handbook of photographic science and engineering: New York, John Wiley and Sons, 1416 p.
- U.S. Bureau of the Census, 1970a, Areas of the United States: U.S. Department of Commerce, Bureau of the Census, Area Measurement Report Nos. 1-52.
- 1970b, Census tracts--1970 census of population and housing: U.S. Department of Commerce, Bureau of the Census Final Report Nos. PHC(1)-1-241.
- 1972a, County and City data book: U.S. Department of Commerce, Bureau of the Census, 1020 p.
- 1972b, Geographic identification code scheme: U.S. Department of Commerce, Bureau of the Census Final Report Nos. PHC(R)-1-4.
- U.S. Executive Office of the President, Office of Management and Budget, 1972, Standard industrial classification manual: 1972: Wash., D.C., 649 p.
- U.S. Geological Survey, 1982, Boundary descriptions and names of regions, subregions, accounting units, and cataloging units: unpublished data on file, Reston, Va., Water Resources Division.
- U.S. Urban Renewal Administration, Housing and Home Finance Agency, and Bureau of Public Roads, 1965, Standard land use coding manual, a standard system for identifying and coding land use activities: Wash., D.C., 111 p.
- Wolf, P. R., 1974, Elements of photogrammetry: New York, McGraw-Hill, 562 p.

APPENDIXES

APPENDIX A
SITES IN NUMERICAL ORDER

<u>SITE</u>	<u>LAND USE CATEGORY</u>	<u>PAGE</u>
Site No. 1 (Single-Family Homes)	11	31
Location: Manchester		
St. Louis County, Missouri		
Geographic Coordinates: 38°36'N, 90°31'W		
Site No. 2 (Inner-City Residential)	11	32
Location: St. Louis		
St. Louis City, Missouri		
Geographic Coordinates: 38°36'N, 90°14'W		
Site No. 3 (High-Rise Residential)	11	33
Location: St. Louis		
St. Louis City, Missouri		
Geographic Coordinates: 38°31'N, 90°13'W		
Site No. 4 (Shopping Center)	12	38
Location: Mehlville		
St. Louis County, Missouri		
Geographic Coordinates: 38°31'N, 90°20'W		
Site No. 5 (Hospital)	12	49
Location: St. Louis		
St. Louis City, Missouri		
Geographic coordinates: 38°38'N, 90°16'W		
Site No. 6 (Intermediate School)	12	51
Location: Webster Groves		
St. Louis County, Missouri		
Geographic Coordinates: 38°34'N, 91°22'W		
Site No. 7 (Sports Stadium)	12	47
Location: St. Louis		
St. Louis City, Missouri		
Geographic Coordinates: 38°38'N, 90°12'W		
Site No. 8 (Rolling Mills - Steel)	13	55
Location: St. Louis		
St. Louis City, Missouri		
Geographic Coordinates: 38°37'N, 90°18'W		
Site No. 9 (Barge Building)	13	56
Location: St. Louis		
St. Louis City, Missouri		
Geographic Coordinates: 38°32'N, 90°15'W		
Site No. 10 (Highway Intersection)	14	69
Location: St. Louis		
St. Louis City, Missouri		
Geographic Coordinates: 38°38'N, 90°17'W		

Site No. 11	(Truck Terminal)	14	69
Location:	St. Louis		
	St. Louis City, Missouri		
Geographic Coordinates:	38°31'N, 90°12'W		
Site No. 12	(Railroad Yards)	14	70
Location:	St. Louis		
	St. Louis City, Missouri		
Geographic Coordinates:	38°35'N, 90°12'W		
Site No. 13	(Sewage Treatment Plant)	14	74
Location:	Lemay		
	St. Louis County, Missouri		
Geographic Coordinates:	38°32'N, 90°17'W		
Site No. 14	(Municipal Water Treatment Plant)	14	72
Location:	St. Louis		
	St. Louis City, Missouri		
Geographic Coordinates:	38°45'N, 90°11'W		
Site No. 15	(Industrial and Commercial)	15	75
Location:	Robertson		
	St. Louis County, Missouri		
Geographic Coordinates:	38°46'N, 90°23'W		
Site No. 16	(Mixed Urban or Built-up Land)	16	76
Location:	St. Louis		
	St. Louis City, Missouri		
Geographic Coordinates:	38°38'N, 90°15'W		
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	St. Louis City, Missouri		
Geographic Coordinates:	38°38'N, 90°17'W		
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	St. Louis County, Missouri		
Geographic Coordinates:	38°30'N, 90°17'W		
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	St. Louis County, Missouri		
Geographic Coordinates:	38°32'N, 90°36'W		
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Location:	St. Louis		
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Geographic Coordinates:	38°39'N, 90°12'W		
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Location:	Cape Girardeau		
	Cape Girardeau County, Missouri		
Geographic Coordinates:	37°16'N, 89°32'W		

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Location:	Cape Girardeau		
	Cape Girardeau County, Missouri		
Geographic Coordinates:	37°16'N, 89°34'W		
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Location:	Kelso		
	Scott County, Missouri		
Geographic Coordinates:	37°11'N, 89°33'W		
Site No. 24	(Sand Bar)	73	104
Location:	10 miles northeast of Hayti		
	Pemiscot County, Missouri		
Geographic Coordinates:	36°20'N, 89°36'W		
Site No. 25	(Plantation Pine)	42	94
Location:	New Madrid		
	New Madrid County, Missouri		
Geographic Coordinates:	36°32'N, 89°26'W		
Site No. 26	(Canals)	51	97
Location:	Kennett		
	Dunklin County, Missouri		
Geographic Coordinates:	36°10'N, 90°01'W		
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Location:	Piedmont		
	Wayne County, Missouri		
Geographic Coordinates:	37°13'N, 90°30'W		
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Location:	Bloomfield		
	Stoddard County, Missouri		
Geographic Coordinates:	36°53'N, 89°55'W		
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Location:	Dexter		
	Stoddard County, Missouri		
Geographic Coordinates:	36°49'N, 89°58'W		
Site No. 31	(Swamp)	61	101
Location:	Puxico		
	Stoddard County, Missouri		
Geographic Coordinates:	37°01'N, 90°10'W		
Site No. 31	(Marsh)	62	102
Location:	Puxico		
	Stoddard County, Missouri		
Geographic Coordinates:	36°59'N, 90°10'W		
Site No. 32	(Swamp and Marsh)	61	102
Location:	Wappapello		
	Wayne County, Missouri		
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 Location: Piedmont
 Wayne County, Missouri
 Geographic Coordinates: 37°08'N, 90°46'W

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 Location: Bunker
 Reynolds County, Missouri
 Geographic Coordinates: 37°32'N, 91°09'W

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 Location: Buick
 Reynolds County, Missouri
 Geographic Coordinates: 37°34'N, 91°08'W

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 Location: St. James
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	Pulaski County, Missouri			
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	Pulaski County, Missouri			
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	Pulaski County, Missouri			
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Location:	Fort Leonard Wood			
	Pulaski County, Missouri			
Geographic Coordinates:	37°46'N, 92°08'W			
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	Laclede County, Missouri			
Geographic Coordinates:	37°41'N, 92°40'W			
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Location:	Lebanon			
	Laclede County, Missouri			
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Location:	Springfield			
	Greene County, Missouri			
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	Greene County, Missouri			
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	Greene County, Missouri			
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	Greene County, Missouri			
Geographic Coordinates:	37°11'N, 93°16'W			
Site No.	56	(Federal Hospital)	12	50
Location:	Springfield			
	Greene County, Missouri			
Geographic Coordinates:	37°10'N, 93°19'W			

Site No.	57	(Hospital)	12	49
Location:	Springfield			
	Greene County, Missouri			
Geographic Coordinates:	37°11'N, 93°17'W			
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Location:	Springfield			
	Greene County, Missouri			
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	Greene County, Missouri			
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	Greene County, Missouri			
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	Taney County, Missouri			
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Location:		Jefferson City				
		Cole County, Missouri				
Geographic Coordinates:		38°35'N, 92°11'W				
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Location:		Reform				
		Callaway County, Missouri				
Geographic Coordinates:		38°45'N, 91°45'W				
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		Boone County, Missouri				
Geographic Coordinates:		39°58'N, 92°26'W				
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		Howard County, Missouri				
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Location:		Windsor				
		Henry County, Missouri				
Geographic Coordinates:		38°34'N, 93°35'W				
Site No.	75	(Not Used)				
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Location:		Kansas City				
		Jackson County, Missouri				
Geographic Coordinates:		39°06'N, 94°32'W				
Site No.	77	(Warehouse)		12		45
Location:		Kansas City				
		Jackson County, Missouri				
Geographic Coordinates:		39°07'N, 94°34'W				
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Location:		Kansas City				
		Jackson County, Missouri				
Geographic Coordinates:		39°03'N, 94°29'W				
Site No.	79	(Central Business District)		12		39
Location:		Kansas City				
		Jackson County, Missouri				
Geographic Coordinates:		39°06'N, 94°35'W				
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Location:		Kansas City				
		Jackson County, Missouri				
Geographic Coordinates:		39°06'N, 94°37'W				

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Location:	Mound City		
	Holt County, Missouri		
Geographic Coordinates:	40°04'N, 95°15'W		
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Location:	Fortescue		
	Holt County, Missouri		
Geographic Coordinates:	40°05'N, 95°21'W		
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Location:	New Hampton		
	Harrison County, Missouri		
Geographic Coordinates:	40°16'N, 94°10'W		
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Location:	Potosi		
	Washington County, Missouri		
Geographic Coordinates:	37°55'N, 90°51'W		
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	Nodaway County, Missouri		
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Location:	Spickard		
	Grundy County, Missouri		
Geographic Coordinates:	40°15'N, 93°13'W		
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Site No. 89	(Recreational Homes)	11	36
Location:	Trenton		
	Grundy County, Missouri		
Geographic Coordinates:	40°06'N, 93°44'W		
Site No. 90	(Coal Processing Plant)	13	67
Location:	Hartford		
	Putnam County, Missouri		
Geographic Coordinates:	40°29'N, 92°52'W		
Site No. 91	(Sewage Treatment Plant)	14	74
Location:	Kirksville		
	Adair County, Missouri		
Geographic Coordinates:	40°09'N, 92°34'W		
Site No. 92	(Cemetery)	17	79
Location:	Kirksville		
	Adair County, Missouri		
Geographic Coordinates:	40°10'N, 92°34'W		
Site No. 93	(Cropland)	21	80
Location:	Plymouth		
	Livingston County, Missouri		
Geographic Coordinates:	39°37'N, 93°43'W		

Site No. 94 (Deciduous Trees) 41 93
 Location: Kirksville
 Adair County, Missouri
 Geographic Coordinates: 40°11'N, 92°38'W

Site No. 95 (Turkey Farm) 23 86
 Location: Winigan
 Sullivan County, Missouri
 Geographic Coordinates: 40°02'N, 92°56'W

Site No. 96 (Thomas Hill Power Plant -
 Thermal) 13 64
 Location: Thomas Hill Reservoir
 Randolph County, Missouri
 Geographic Coordinates: 39°33'N, 92°38'W

Site No. 97 (Coal Strip Mine) 75 105
 Location: Thomas Hill Reservoir
 Randolph County, Missouri
 Geographic Coordinates: 39°32'N, 92°38'W

Site No. 98 (Not Used)

Site No. 99 (Farmstead) 24 88
 Location: Maitland
 Holt County, Missouri
 Geographic Coordinates: 40°07'N, 95°04'W

Site No. 100 (Chemical Plant) 13 67
 Location: Louisiana
 Pike County, Missouri
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Site No. 101 (Not Used)

Site No. 102 (Forb Prairie) 31 89
 Location: Kingdom City
 Callaway County, Missouri
 Geographic Coordinates: 39°57'N, 92°00'W

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	13	37	61
Bunker	13	35	59
Cape Girardeau	13	21	57
	75	22	106
Chamois	21	68	81
Columbia	12	72	46
Dexter	75	30	107
Edgehill	43	39	95
Ft. Leonard Wood	12	48	52
	17	47	77
Fortescue	52	83	98
Hartford	13	90	67
Hayti	73	24	104
Ironton	12	40	41
Jefferson City	12	69	43
	51	70	96
Jerome	21	44	80
Kansas City	12	76	44
	12	77	45
	12	78	47
	12	79	39
	13	81	66
Kelso	22	23	82
Kennett	51	26	97
Kingdom City	31	102	89
Kirksville	14	91	74
	17	92	79
	41	94	93
Lebanon	12	49	40
	13	50	62
Lemay	14	13	74
Louisiana	13	100	67
Maitland	24	99	88
Manchester	11	1	31
Mehlville	11	4	38
	17	18	78
Montreal	24	38	87
Mound City	62	82	103
New Franklin	22	73	83

<u>City</u>	<u>Land Use Category</u>	<u>Site No.</u>	<u>Page</u>
New Hampton	32	84	90
New Madrid	42	25	94
Peerless Park	76	19	109
Piedmont	53	33	99
	76	28	108
Plymouth	21	93	80
Potosi	13	85	62
Puxico	61	31	101
	62	31	102
Ravenwood	23	86	85
Reform	13	71	64
Robertson	15	15	75
St. James	22	43	83
St. Louis City	11	2	32
	11	3	33
	12	5	49
	12	7	47
	13	8	55
	13	9	56
	14	10	69
	14	11	69
	14	12	70
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	17	17	77
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	12	57	49
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	13	60	64
	14	61	71
	14	62	72
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	75	97	105
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Vichy	14	42	71
Wappapello	61	32	102
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Windsor	41	74	92
Winigan	23	95	86

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AIR PHOTO ANALYSIS,
PHOTO INTERPRETATION LOGIC,
AND FEATURE EXTRACTION

J.N. Rinker
P.A. Corl

JUNE 1984

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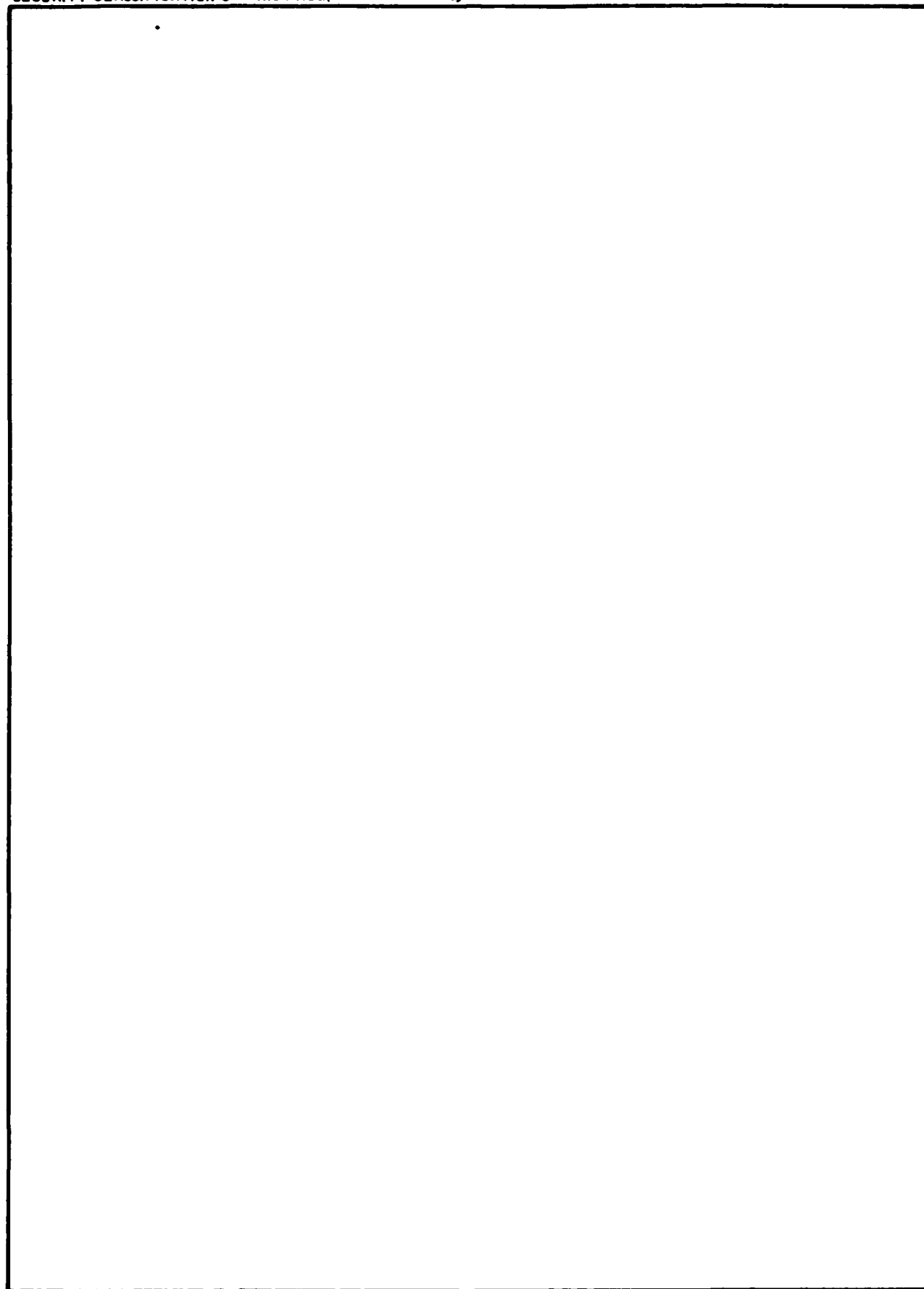
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This is a status report about some of the research efforts within the Center for Remote Sensing (CRS) that are associated with image analysis. Emphasis has been placed on the manual procedure of photo analysis, photo interpretation logic, classification schemes, and knowledge based systems. Information derived from other sources and information presented by contributors are acknowledged in the appropriate sections.		

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PREFACE

This study was conducted under DA Projects 4A161102B52C, Task C, Work Unit 0008, "Photo Interpretation Logic," and 4A762707A855, Task C, Work Unit 0034, "Photo Interpretation Logic and Feature Extraction." The study was done under the supervision of Dr. Jack N. Rinker, Team Leader, Center for Remote Sensing, and Dr. Robert D. Leighty, Director, Research Institute.

Special thanks are extended to Ms. Barbara Jayne, Liaison Office, for preparing several of the illustrations in Appendixes A and I of this report.

COL Edward K. Wintz, CE, was Commander and Director and Mr. Walter E. Boge was Technical Director of the Engineer Topographic Laboratories during the report preparation.



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AIR PHOTO ANALYSIS

Jack N. Rinker

INTRODUCTION

The more commonly used image forms are photography, radar, LANDSAT, infrared thermal, and passive microwave. With the exception of LANDSAT, these systems are used in both aircraft and satellites for obtaining general and specific information about the atmosphere, the terrain, and the oceans, as well as for detecting special features and targets. From the standpoint of gathering information about the terrain in terms of identities, composition, and properties, the most frequently used instruments are stereo aerial photography, radar, and LANDSAT. Information can be extracted from these images in three general ways: (1) manual; (2) interactive, which includes using knowledge-based systems and supervised digital classification procedures, such as used with LANDSAT; and (3) automatic, which includes pattern recognition and unsupervised digital classification techniques. Obviously, there can be mixes of these three.

In this report, the term **manual** denotes the minimum of mechanical assistance, i.e. the analysis depends on the images, eyes, mind, hand lens, and pocket stereoscope. The terms **machine** or **machine assisted** will be used to designate those procedures commonly referred to as automatic pattern recognition, digital analysis, and man/computer interactive analysis. The automatic procedures are restricted to a few very obvious types of feature discrimination, and at present, these procedures are of little practical use and are not likely to be significantly improved in the foreseeable future. On the other hand, interactive techniques are constantly being developed and have far less restrictions than do the automatic procedures. Also, interactive techniques based upon digital classification of spectral data will probably improve significantly in the future as satellites with more and narrower spectral band passes are launched.

At present, however, the manual analysis of stereo aerial photography represents the state of the art insofar as obtaining reliable and detailed information about any given region of the earth in terms of its composition, properties, use, and probable response to stress, i.e. items that are of direct and practical use to engineering and military applications. Whatever use of the terrain is envisioned in terms of building on it, tunneling through it, extracting from it, moving over it, or seeking cover and concealment, certain pieces of information are needed before decisions can be made. These pieces can come from several sources, including personal knowledge, field and laboratory work, maps and literature, and remote sensing, especially in the form of stereo aerial photography.

In general, image analysis and interpretation techniques tend to fall into one of two broad overlapping categories, which, at the extremes, can be defined as procedures associated with detecting, targeting, and monitoring on the one hand, and procedures associated with deductive and inductive reasoning on the other. At present, applying machine and machine-assisted procedures tends to be limited to the tasks of detecting and monitoring.

Targeting, detecting, and monitoring techniques require that the feature, whatever it is, have some characteristic that is different from its background and that, hopefully, cannot be confused with any other object in the field of view. These differences can be based on such things as shape, size, arrangement, color, spectral absorption and reflection, temperature, etc. Applications that fall into this category include: (1) detecting discrete objects such as roads, airports, dams, vehicles, specific crops, number of lakes per area, etc.; (2) detecting changes in patterns; (3) detecting and mapping flood boundaries, flood and storm damage, insect damage, diseased crops, alteration zones, and camouflage sites; and (4) estimating values such as crop yield, percent of tree cover, etc. For some of these applications, other remote sensors (radar, thermal, LANDSAT) can be of more use than air photos. As a group, however, it is these applications that have provided the basis for whatever success has been achieved by machine techniques, and of these, those that are based on distinguishing colors and color changes (spectral signatures, multiband, etc.) have had more successes with machine and machine-assisted procedures than have those that rely on identifying shape and arrangement. Because future systems will have more spectral channels and narrower bandpasses, there will be an increase in the ability to discriminate various objects and surfaces. It remains to be determined, however, if there will be a corresponding increase in the ability to identify these various objects and surfaces.

Deductive and inductive reasoning procedures produce information that is broader in scope, and more complex in content, than that derived by using targeting and detecting techniques. These procedures are directed towards gaining as much information and understanding as possible about the area in question, i.e. the nature of the materials in terms of structure, composition, and properties; the characteristics of the vegetation; the climatic factors; and man's activities. This information forms what can be called an environmental data base, which can then be interpreted with respect to such problems as resources inventory (including ground water), regional planning, site selection and evaluation, cross-country movement, and prediction of environmental impact as the result of any given action. This procedure of analysis relies upon the inductive and deductive evaluation of various lines of converging evidence derived from the visual examination of image patterns. Insofar as determining the nature of the terrain in terms of identities, composition, and conditions, the most important pattern elements are those associated with three-dimensional shapes; thus, the mainstay of this type of analysis is stereo aerial

photography, and as yet, three-dimensional shapes do not lend themselves to machine evaluation. It is a manual task and the burden of the work falls on the individual. It is a task, however, that might benefit, at least in part, from the use of interactive systems. The benefit in this case would be in using a technique that enables a less skilled and less experienced individual to proceed down paths of reasoning that a skilled and experienced analyst would follow intuitively. Although one might argue that each pattern element, i.e. landform, drainage, soil, tone, etc., can serve as a target and thus lend itself to machine applications, the fact is that most natural pattern elements cannot be held to the rigid and exact descriptions needed in automatic targeting and detecting procedures. The important pattern elements of landform, drainage, and gully cross sections are associated with shape, and these shapes are neither exact nor invariant, but undergo changes as a result of slight variations in composition or in climate. Massive beds of limestone do not have but one shape; neither do beds of sandstone, deposits of basalt, nor patterns of a given drainage type. Although the shapes of massive beds of similar limestone are not identical, neither will they be completely dissimilar, i.e. they will have at least some characteristics in common. It is more a matter of theme and variations. The fact that they are not exact replicas indicates that there are slight differences in composition, conditions, or climate. A skilled and experienced analyst recognizes the similarities and differences and, on the basis of judgment and inference, makes a prediction as to what group of shapes this particular pattern belongs to and what material or conditions it most likely represents.

The photo analysis procedure used by the Center for Remote Sensing (CRS), and on which it concentrates its research, is based on the published and unpublished notes of Robert E. Frost* and other staff members of the School of Civil Engineering of Purdue University during the late 1940's and early 1950's.^{1,2} At that time, the procedure was directed towards the photo interpretation of soils and rocks for engineering purposes, and still retains much of that perspective. Over the years CRS and its predecessor organizational units have tested, evaluated, augmented, and modified the procedure by field research and application projects in many areas of the world. The application tasks included engineering and geologic problems ranging from locating engineering materials through site selection for roads, airports, etc., to large Department of Defense (DOD) applications such as the layout of Thule Air Base, Greenland, (done by Robert E. Frost and some of his staff while at Purdue University) or the environmental data base prepared over much of Wisconsin for the Navy Project Sanguine. Included in these

*Mr. Frost currently works for the U.S. Army Engineer Topographic Laboratories (ETL).

¹R.E. Frost. 1950. *Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photographs*. Prepared by the Purdue University Engineering Experiment Station for the St. Paul District, Corps of Engineers, Department of the Army.

²R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes*. School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

DOD applications were smaller projects associated with insurgency, tunnels and caves, defoliation, etc. In addition, this photo analysis procedure has formed the basis for a series of intensive short courses that have been presented within the U.S. and Latin America.

This method of photo analysis relies on associating numerous threads of converging evidence and requires an understanding of the origin and relation of landscape features, as well as the relation of these features to their aerial formed images. In practice, the procedure is divided into two phases, the regional analysis and the local analysis.

For the regional analysis, relatively small scale imagery is used, such as LANDSAT or photo index sheets, preferably both. The purpose of the regional analysis is to establish the broad frame of environmental conditions that are contained within, as well as around, the area of interest. In this part of the analysis, general decisions are made as to boundaries separating economic pursuits, vegetation classes, landform units, and soil characteristics.

For the local analysis, effort is focused on the landscape pattern units via larger scale stereo imagery, which provides the detail needed to fill in the regional information and to make decisions as to types and conditions of materials. A number of photo scales are available, e.g. 1:20,000, 1:40,000, 1:60,000, and 1:120,000. In recent years, the tendency has been to take aerial photography at the smaller scales, especially 1:40,000 and 1:60,000. When available, the larger scale of 1:20,000 is usually preferable because it is a very good compromise in terms of the amount of photography needed to cover an area and the size of pattern detail that must be seen. Much of the fine structure such as gully cross section, and subtle changes in gully gradient or concavity of slopes, is not readily seen in the smaller scales, i.e. < 1:40,000. In some instances, color photography is also available, either as normal color or false color. Although it is certainly usable, color photography is not needed for a general photo analysis and does not contribute enough additional capability to justify the increased cost. For certain detection tasks, however, such as some vegetation mapping, locating diseased vegetation, or locating wetlands boundaries, it is more useful than panchromatic photography.

Reduced to the simplest of terms, the principles for this procedure, originally stated in Frost,³ can be expressed as follows:

³R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes*. School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

1. An air photo is a pictorial representation of the various features within the landscape and is composed of pattern elements that serve as indicators of materials, conditions, and events that are related to the physical, biological, cultural, and climatic components of the landscape.

2. Similar materials and conditions in similar environments produce similar patterns, and unlike materials and conditions produce unlike patterns.

3. The type, quantity, and quality of information that can be obtained by photo analysis is proportional to the background, knowledge, skill, and interest of the analyst.

The foundation of this method rests in principle 2, i.e. similar materials and conditions in similar environments produce similar patterns, and unlike materials and conditions produce unlike patterns. There are many patterns to be evaluated and most of them can be evaluated only by stereo viewing. Based upon the statement in principle 2, one can reason that if the patterns are uniform across an image, then the materials and conditions, whatever they might be, will be uniform throughout that area. If any pattern element changes, e.g. gully cross section, gradient, soil tones, hill shape, vegetation texture, etc., then either the materials or the conditions, or both, must have changed. In some cases, specific pattern elements are uniquely related to the identity of a material, or to a given condition. Also, many of the pattern elements must be evaluated in relation to climate and season as these can cause considerable modification.

The analysis of any given pattern involves at least three steps: first, identification; second, description; and third, signification. The last step is the most important and, without doubt, the most difficult, requiring more in terms of knowledge, experience, and judgment than does either of the first two steps.

Identification is the act of recognizing any given pattern and either tracing out its domain or otherwise using it during the analysis. By definition, the pattern must be different beyond that boundary; therefore, there must be a corresponding change in materials or conditions, or both, as that boundary is crossed. Depending on the pattern being considered, the boundary might enscribe a group of items of the same shape, a surface of uniform tone and texture, a drainage net of uniform spacing and arrangement, or some other identifiable property. The boundary denotes the location of a change; it does not necessarily give information about the contents within.

The next step is to describe in detail the characteristics of the subject pattern in terms of size, shape, spacing, arrangement, symmetry, etc. The description is then evaluated in terms of its significance, the last step. Each pattern element signifies, or suggests, something about the nature of the material in terms of its characteristics, its condition, or its probable composition.

Although these points about observation, deduction, identification, and significance seem obvious, if not trivial, they are important. First, they are interwoven to some extent throughout all applications of the photo analysis procedure. Second, an understanding of these issues sheds light on the very real problems associated with applying photo analysis to stated Army needs, evaluating remote sensing techniques against specific tasks, developing classification systems, and determining skill levels required. There are, of course, many patterns yet unknown as well as many patterns that are not understood. There are many different pattern elements within an air photo, and in order to apply the stated principles in an effective manner, one must follow some sort of systematic procedure to ensure that all elements are considered. The scheme that we currently use classifies the pattern elements into the following categories: landform, drainage (plan and elevation), erosion, deposition, vegetation, cultural, photo tones and texture, and special. Each of these factors provides some information as to the nature of the terrain and its materials in terms of their physical properties and probable composition, and it is this sequence of classes that forms the basis for a systematic procedure for the analysis of terrain features by use of air photos. This procedure has a number of practical advantages.

1. **Simplicity.** Although the concept of photo analysis is simple, it does not follow that skill, experience, judgment, and knowledge are not needed to implement it. As is frequently the case, the implementation of a simple procedure requires more skill, capability, and judgment than does the implementation of a complex procedure. Simple procedures rely on the individual to correlate details and render judgment; complex procedures incorporate the details and sequential steps and rely on an individual following them. Simple procedures, however, provide versatility and set the basis for universality, economy, and rapidity.

2. **Universality.** The nature of the various patterns in terms of cause and effect provides a basis for obtaining information about the terrain independent of location or, indeed, without the need of knowing the location represented by the imagery. Although auxiliary information in terms of location, physiographic area, climate, etc., can be useful, and although the location is probably always known, these items are not necessary to the task of obtaining information from the photos.

3. **Economy.** Air photo prints are among the more economical, if not the cheapest, of imagery forms available, and they are readily at hand in the commercial world as well as within the military structure. As a minimum, the needed equipment consists of a large hand lens and a pocket-type folding stereoscope.

4. **Rapidity.** As yet, no other procedure can match the quality and quantity of information that can be derived in a given time frame. An experienced team of four to five individuals can produce an environmental data base of an area some 20 by 40 miles complete with overlays, text, and interpretation with respect to a problem, and do so in 15 to 20 working hours.

Because the pattern sets of landform, drainage (plan and elevation), erosion, deposition, vegetation, cultural, tone and texture, and special are the conveyors of information about the terrain, they are the basic components of this procedure of manual analysis of aerial photography. In the following section, these groups will be discussed in summary form, but with enough information to at least define them and explain why they are important and how they are used. As information and research results accumulate, some of these sections will be expanded into individual reports.

PATTERN ELEMENTS

LANDFORM. This pattern refers to the shape, size, arrangement, and orientation of any given surface feature and its location within, and relation to, the surrounding area. It is the most important of the pattern elements because it is directly related to the nature of the resident material in terms of composition and properties. An understanding of landform development makes it possible to bound areas of similar materials and conditions, determine their physical characteristics, and at times predict their composition and texture. Such events as deposition, sedimentation, and volcanism constantly add new materials to the earth's surface. Other events, such as folding, uplifting, or lowering of the ocean levels constantly elevate these materials above the base level; whereupon other events begin immediately to reduce the mass back to its base level. The force of gravity, coupled to the energy of flowing water or wind, and to the action of freeze and thaw, or of water as a solute, does this by removing bits and pieces and carrying them to the lows. But the bits and pieces are removed in a way unique to the material and action combination. As a result, the landscape shows a variety of shapes and arrangements. Within this variety, however, there are such firm relations between cause and effect that one can frequently glean from the stereo photo patterns of landform some idea of what went on, what is going on, and what is present in terms of general composition and physical properties.

The chemical and physical properties of a substance depend on the identities of the atoms, and collection of atoms, that make up the molecules of the substance. In the case of rocks and their detrital material, these molecules are called minerals. Different minerals have different physical and chemical characteristics with relation to hardness, plasticity, porosity, permeability, solubility, and thermal expansion. As a result, different rocks and soils exposed to the same action, or the same material exposed to different actions, will develop different patterns of shape, tone, and texture. Because the forces that do the shaping vary with climate, the same material can have different landforms in different regions. Limestone, for example, can be a hard, durable, and resistant rock. It is, however, soluble in dilute carbonic acid formed from available water and carbon dioxide from various sources. In a warm region with an abundance of water, limestone can be the easiest to degrade of the resistant materials and, therefore, can be a valley former. In an arid region, without water to act as an agent of dissolution, the limestone can be the hardest and most resistant rock in the area. It can form the highs, such as hills or ridges, or serve as a protective cap over less resistant beds. In either case, other pattern elements are usually present that support the concept for the material being a sedimentary rock, and most probably limestone. Because of these firm relations, shape or landform is considered to be the most important of the pattern elements, and wherever the shape changes in any aspect, there is the basis for a corresponding change in materials or conditions, or both.

In this part of the photo analysis, areas are outlined in which the terrain elements within are uniform in shape, size, spacing, arrangement, and orientation. Wherever any aspect of landform changes, there is a basis for a boundary denoting some change in materials or conditions, or both. The area of study represented by the stereo photography might contain but one shape, a plain for example. Thus, one would expect a uniformity in composition throughout that area, i.e. the surficial soils would be essentially the same all over. On the other hand, the study area might contain three landform units, all hills. Within each bounded area the hills are the same, but each group differs from the others. Thus, the bounded areas also represent three different materials, or material/condition combinations.

Each landform unit must be described in terms of shape, size, spacing, arrangement, symmetry, slope, angularity, etc., and then evaluated with reference to the significance of these observations. Profiles should be drawn across the stereo field of view. As the analysis develops, these can be converted into possible geologic cross sections. The complexities of landform classification found in most texts and articles are beyond the needs of this type of analysis, at least for the present. However complicated, the units can be assigned into one of four general categories: plains, hills and mountains, basins and valleys, and escarpments.

Plains. This category refers to a flat surface, large or small, but not necessarily level or with any elevation restrictions. Such surfaces can be established by depositing sediments in low areas, by large lava flows, by exposure of flat-lying intrusive masses, and by grinding or eroding an irregular surface into a flatter one. In size such plains range from small stream terraces to large regions, such as the Great Plains of the United States, or extensive areas of the Precambrian Canadian Shield. Identifying a surface as flat depends on one's regional point of view and on the scale of the imagery. Many topographic variations exist that can appear hilly to a person on the ground but which, nevertheless, are properly classified as plains. This has led to descriptors for plains such as rolling, undulating, pitted, dissected, etc. At small scales, such as those associated with LANDSAT (1:250,000 to 1:1,000,000), most of the Canadian Shield would be mapped as a plain. At air photo scales of 1:20,000, much of the shield area would show as rugged terrain, and it would most likely be mapped as containing several landform units, and possibly none of them would be classified as a plain. From the standpoint of this type of photo analysis, the significance of a plain is that it suggests deposition of some sort, for that is the easiest way to establish a plain. This is usually by means of sedimentation, i.e. a settling out of material suspended in a water-filled basin or trough, either marine or fresh. Deposits such as alluvial fans have a hill-like profile across their width and are not usually considered to be plains. On a large fan, the imagery might

show only a portion of it, and that portion could be classified as a plain. In any event, the significance is a suggestion of the presence of sedimentary rocks or granular material. Although a lava flow can form a plain, other pattern elements would prevent it from being considered as a sedimentary unit or granular deposit.

Hills and Mountains. This category refers to elevations above the base level of the region in question. The distinction between hill and mountain is a blurred one that is based mostly on local usage, or personal preference. The *Glossary of Geology*⁴ gives 300 meters (1000 ft) as the elevation difference between base and summit that divides the two classes, i.e. under 300 m, it is called a hill, and over 300 m, it is called a mountain. Hills can be formed by depositing material on top of the ground; by sub-surface material pushing the surface up, or pushing up through the surface; by forcing the surface into a series of ripple-like folds; by faulting; and by cutting into, or eroding into, a previously flat surface. Each of these processes results in patterns that are suggestive of origin, and consequently of materials. A flat-lying area of sediments can be called a plain only so long. There comes a time when the forces of erosion have so extended and deepened the valleys and have removed so much of the original surface that that which is left can only be classified as hills. These hills, however, will still retain clues as to their sedimentary nature. Whatever the source of the hill, or mountain, the characteristics of its shape provide clues as to its origin, which, in turn, serve as indicators of its physical properties, such as hardness, perviousness, cohesiveness, etc. At this point, one can frequently make an inference, based on experience and judgment, as to possible composition.

In general, hills and mountains that are made of hard, durable, igneous and metamorphic rocks have sharp, angular, and irregular outlines in both plan and elevation. They are devoid of symmetry and do not show finger-like extensions or ridges. Granitic rocks can show a softening of the angularity, but it is not a roundedness easily confused with the rounded slopes of soft materials. The surficial characteristics of igneous and metamorphic rocks depend on the molecular groups or minerals involved, the climatic region, and the amount of fracturing. In large masses of granite that are not fractured, or in which the fractures have been sealed by other materials and forces, the whole can have a smooth rounded shape. If the mass is intensively fractured, then the pattern is more jagged and can contain needle-like features. Usually, granite rocks have a lumpy surface

⁴Am. Geol. Inst., 1972. *Glossary of Geology*. Washington, DC.

texture. The pattern of a lumpy surface, or of needle-like spires, is not in itself sufficient to identify the rock type, because similar patterns can be found in other rocks under other conditions. For example, some tropical limestone weathers to present a lumpy surface, and needle-like spires can be found in massive beds of limestone and in columnar basalt.

The sedimentary rocks — sandstone, shale, and limestone — have other shape characteristics. The fact that these rocks are formed by a continuing, or sequential, deposition of suspended matter causes them to have a layered nature. These layers, or beds, can be of one type rock, or they can be different rocks; and the layers can be thin, i.e. measured in millimeters, or they can be thick and measured in tens or hundreds of meters. This originally horizontal, flat-lying, layered structure can be uplifted, tilted, folded, fractured, and weathered in all sorts of complex ways, but not all the basic characteristics associated with a layered system will be destroyed. Flat-lying and nearly flat-lying beds that have been dissected by erosion develop hills with ridges, or finger-like extensions, that have symmetrical profiles across them. If the layers are made of sandstone or limestone and are thick, i.e. measured in tens or hundreds of meters, the hills will be blocky with steep, if not vertical, sides. Clay shale beds do not have this thickness, and even if they were thick, the hills would show a rounded profile because of the cohesive nature of clay. As the beds become thinner, the massive blocky structure is lost and other slope shapes develop. If a more resistant material is interbedded in the sequence, a stair-step pattern becomes evident. With thinner beds, the steps, if present, become imperceptible in conventional stereo aerial photography, with the result that the hills have rather smooth-looking slopes. The shape of the slope can also be a pattern element that is indicative of the nature of the materials. If the rocks are thinly interbedded sandstones and shales, the slopes tend to have a uniform gradient down most of the hillside. If the rocks are thinly interbedded limestones and shales, the slopes tend to become concave and exhibit a noticeable flare in the lower third of the hill. In general, sandstones develop sharper ridge lines and more angular patterns than do limestones. If a sandstone is very soft, or contains a significant amount of calcium carbonate, it begins to resemble the landforms developed in limestones. Clay shales show the ridge-like extensions associated with flat-lying sedimentary rocks, but being made of soft cohesive and plastic material, the profiles and contour lines tend to be very gently rounded.

Sedimentary beds that are tilted retain many of the characteristics mentioned earlier, i.e. blockiness, stair-steps, etc.; but, in addition, they develop other landforms. Sooner or later the edges of tilted beds will become exposed and will weather and erode according to their composition. The resulting landform is a series of parallel V-shaped ridges that form a sawtooth-type profile across them, which can be either symmetrical or asymmetrical. A symmetrical profile suggests that the beds are dipping at 45° . The ridges, which represent the length of the exposed beds, can be very long, i.e. kilometers.

Basins and Valleys. These structures refer to depressions that are sufficiently large to provide a significant separation between the adjacent higher elevations. Basins do not have surface outlets, can vary greatly in size and shape, and are produced by several events, including folding and erosion. Whatever the cause, it is an area in which sediments can accumulate. The characteristics of a basin can provide information as to composition of the parent material and the forces that brought the depression into being. Valleys usually have surface outlets and are usually elongate. Most frequently, they are caused by stream erosion, but are also produced by moving ice, folding, faulting, and solutioning. Solution valleys, such as in limestone areas, can be fairly extensive and complex and yet not exhibit a surface outlet. Although valleys provide passages for the transport of water and materials, they can collect sediments by a variety of processes, e.g. fluvial, glacial fluvial, etc. The shape characteristics of a valley provide information about parent materials and the nature of the processes that created the valley.

Escarments. Escarpments are usually long, fairly continuous steep slopes or cliff faces that separate some landform units. They also exist, however, as broad, gently sloped bands that most frequently result from faulting and subsequent erosion. Although they are not usually considered as a type of landform, they are included to indicate that, where they do occur, they merit evaluation. They are important pattern elements, and their characteristics can provide information about composition and the nature of the causative forces.

Refer to appendix G and report ETL-0261⁵ for further information about landform patterns for some rock types.

DRAINAGE. This refers to all drainageways, including standing water, as well as channels that water would follow if it fell on the surface. Drainage patterns are next in importance after landform, and they provide information about soil permeability, soil texture, cohesiveness, areal homogeneity, ease of erosion, ground slope, relative depth of soil mantle, presence of and type of rock, and dip of beds. With experience, one can make a judgment from these patterns as to probable general composition. As water flows

⁵Judy Ehlen. 1981. *The Identification of Rock Types in an Arid Region by Air Photo Patterns*. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL-0261, AD-A109 144.

over a surface, it can scour out ever-deepening and ever-lengthening channels whose shape, intricacies, and arrangement form patterns that are directly related to the materials containing them. These patterns are evaluated in two ways. The first is an analysis, in terms of pattern type and density, of the surficial arrangement of the drainage net as one would see it looking down on it. This is called the Drainage-Plan. The second is an analysis of the cross sectional shapes and gradients of the channels that carry water to the collectors. This is called the Drainage-Elevation.

Plan. Aside from forms of control such as caused by bedding, jointing, and fractures, the drainage pattern and its density are functions of soil permeability, slope, and the climate, especially the amount and distribution of precipitation. Well-defined surface drainage patterns do not develop on pure granular materials, such as sands and gravels, because the water drains downward through the spaces between the granules and downslope until it finds a low, or until it exits from the material. With sufficient water, this mass of material becomes saturated, at which point the water must flow over the surface, and can leave a trace of its passing in the form of an erosional scar, or a series of tone changes. With torrential rains, water can fall on a surface faster than it can drain into the interior, and under such conditions, the water will flow over the surface. Aside from patterns of infiltration basins, drainage patterns do not usually develop on the surfaces of granular deposits. At the edges of a dissected deposit, such as a granular terrace, there will usually be a few gullies, but these will not extend very far into the plain, and they are not branched into ever-smaller tributaries. If the granular material is well graded and contains some small fraction of the fines in its composition, the permeability will be reduced and the gullies will extend farther back.

In materials that are not wholly permeable, such as clays or soils that contain a significant amount of clay and silt, some of the water runs over the surface and scours out a drainage pattern. The less the permeability, the more the surface runoff and the greater will be the erosional scouring and the number of gullies. A relative index of permeability can be obtained for a drainage pattern by expressing the drainage in terms of total length of the combined drainageways in relation to a unit area, e.g. kilometers of drainage per square kilometer of terrain. Lower values of the ratio are associated with the more permeable materials. In making this kind of an evaluation, one should remember that slope differences can cause different drainage densities for materials having the same permeability and also that vegetation can hide drainage channels that would contribute to the overall density, if they could be mapped.

For a soil composed of expansive clay particles and in a dry condition, some initial portion of a rainfall will drain internally through the dessication cracks and voids and not run over the surface. As this water comes in contact with the clay particles, they expand, filling in the cracks and voids, at which point the mass becomes impermeable, and the water must flow over the surface, leaving as a sign of its passage an intensively developed network of drainageways. In general, and for similar slope conditions, the finer the drainage net, i.e. the closer the gullies are spaced, the less the permeability and the finer the texture of the material.

In this part of the stereo photo analysis, all standing water, low spots, and paths that water would follow if it fell on the surface are traced out on the overlay material. It is important to record as much as possible of the fine detail, especially the first-order drainage, i.e. the small unbranched tributaries that terminate at the limits of a watershed. Such detail provides a basis for better identification of drainage basin limits and divides and for developing inferential information as to geological structure and stratigraphy. This overlay can be removed from the photomosaic and placed on a smooth, light-toned background so that the drainage patterns can be examined in isolation. The pattern is evaluated in terms of homogeneity, arrangement, density, and angularity. Wherever any one of these characteristics changes, there is a basis for a boundary that denotes some change in materials or conditions, or both. If, for example, the pattern was uniformly the same throughout the area of study, then one must conclude that surficial materials and conditions, whatever they might be, are also uniform throughout that area. If one can break out three drainage patterns or three variations of a common pattern, then one must assume that the area contains at least three different materials or conditions, or some combination of both. Sometimes it is difficult to locate an exact position for a boundary between two patterns. For example, a drainage pattern might change gradually from one end of the study area to the other, in the sense that at one end the pattern shows fewer contributing gullies to the collectors than at the other end. This could be caused by the fact that the rock, say a sandy, silty shale, contains a gradually lessening amount of sand as one goes across the study area, which would gradually and slightly alter the permeability of the material and the resulting drainage pattern.

Once the boundaries have been established and the various drainage patterns described, the significance of these findings must be determined. There are some relations that apply in general. As stated previously, the denser or more finely divided the drainage net, the more impermeable and fine grained the material. The more angular are the intersections of gullies and channels to their collectors, the harder and more resistant the material. In soft and easily eroded material, such as clay shale, silt deposits, limestone, or soft sandstone, the wanderings and intersections of collectors and gullies are curved and rounded. As the material becomes harder, the intersections become more angular. Sinusoidal roundedness in the drainage plan is indicative of roundedness in the landform profile, and angular paths and intersections are indicative of an angular landform profile.

Several types of drainage patterns, along with the materials and conditions to which they are linked, are listed on the Drainage Factor Pattern Sheet in appendix A. These patterns represent pure, or idealized, forms and although they do occur in the field, they are not found as frequently as are the transitional and combined patterns. The more common patterns of this group are dendritic, parallel, rectangular, trellis, radial, and annular.

The dendritic, or branching tree-like pattern, is probably encountered more frequently than any other. In this pattern there is no indication of control over the direction of flow, other than downhill. The tributaries form acute angles with the main collectors, and the individual streams tend to be curved rather than straight. This pattern develops on materials that have uniform resistance to erosion. As such, it is indicative of homogeneity in composition and structure and is associated with relatively incompetent rock and soil materials. In sedimentary rocks, such a pattern has an added structural connotation in that the units must be horizontal, or nearly so. The significance of this pattern is that it is an indicator of homogeneity in materials and conditions, both areally and vertically, at least to the depth of erosion.

A parallel drainage pattern indicates a single direction of flow. Such patterns are found on soil and rock materials that are uniform in composition and structure and that are on an inclined surface. The tributaries joining the collectors form acute angles that become smaller, or more acute, as the slope increases. Parallel patterns can also be caused by closely spaced parallel fractures in homogeneous rock that is at or near the surface.

A rectangular drainage pattern indicates two directions of flow, or orientation of stream segments, that are about equally developed. Usually the tributaries join their collectors at right angles, and the stream segments tend to be straight rather than curved. This pattern is a result of structural characteristics in the rocks brought about by intersecting sets of fractures or foliations and is indicative of relatively competent material at or near the surface.

A trellis pattern also has a rectangularity established by two directions of stream orientation. In this case, however, the directions are not equally developed, i.e. one direction has more drainage than the other. The tributaries join their collectors at right angles, and stream segments tend to be straight. This pattern develops on structurally altered rocks composed of nonuniform materials at or near the surface. This type of control is most frequently associated with tilted, interbedded, competent and incompetent sedimentary units, and some low grade metamorphic rocks. The longer parallel streams follow the direction of the bedding, i.e. strike, or the principal foliation. In sedimentary sequences, the tributaries on opposite sides of collectors usually show a difference in

length, as well as in the patterns of junctures. Tributary junctures that develop on dip slopes tend to be Y-shaped, and those that develop on scarp slopes tend to be T-shaped. Tributaries that are equal in length on both sides of collectors are suggestive of beds dipping about 45° . T-shaped tributaries on both sides of a divide indicate that the bedding, or foliation, is vertical, or nearly so.

A radial drainage pattern arises when the drainage is directed away from, or towards, a central topographic high or low. On a local basis, the drainage channels can be nearly parallel. Drainage that flows from a central high is called centrifugal and is most frequently associated with volcanic cones and plug-like intrusive rocks. Drainage that flows inward towards a central low is called centripetal and is frequently associated with sedimentary basins.

Annular drainage patterns also show symmetry about a central point, either a topographic high or low, but with two components of direction – radial and concentric. The tributaries follow radial courses and intersect at right angles with the collector streams, which are following concentric courses. This pattern is an indicator of structural domes or basins and can be found in areas of sedimentary and low grade metamorphic rocks, as well as in igneous terrain.

Elevation. This pattern refers to the shapes of the gullies in cross section and in gradient. It is an important pattern element because soil textures and soil profile features can be interpreted directly from a detailed study of gully systems and gully characteristics. Bedrock is continuously being broken down by mechanical means into ever smaller pieces, which accumulate in various parts of the landscape as deposits of particles ranging in size from boulders to pieces visible only with a magnifying lens. There are limits, however, to the particle size that can be produced by grinding, and it is about 0.002 to 0.003 mm (2 to 3 micrometers). These smaller particles are called silt. There is another group of particles that result not from grinding, but from weathering (chemical decomposition) and subsequent recrystallization of the soluble products. These are called the clay particles. Although these plate-like particles have a size distribution that overlaps the silt group, the overwhelming majority of them have sizes less than 0.002 mm. The designation of particle sizes associated with gravel, sand, silt, and clay depends on the soil classification system being used. In *The Unified Soil Classification System*,⁶ the approximate ranges are

⁶Arthur Casagrande. *The Unified Soil Classification System*. Corps of Engineers, U.S. Army, Technical Memorandum No. 3-357, Vols. 1 and 3, March 1953. (The Unified Soils Classification System was developed by Dr. Casagrande and was adopted by the U.S. Army Corps of Engineers in 1942 as the Airfield Classification System. Other agencies also used this system and extended its application to all phases of soil work. In 1952 discussions were held between the Corps of Engineers, the Bureau of Reclamation, and Prof. Casagrande. The result was a modification of the Airfield Classification System and a renaming of it as the Unified Soil Classification System. Several references provide details of this system).

Soils Manual for Design of Asphalt Pavement Structures, 2nd Ed., Apr 62. The Asphalt Institute, Manual Series No. 10.

Earth Manual, 1st Ed. revised, 1963. U.S. Dept. of Interior, Bureau of Reclamation.

U.S. Government Printing Office.

PCA Soil Primer, 1962. Portland Cement Assoc., Skokie, Illinois, pp. 25.

coarse gravel	—	19 to 75 mm (.75 to 3 inches)
fine gravel	—	4.8 to 19 mm (.19 to .75 inch)
coarse sand	—	2 to 4.8 mm (.08 to .19 inch)
medium sand	—	.4 to 2 mm (.02 to .08 inch)
fine sand	—	.07 to .4 mm (.003 to .02 inch)
finer (silts and clays)	—	less than .07 mm (.003 inch)

Note that in the Unified System size distinction is not made between silts and clays. These are differentiated on the basis of their behavior. Refer to appendix D for further details on particle sizes.

Gravel and sand are the coarse-grained parts of the soil, and the distinction between the two on the basis of size is an arbitrary one, for the engineering properties are similar throughout, varying primarily in degree. As sand becomes finer, it acquires some of the characteristics of silt, especially a decreased permeability, and it can be visually indistinguishable from silt. There are also distinctions based on chemical composition and physical properties that are associated with the various groups of particles. Gravels consist of fragments from igneous, metamorphic, and sedimentary rocks. Consequently, they have a varied chemical, or mineral, composition. It is an infrequent event to find gravel deposited without sand. The two are usually together, either intermixed as in a well-graded deposit, or interleaved as lenses and layers of coarse sandy gravel alternating with coarse sand, etc., and frequently with some amount of precipitated material present. Whatever its composition, a deposit is an indicator of the types of rock available to the stream that formed the deposit, an item of information of little concern to the photo analysis, but which can be of use during a ground reconnaissance.

Sand, on the other hand, is most frequently made of quartz (*silicon dioxide*), an abundant substance that is hard, resistant, inactive chemically, and durable through long periods of time. There are other kinds of pure sand, such as gypsum and coral, but these represent but a small fraction of the whole. Coarse sand frequently contains other particles, but as the grain size becomes smaller, the quartz fraction becomes larger. Fine sand is usually pure quartz — the sturdy unweatherable residue of the degradation process. Sand grains can be rounded or irregular as a result of how much abrasion they have received. They are neither cohesive nor plastic, and in bulk, their water-holding capacity is very low. Because of the large sizes of the pore spaces, the passage of water can be rapid. Because of the small sizes and the lack of cohesiveness, sand can be carried by the wind.

Silt and clay are the fine-grained components of a soil and are called the nonplastic fines and the plastic fines, respectively. They are important as a group because they significantly alter the engineering characteristics of soil when present in small amounts. If a granular soil contains as little as 10 percent of fines, it can lose much of its permeability and be subject to frost heaving. As a result, soils that contain any significant amount of silt and clay are sources of engineering problems because they can have pronounced changes in physical properties caused by changes in water content or by being disturbed. When in a dry, powdered state, silt and clay are visually indistinguishable. When chewed, silt has a gritty feel, and clay has a creamy feel. In the presence of water, they have very different properties.

Silt particles, the end result of the grinding process, are irregular in shape, are seldom smooth or flat, and are composed mostly of quartz. They could be accurately described as micro-sand particles. Being composed of quartz, both sand and silt are very inactive in a chemical sense. The silts, however, are so small that they have some different physical properties. The pores between the grains are restricted enough to influence the passage of water, and consequently, these soils are not as permeable as sand. By the same token, they have a higher capillary rise and a higher water retention capability. Because silt particles frequently have an adhering film of clay, the smaller ones can show evidence of cohesion, plasticity, and adsorption. Being small and noncohesive, silt can be transported by the wind as well as by water, and it occurs as aeolian and fluvial deposits, both pure and mixed. Silt is unstable when water is present and can turn "quick" when saturated. It is somewhat impervious, it is difficult to compact, and its properties in place are very different from those of the disturbed soil.

Clay particles are small enough so that surface effects override mass effects, and most of the particles are small enough to have colloidal properties. These particles are flat, have about 10,000 times more surface area than an equivalent weight of medium grade sand, and surface forces can be very strong. Consequently, surface phenomena such as cohesion (particles sticking together) and adsorption of water, chemicals, and gasses are very pronounced in the clays. Because the clays are formed by processes of chemical decomposition and recrystallization, they vary greatly in mineral and chemical composition. Clay is highly plastic when moist, and it forms hard cohesive masses when dry. Clay soils are practically impervious, difficult to drain, difficult to compact if wet, and undergo volume changes as a function of water content.

The patterns of drainage-elevation, i.e. gully cross section and gradient, that develop in a soil are determined by the properties of permeability, cohesiveness, plasticity, compressibility, etc., and these are functions of the amounts of clay, silt, sand, and gravel in the soil, the soil profile development, and the climate. In general, there are three basic gully cross section and gradient combinations that correspond to the three textural groups of granular soils (sands and gravels), silty soils, and clayey soils.

In noncohesive granular materials, the gullies are V-shaped in cross section and have short, steep gradients, i.e. the gullies are slightly longer (4 to 6 times) than the width of the gully at the top of the V. With more of the fines present, the gullies become longer. In well-graded deposits that have been dissected, such as river terraces, the exposed walls can be vertical.

In silty soils the gully cross section has a flat bottom and steep-to-vertical sides. The gullies can be relatively long and have a gentle gradient throughout, except where it steepens at the headwall. The manner in which the silt was deposited (aeolian or fluvial) also influences the shape. Flat-bottomed gullies with vertical walls can be formed in any noncohesive deposit as a result of subsurface drainage or ground water sapping. Conditions necessary for this can occur in saturated alluvial deposits as a result of an increase in ground water levels or of excessive rainfall. Vertical walls can also be caused by undercutting, as in a river cutting into a loessal bank, i.e. a bank of wind-deposited silt. In fluvial deposits of silt, the gullies have this boxy shape, which could be the result, in part at least, of subsurface flow undercutting at the base with a subsequent slumping. In aeolian deposits, the gully walls are steep, but not vertical. Based upon our field measurements, the walls are most frequently between 55° and 60°.

Nongranular, cohesive, and plastic soils, i.e. the clays and silty clays, develop a gully with a saucer-shaped cross section and a long gentle gradient. In a relatively pure clay soil, the saucer-shaped cross section is very broad, shallow, and gently rounded.

Additional information about drainage patterns in relation to rock type can be found in appendix G and in ETL Report 0261.⁷

EROSION. Landform, drainage, and erosion are interrelated. Without erosion, drainage patterns and, consequently, landforms could not evolve. There are several forms of erosion, however, and each leaves a pattern that can provide information about the composition of materials, conditions, and climate. The term "erosion" is used here to refer to the overall procedure of breaking down earth surface materials, i.e. soils and rocks, and of moving the pieces from one place to another. In keeping with most usage, weathering as a destructive process is included as a form of erosion even though it does not involve transport of the altered material. Processes that are responsible for loosening, breaking, or dissolving earth surface materials include

⁷Judy Ehlen. 1981. *The Identification of Rock Types in an Arid Region by Air Photo Patterns*. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL-0261, AD-A102 893.

Mechanical

- running water
- rainfall
- waves
 - impact
 - compression of air
- moving ice
- corrasion
- expansion in confined spaces
 - freezing of water
 - crystallization

Chemical

- dissolution (limestone, gypsum, etc.)
- weathering

Thermal

- thawing (thermokarst, and the active zone in regions of permafrost)
- temperature changes (differential coefficients of expansion for different crystals)

The forces that are responsible for moving the altered or loosened material are running water (including currents), wind, ice, and gravity. The mechanical destruction of the land, with removal of the pieces by running water, is the most common of the erosive processes, and because of the importance of its patterns, it is discussed and evaluated under the heading of drainage. Each erosional process has associated with it patterns of shape, tone, and texture. Because of these patterns, one can identify the types of erosive mechanisms and, therefore, infer something as to the composition and properties of the material. In this part of the analysis, one looks for indicators of the mechanisms of erosion, describes them, and evaluates their significance. For example, occurrences of blowouts on a surface are suggestive of the presence of a sandy material; the presence of sinkholes, a form of chemical erosion, is indicative of limestone; the presence of depressed center polygons in permafrost regions (freeze-thaw) is indicative of a silt/ice mixture and the possibility of large amounts of subsurface ground ice.

DEPOSITION. Material that is eroded away must be deposited elsewhere, and the resulting patterns are controlled by the nature of the material, conditions, and climate. The regional desposits that form sedimentary rocks are not considered as part of this pattern group. Some depositional formations are large enough to be classified as landform patterns, e.g. large deltas, fans, terraces, dunes, volcanic cones, etc. Even so, their patterns are indicative of composition.

This part of the analysis serves as a checkpoint to review the imagery for indicators of deposition and to evaluate their significance. Some of these patterns are associated with relatively small features, e.g. examining gully mouths to see if fans are present, which, if found, would indicate that there is a source of granular material upstream. Most depositional patterns are caused by mechanisms involving water, wind, ice, gravity, biological material, and man.

The patterns of water-deposited materials that are of interest in this part of the analysis are those forms of depositions brought about by moving water, i.e. rivers and streams, flood (including the sheet variety), currents, and waves. These deposits are mostly materials in the forms of stream terraces, fans, deltas, beaches, beach ridges, bars, eskers, kames, outwash, etc. This deliberately ignores the subaqueous deposits that form in seas, estuaries, lakes, and ponds and which are still submerged. The nature of a deposit in terms of composition is a function of the source of the material and of the speed and depth of the moving water. Consequently, these deposits contain materials that range from silt-sized particles to boulders, show some degree of sorting, and frequently show some degree of stratification. As an example, fans show a lateral sorting, with the coarse fraction at the gully mouth and the finer fraction at the leading edge. The cross section profile of a fan is also related to particle size distribution. The higher the arch of a fan as compared to its width, the coarser is the composition.

Compared to water-associated deposits, wind-deposited material has a more restricted grain size distribution, usually silt and sand-size particles. Most aeolian deposits form features that are large enough to be evaluated as landforms, e.g. dunes, loessal ridges, loessal plains, etc. In general, aeolian deposits show streamlining, smoothly arced edges, interconnected shapes, fluting; and they tend to look "windswept." Shape can provide information about composition. In sand dunes, the shape is related to wind speed and its constancy in direction. Long lineal dunes, i.e. tens of kilometers in length, are shaped by very strong winds with a constancy of direction. Of the dune formations, they are likely to have the most coarse particle-size distribution. Moderate winds are associated with barchane dunes and weak winds with transverse dunes. The latter type usually has a finer soil texture. Irregularly shaped dunes or star-shaped dunes result from changing wind directions.

Deposits associated with ice are complex masses of material that are sometimes difficult to classify because there are many overlapping types, and the precise mode of formation is frequently uncertain. Many of these deposits are poorly sorted and sometimes stratified. Those that are caused by running water (glacial melt) have been mentioned, i.e. eskers, kames, and outwash. Deposits that are formed by action of the ice, in contrast with action of the meltwater, include moraines, drumlins, and till. Moraines can be formed in different ways. A terminal, or end, moraine is formed by the edge of an advancing glacier shoving surface material ahead of it into long, curved, ridge-like features that outline the shape of the advancing sheet of ice. This material is frequently composed of till, but can consist of the resident soil and rocks of a previously unglaciated area. Consequently, this type of moraine can vary greatly in composition, although it is usually unsorted and unstratified. Lateral moraines form at the sides of a glacier as a result of the moving ice plucking and scraping material from the valley walls and distributing it along the edge. Material can also be deposited by melting the ice of a stagnant glacier out from under material suspended in a shear plane or resting on the surface as a perched moraine. Morainal forms are not as well sorted as the water deposited features, and contain more of a nongranular fraction. Drumlins are long, rounded, low-lying hills shaped by the action of the glacier on the till at the ice-ground interface. Ice that melts in cyclic freeze-thaw sequences can also move material, as well as provide some degree of sorting. It is this mechanism that brings large rocks to the surface in a poorly sorted soil, produces frost boils, and contributes to the slow downhill movement of the surficial material in periglacial areas, i.e. solifluction.

Although gravity is the ultimate cause of all deposits, airborne or waterborne, its use here is restricted to those materials that have slid or fallen directly onto their resting places, i.e. water and wind were not involved in the transport. The pattern elements of interest here are associated mostly with talus, avalanches, slides, slumps, etc.

The common biological deposits are peat and muck, which are derived from the accumulation of vegetation in low-lying areas such as ponds, bogs, swamps, estuaries, etc. In an aerial photograph, these are seen as dark or black flat surfaces surrounded by higher ground. Although they have a high economic value, they are problem areas for engineering construction.

Man-induced deposits most frequently occur in the forms of tailings piles and ponds associated with mining and ore production, ridge-like mounds and hills from strip mining and quarry operations, and landfill (dredge or hauling).

VEGETATION. As to which photo pattern is next in importance is a moot point. At present we give the edge to vegetation for two reasons. First, vegetation information is important to many different tasks. As an example, the results from an analysis of vegetation patterns can be used to provide information about the vegetation itself in terms of type, spacing, density, canopy closure, stem diameter, vigor, etc.; or to provide information that is directly or indirectly linked to other characteristics such as climate, soil texture, soil or rock type, depth of soil mantle, presence of ground water, potability, etc. Second, and perhaps more important, vegetation patterns have not been exploited to their full potential. Based on the accumulated evidence, one can only conclude that the limit to the indicative uses of vegetation patterns is our lack of knowledge. Consequently, research efforts in this field of study should receive more emphasis. Although much is known, in a general sense, about vegetation and environmental characteristics, very little is known about the details of the intricate network of relations between vegetation type, state and vigor, climate, landform, soil texture, moisture, ground water, chemical composition (of plants and soils), and associated spectral reflectance, fluorescence, and radiometric properties. Once established, these relations might provide usable indicators as to soil composition, soil conditions, mantle depth, water sources, water potability, mineralization, and salinity, let alone provide an improved vegetation mapping capability. As to how much proves to be reliable and useful, only the results from research can tell.

Air photo scales suitable for engineering soils evaluation and environmental data base preparation, i.e. in the 1:20,000 scale range, are too small for use in species identification. Vegetation types or large pure stands can, however, be identified and boundaries established between groups. These boundaries are frequently associated with changes in soil texture, soil moisture, topography, landform, and orientation, and they give supportive information to factor boundaries established in earlier phases of the analysis. Arid regions research done by ETL has established some usable relations between landform, soil texture, and vegetation community.⁸ Although these results must be tested in other regions, there is no doubt that knowledge of either landform or soil texture within an area can set the basis for a fairly accurate prediction of the vegetation communities, and vice versa. Also, vegetation patterns can provide information about climate. A closed canopy forest requires over 76 cm (about 30 inches) of rain per year. Some species in certain locations require much more than that. Progressively less rain means progressively less tree cover and more shrubs and grasses. A continuous grass cover requires at least 25 cm (10 inches) of rain per year, with some grasses needing double that amount. When the annual amount of precipitation falls below 25 cm, the grass cover breaks into clumps, specialized species appear, and the vegetation becomes more widely separated.

⁸Melvin B. Satterwhite and Judy Ehlen. 1980. *Vegetation and Terrain Relationships in South-Central New Mexico and Western Texas*. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL-0245, AD-A095 159.

The procedure for classifying the vegetation during an image analysis is a function of the nature of the project, and schemes are frequently tailor-made to fit project goals. As will be discussed in the section on data base preparation, the analysis can be simple or complex as a function of the classification scheme used. At present no existing system combines simplicity, photo-based origin, Army needs, and the capability to incorporate other data sources. Such a system is being developed at ETL (refer to appendix E).

CULTURAL. The analysis of cultural patterns can be done for at least three reasons: (1) to derive information about the culture itself, (2) to use the cultural patterns to derive information about other terrain factors, and (3) to use the cultural patterns directly in terms of some military problems. As an example of the first, the economic characteristics of a given society can be deduced by an analysis of the cultural patterns. As an example of the second, a pattern of cultivated fields, such as the alternating tones of fallow farming, can provide clues as to soil texture and the general climate, or the presence of a quarry can support predictions of rock type. As an example of the third, the knowledge of the location of above-ground structures provides information with reference to the military problems of cover and concealment and cross-country mobility. Because cultural information is needed for so many different uses, it has not been possible to provide a single satisfactory classification scheme, let alone a scheme based on the analysis of photo patterns.

From the military point of view, terrain information needs are better expressed as a land cover/land use map, which is a combination of the patterns of culture, vegetation, and surficial geology. Of the classification schemes presently available, none of them adequately meets Army requirements, and none of them is well suited to the use of remote sensing techniques. The classification scheme should be as simple as possible, at least through the first level, and perhaps into the second; and it should provide a basis for incorporating into the higher levels, technical details from the literature or ground surveys. Within ETL, over 20 classification schemes have been evaluated, and one was tested by photo analysis. No one system lent itself readily to the use of remote sensing imagery, and neither did any one system adequately address Army needs. ETL is trying to develop a land cover/land use classification that will meet these goals. A review of this effort is in appendix F.

PHOTO TONES AND TEXTURE. Photo tone and texture are descriptive terms that do not lend themselves to precise definitions. Nevertheless, these patterns can provide information about specific materials or conditions, as well as information to support conclusions developed during the analyses of other factors. When used with respect to black and white photography, photo tones refer to the gray levels in the image. If used with respect to color photography, photo tones refer to the color. When the colors are other than the neutral ones (white, grays, black), they are difficult to describe.

In the case of panchromatic photography, the photo tones represent the brightness of an object as averaged over a very broad spectral bandpass. Evaluating a tone is relative, is frequently done within a frame of photography, and is expressed in such terms as light, dark, lighter than, darker than, redder than, uniform, speckled, etc. Although photo tones can be measured and expressed in terms associated with optical density and Munsell notation, etc., no practical use is gained by such procedures because, for most terrain surfaces, photo tones do not have an absolute relation to anything. Frequently there is some range of tones associated with some range of conditions, but it is not absolute in the sense that if A, then always B, or if the optical density is 0.21, then the surface is granite, or if it has a particular Munsell notation, then it is a wheat field.

The tones in an aerial photograph are the end product of a number of interactive items and events. Included in these are the molecular nature of the surface material; the quality of the light (sunlight, skylight, time of day, season, atmospheric properties); slope and orientation of the surface; angular relations between the surface, the camera, and the sun; off-axis variation in exposure (this can be equivalent to over one-half an f-stop from principal point to edge of format when using a wide angle lens); presence of surficial structure; local meteorological conditions (dry, wet); spectral transmission characteristics of lenses and filters; and characteristics of the emulsion and of the processing method. For high altitude or satellite systems with long focal length lenses or with small scan angles, which are recording at near constant or similar sun times, the variations caused by some of these relations are reduced. For conventional aerial photography, however, the changes can be significant. For example, because of off-axis falloff of exposure, a material can have different gray tones or different colors as a function of whether it is directly beneath the camera or off to one edge of the format. A wide angle lens increases this effect.

The term "wide angle" refers to a lens whose focal length is less than the maximum dimension of the format. A normal lens is one whose focal length is approximately equal to the maximum dimension of the format, and a telephoto is a lens whose focal length exceeds the maximum dimension of the format. As used here, the term "format" refers to the image size recorded by the camera, e.g. 35 mm, 4 by 5 inches, 9 by 9 inches (aerial camera), etc. In the case of the 35 mm camera, the diagonal of the rectangular image formed on the film is about 50 mm, and for that camera, a 50 mm lens

is the normal lens. For a 9- by 9-inch aerial camera, the diagonal of the square image recorded on the film is about 12.7 inches, and a 12-inch focal length lens is considered to be normal. A 6-inch focal length lens is frequently used with a 9- by 9-inch aerial camera, and for this camera, that is a wide-angle lens. Consequently, there is considerable falloff of exposure at the edges and corners of the picture.

Tone variations can also occur as a result of changes in the angle between the sun, the features on the ground, and the camera. For example, considering only sunlight and neglecting skylight, an area on the ground that is towards the sun from the camera station can add a specularly reflected component of sunlight and show as a light tone in the positive image. When this same area is away from the sun, with reference to the camera station, then its image cannot receive a specular contribution and is formed only from backscattered sunlight, which results in a darker tone in the positive image. Surface roughness also influences the directional scattering of incoming light. Frequently occurring surficial variations in relief that are equal to, or greater than, the wavelength of the incoming radiation will cause the light to be scattered in different directions. The light that is of concern to photography has wavelengths that are less than 1 micrometer. Consequently, most surfaces are rough and scatter light in all directions, sometimes more in one direction than another. As a result of these effects, two materials can have a high contrast at the trailing edge of the format, with A being dark gray and B being light gray, and they can show a reversal of this contrast when the same materials occur near the leading edge of the format. The boundary of a tone pattern can also have a shape that can be frequently related to other events and conditions.

Texture refers to the visual impression of surface structure, and in some instances it is difficult to describe texture separate from tone. Descriptive terms include smooth, coarse, silky, mottled, speckled, banded, etc. For example, an area containing a dense stand of pine trees will have a different texture than a mixed hardwood stand, and a plantation of pine trees with its 2-dimensional arrangement of rows has a very different texture than a natural pine forest. Large areas of sedimentary rocks exposed across the beds can present a striated appearance, and when closely spaced these striations can give a grain-like appearance to the terrain similar to wood grain. Some examples and further discussion of tone and texture patterns as used in the context here can be found in other publications.^{9,10}

⁹R.E. Frost. 1950. *Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photographs*. Prepared by the Purdue University Engineering Experiment Station for the St. Paul District, Corps of Engineers, Department of the Army.

¹⁰J.N. Rinker. 1975. Some technical aspects of film emulsions in relation to the analysis and interpretation of aerial photographs. *Aerial Reconnaissance for Archaeology*. Ed. D.R. Wilson. The Council for British Archaeology, 7 Marylebone Road, London NW1 5HA. CBA Research Report No. 12. Derry and Sons, Ltd., Nottingham, England.

In most cases, these patterns are associated with areas of relatively bare or exposed soil and rock or with an area of uniform vegetation cover. Although photo tones and texture are important sources of information, care must be taken in evaluating them, especially those of soils because climate and season greatly influence the development and the detectivity of these patterns. With respect to soils, tones and textural patterns can provide information about identity, origin, uniformity, horizon development, moisture relations, etc. As an example, in panchromatic photography, silt has a bright uniform photo tone and a silky texture. Soils of the Wisconsin glacial till show an intricate mottling of light and dark gray tones that are related to soil texture and moisture conditions, and soils of the Illinoian glacial till develop white fringes around gullies, which are indicative of a profile development, i.e. a gradual alteration of the soil into layers of different composition. Curvilinear tone streaks on low flat areas are suggestive of fluvial deposition. A rectangular light-toned network in flat farmland is indicative of the presence of drainage tiles, which in turn suggests a high water table and waterlogged soils. With respect to exposed rocks, tone and texture can provide supportive information as to type. For example, in igneous rocks, the mafic group, which includes basalt and gabbro, has dark photo tones; and silicic rocks, such as granite, tend to have lighter tones. For further information on tone and texture characteristics of some rock types, refer to appendix G. With respect to vegetation, tone and texture can provide information about composition or vegetation type.

SPECIAL. This category includes items that do not easily fit under other factor headings, or items that although discussed under other factors, are sufficiently direct indicators of identities and conditions that they warrant additional evaluation. This part of the analysis serves as one more checkpoint to examine the imagery for clues to support previous findings or to suggest new relations or identities. These patterns frequently depend on some inherent quality of the material or on some inherent nature of an action. Typical patterns include joints, faults, soil slumps, mudflows, tears, and some patterns of drainage, erosion, and tones. As an example, windblown silt deposits have an internal vertical structure that accounts for several patterns that serve as direct indicators of the presence of such a material. These include the pinnate drainage pattern, flat-bottomed steep-sided gullies, terracettes and pinnacles on gully walls, and vertical-faced road cuts. The pinnate, gully cross section, and road-cut patterns would be evaluated under their respective sections, i.e. drainage and cultural. The terracettes and pinnacles, too small to be considered as landforms, would probably be discussed under this section. Another example, slumps and tears in an otherwise smooth valley wall would be indicative of instability and potential engineering problems.

Within this category, an important member is that collection of pattern elements called lineations, including curvilinear. They are called lineations because they are seen in the imagery as lines of various lengths and distinctness crossing the landscape. One group of lineations is associated with fractures in the rocks, i.e. joints and faults. The term "fault" indicates a perceptible displacement between the sides of a fracture along the fracture plane. In length, these features range from small cracks barely discernible with a handlens to transcontinental lineations. These fractures are a record of the rock's response to stress applied through a variety of forces, such as tension, compression, torsion, thrust, shearing, mass expansion, mass shrinkage, etc. The causative agents include movement of molten rock that can result in a surface upwelling, i.e. a dome; the folding, twisting, bending, and stretching of rock as a result of plate movements; the expansion of a previously compressed mass; or the volume changes as a result of cooling from a liquid phase to a solid phase. Another form of lineations can be seen in the exposed beds of tilted sedimentary rocks. In these instances, the lines mark the contact between beds of different composition. Lineations are usually visible in the imagery as a series of aligned discontinuous tone changes, such as light streaks in the soil caused by better drainage over a fracture, dark streaks where water has been blocked and the soil is moist, lines of taller vegetation due to more available moisture, segments of drainage channels, escarpments, etc.

The patterns of lineations are important for several reasons. In an evaluation of an area from an engineering or construction standpoint, a rock that has a pattern of closely spaced intersecting fractures would certainly be suspect as a zone of weakness and potential instability. In limestones, the fracture pattern, in conjunction with the drainage and overall structure, can be indicative of possible subsurface voids. Fractures also serve as conduits to recharge the ground water table. The path to the water table can be short and direct or a very long, slowly descending lateral one. Consequently, the fracture pattern, in conjunction with geological structure and soil and rock composition, is important to the task of searching an area for a possible source of water. Being conduits, the fractures can convey unwanted material into a water table. Thus, they must be evaluated when searching for a site for waste disposal, either surface or deep-seated.

This summarizes the important characteristics of the factor patterns associated with this manual procedure of photo analysis. As results from in-house research and the scientific literature accumulate, some of these sections will be rewritten and illustrated. Without doubt, new pattern relations will emerge, and equally without doubt, some of our current concepts will need modification. In some of the factor groups a classification of the pattern elements would be of use, and in some instances such an effort has been started. In other instances, there is a hodgepodge of information to be sorted, evaluated, and tested before a semblance of a classification scheme can emerge or a decision made to abandon the effort. This is particularly true for the photo tone and texture group of patterns. In any event, these are the patterns that carry information about the terrain and on which an analysis is based. The following section discusses some of the problems associated with getting the information from the photos, classifying it, and converting it into some form of data base.

FEATURE EXTRACTION AND DATA BASE PREPARATION

J. N. Rinker and P. A. Corl

The manual procedure of image analysis, particularly of stereo aerial photography, provides a versatile and rapid means for obtaining reliable information about the terrain in terms of its origin, composition, properties, climate, and probable response to stress. The results of a photo analysis can be expressed as an environmental data base, i.e. a collection of photomosaics and factor overlays, which, in turn, can be interpreted with respect to a specific problem. Consequently, this procedure has direct application to many general problems, as well as to specific tasks. Examples of these include

1. General worldwide problems associated with
 - a. Identifying and mapping geological structure, rocks, soils, vegetation, or land cover/land use
 - b. Engineering site selection and evaluation
 - c. Location of engineering materials
 - d. Land use planning
 - e. Probable location of minerals
 - f. Probable location of ground water
 - g. Waste disposal
 - h. Environmental data base preparation
 - i. Environmental impact prediction
2. Specific military problems such as
 - a. Cross-country movement
 - b. Cover and concealment
 - c. Analysis of an area of operations
 - d. Data base development for MGI, DLMS, TTPDB, etc.

The first step in obtaining information for a data base by image analysis is to extract information from the imagery. A general understanding of how this is done provides insight into both manual and machine procedures, as well as into the nature and level of competence required in a manual analysis and in data base preparation.

Regardless of the pattern elements involved, or the goal of an analysis, there are but three ways of obtaining information from imagery. They are direct observation (d), measurement (m), and inference (i). Direct observation denotes the act of seeing or detecting a feature or pattern element directly in the image. Examples include detecting, marking, tracing, or bounding roads, structures, airports, bridges, rivers, ponds,

wooded areas, hills, drainage nets, landform units, etc. In general, it is easier, in the sense of requiring less skill, to detect cultural objects than natural features. There are exceptions to this, of course, because some cultural features, such as isolated towers, can be difficult to find, and some natural features, such as rivers, ponds, isolated volcanic cones, etc., are readily detected by direct observation. Natural features such as landform, drainage net, and gully cross section require more skill and experience in order to observe their shapes accurately. Some of the direct observation tasks can be done by machine or can be greatly assisted by machine procedures, particularly for features with well-defined shapes and sharp boundaries or with well-defined spectral characteristics.

Measurement refers to the use of devices to determine distance, length, width, height, slope, area, volume, tree density, direction, etc. There are also measurements such as optical density and the handling of density changes by fourier transforms. These, however, are not considered in this discussion. Again, different levels of skill and training are required for different types of measurements. For example, measuring height and slope is more difficult than measuring width and length.

Inference refers to inductive and deductive reasoning and judgment to derive or predict information not directly apparent in the image. Examples of the type of information produced by this procedure include predicting physical properties and conditions, probable composition and classification (rocks, soils, vegetation, etc.), and response to stress, etc. This procedure requires higher levels of skill, experience, and knowledge than the others. Although obviously based on direct observation and supplemented at times by measurements, the inferential procedure contains the added task of determining the significance of that which is seen. It is the assembled statements of significance that guide the reasoning towards an understanding of and conclusions about the landscape in terms of its properties, conditions, probable composition, and response to stress. Shape, arrangement, tone, and texture can be seen directly, significance cannot. It must be deduced. Consequently, inferential procedures require levels of knowledge, experience, and skill beyond those needed for direct observation and measurement. Fortunately, inferential procedures are not required for many data base information needs. Table 1 lists some of the associations that exist between the basic methods of extracting information and the types of information.

There is an added complication in evaluating skills and associated tasks because direct observation and inference can overlap when one considers the relations between detection, identification, and classification. At times, these three steps are combined into one operation using a single skill level and a single extraction method. At other times, these tasks are distinctly separated with each based on a different method of extracting information and a different level of skill. In general, as an object or a pattern becomes either less distinct or more complex, the steps of detection, identification,

and classification become more separated and require more skill and experience. For example, on large-scale stereo aerial photography, an analyst could detect, by direct observation, an isolated object, identify it as a tree, and classify it as a pine tree, all in one glance. When working with complex patterns, less distinct imagery, smaller scale imagery, or cluttered background patterns, these steps become separated. To continue with the tree as an example, the analyst would first detect an object. Because of its general shape, height, and location, it is identified as a tree. A further evaluation of shape, tree shadow, and tone in relation to that of other trees might lead the analyst to the inference that it is a conifer, possibly a pine tree. A definite separation of steps has occurred.

Cultural patterns also suffer these complications. If a bridge is off center in the format so that there is some obliquity in the stereo view and if the scale is suitable, the analyst could detect, identify, and classify the bridge in one glance. If that same structure, however, is aligned along the flight line and the road and bridge surface have the same brightness, then it is possible that the bridge will not show in the image, that is, it cannot be detected by direct observation. Therefore, its presence is inferred simply because the road crosses a water body. In this instance, the classification cannot be done from the photos.

The goal of the classification also influences the relations between detection, identification, and classification. A simple land cover/land use classification can be done by lower skilled analysts using mostly direct observations, some measurements, and little if any inferential information. In this case, the steps of detection, identification, and classification will be near simultaneous for most units. If the requirements call for a detailed classification of some aspect of the terrain, then the analysis becomes complicated, requires higher levels of knowledge and experience, and is based mostly on inferences drawn from an evaluation of all the pattern elements, as well as a consideration of the climatic regime in which they occur. For these applications, the steps of detection, identification, and classification will be widely separated in both complexity and time requirements.

In some instances, the classification step will be difficult, in others it cannot be completed, and in others the steps of detection and identification might not exist. For example, assume that an analyst has detected a pattern and identified it as a group of buildings among other buildings. The structures are directly noted and duly marked. The next level of classification could be in terms of building type, building height, building use, or building composition. Which of these is chosen depends on the purpose of the analysis. An economic data base would have the classification in terms of use. A military data base might require all four. Building type can be obtained from the photos by direct observation and by using photo keys. Building height can be estimated or

measured. In most cases, building use must be determined inferentially or from other information. With few exceptions, information about building composition must come from other sources. In this example, assume that the analyst wants to identify the building in terms of its use. This identification rests on an evaluation of the relations of the specific structure or group of structures to the surrounding patterns. These include location of the site in relation to the terrain and to other buildings and their types, as well as the absence or presence of transportation, parking, loading docks, etc. From these considerations, the analyst might decide that the buildings are used for commercial/retail operations. Detection and identification took place with ease and near simultaneity; whereas, classification was complicated and time consuming. There are instances, of course, that although the buildings have been detected and identified, the use cannot be determined. For instance, a group of two-story row houses built as single family residences could now contain small retail operations, government offices, and a religious group, without a consequent change in photo pattern.

An example that has the steps of detection and identification missing can be found in the task of trying to get soils information in an area that has a dense, continuous cover of vegetation. Because of the vegetation cover, the soil and rock surfaces cannot be seen. Consequently, the determination of soil properties, i.e. its classification, is the only step involved, and it will be a complex one relying on inferences derived from an evaluation of other pattern elements. In any event, whether dealing with natural features or cultural features, the road from detection, through identification, to classification can be short, long and tortuous, or dead ended.

The human factors of interest and enthusiasm have such a strong bearing on the quality and quantity of work produced by an individual that it is difficult to state absolute training and educational requirements or to assign absolute levels of skill to any given task. Nevertheless, some general statements can be made as to the types of expertise associated with different analysis efforts. For simplicity, three levels of training and experience are presented, essentially the extremes and a midpoint (table 2). A number of typical analysis tasks are listed in table 3. For each task, the associated methods of extracting the information and the level of skill needed to do it are indicated. Note that the task of classification is listed three times and that each entry requires a different level of competency. This supports the earlier statements indicating that classifying pattern elements is a troublesome issue, simple in concept, but not necessarily simple in practice. Nevertheless, it is an issue that is always present because basic to the development of any data base is the fact that some sort of classification scheme is needed in order to express the information. Each pattern element, or group of pattern elements, must be assigned a name or symbol that is indicative of the characteristics of that pattern

element and its relation to other members within its group. These classifications can be based on different principles and can be expressed in different terminology. In a very real sense, it is the classification requirements that determine both the complexity of the analysis and the level of skill needed to do it. For example, one could classify the land cover of an area on the basis of very broad categories, such as vegetation cover, no vegetation cover, water bodies, structures, roads, and railroads. Although simple, the classification does provide information and requires only a minimum of skill. A more informative classification would be vegetation (forest, brush, grassland, mixed), cultural (structures, roads, railroads, bridges, cultivated land), and barren (rock, soil, water). Obviously, this would be a more complete analysis and would require higher levels of skill and experience. Classification can also be based on specific type, use of the land, properties of its components, or origin to name a few alternatives. For example, a soil map could show a first level of classification based on origin because that information is an early step in the logic of predicting soil composition and texture. In table 4 some examples of classification schemes are listed, the types of analysis tasks needed to do them (direct, measurement, inference), and the associated levels of skill required.

The information presented in tables 1 through 4 is of an obvious general nature and, as such, is suggestive rather than absolute. Even so, the tables do show that much practical information that is of direct use to both Army and civilian needs can be obtained by the lower level of the skill groups. Table 5 lists categories that such a group should be able to map, trace, or otherwise identify on stereo aerial photography in the scale range of 1:20,000 to 1:100,000. Although these categories form a relatively simple land cover/land use data base, they provide information directly linked to perhaps half or more of stated specific needs, as well as to general problems such as cross-country movement, evaluation of areas of operation, a first cut at cover and concealment, etc. With a slightly increased skill level, and photo pattern sheets, additional classifications could be made as to canopy closure, road type, general structure type, etc. If classification requirements go much beyond this, then more than a slight increase in skill is needed. Classifying the patterns on the basis of soil composition, surficial geology, or vegetation composition, etc., requires a greater outlay in time, effort, and knowledge. If this increased level of information is worth the extra expense is a moot point. In some cases yes, but in the majority of cases, the answer might well be no. There is a universal and continual need for reliable general information. There is not an equivalent need for specific information. However important that need is when it does exist, it is neither universal in time nor location. A reliable general information data base can usually be augmented as need arises. The routine requirement for levels of, or types of, information above that needed and using a poorly designed classification system can result in getting little, if any, information and in creating a situation that seems hopelessly complex.

During an analysis, a variety of photo-derived information is produced in the form of overlays, sketches, and notes. Some of this information can be portrayed on overlay material in place on the photomosaic by tracing out the factor in question, e.g. the drainage net or the road net. These overlays are referred to as direct factor overlays, and some of them can be prepared by the lower skill level groups. Other elements of information cannot be drawn in place on the overlay and exist as separate sketches and notes. These elements include terrain profiles, gully cross section and gradient, and some measurements. By evaluating the direct factor overlays, sketches, notes, and measurements, other types of information are deduced that can also be expressed on a map-like overlay keyed to the photomosaic. These overlays are referred to as derived factor overlays. For the most part, these involve some form of classification, and consequently, their preparation requires using individuals from the higher skill levels. Table 6 lists the various information groups and data base elements that are routinely obtained from an air photo analysis. Furthermore, these elements and information groups are representative of many of the MGI needs of the Army. At present, machine and machine-assisted techniques seem to be of little consequence in generating any of the material that goes into the overlay, either direct or derived. Even so, they are of consequence in storing, filing, and presenting such information. Attempts to apply machine techniques to data production are being made in several places. Exactly where and how they will be used and the levels of efficiency, practicality, and reliability they can achieve remain to be learned.

TABLE 1. Basic methods for extracting information from imagery by manual procedures

METHOD	SYMBOL	PROCEDURE	COMMENTS
Direct	d	Direct observation or detection of objects, shapes, patterns, arrangement, tone and texture, etc. Identification of simple pattern elements.	In general these methods require less training, experience, and judgment. Of direct help here are photo keys, Air Photo Indicator Sheets, Feature Identification Sheets, and machine assisted techniques of analysis and measurement.
Measurement	m	Determination of dimensions (width, length, height), volume, area, slope, tree density, direction, etc.	
Inferential	i	Inductive and deductive reasoning from associated clues and convergent lines of evidence to derive information not directly apparent in the imagery.	This method requires more ability, training, experience, and knowledge. Of assistance here are P.I. Logic Sheets, Air Photo Pattern Summaries, Air Photo Indicator Sheets. Logic software plus an example data base in an interactive system could also be of assistance.
For each factor, information element, or classification unit, some or all of the following characteristics are wanted.			
DETECTION (d)			
IDENTIFICATION/CLASSIFICATION (d, m, i) Type, species, road/bridge class, etc.			
DESCRIPTION (d, m, i) Shape (plan and elevation), arrangement, orientation, extent, depth, dimensions, slope, gradient, structure, areal and vertical homogeneity, boundary specification, color, tone, texture, etc.			
CONDITIONS (d, i) Status, wet-dry, frozen, unfrozen, seasonality, growth stage, active, abandoned, under construction			
PROPERTIES (i, m) Hardness, porosity, permeability, erodibility, density, spacing, etc.			
SUPPLEMENTAL FEATURES (d, m, i)* Bedding, joint/fractures, faults, strike, dip, slips, sinks, voids, bars, cones, polygons, burns, actual use, etc.			
DYNAMICS (i) Historical development, environmental interaction, mechanisms of change, effect of weather, etc.			
		SIGNIFICANCE (i) Suggests materials, composition, bearing load, etc.	
		SIGNIFICANCE (i) Suggests materials, conditions, nature of the climate, classification, use, etc.	
		SIGNIFICANCE (i) Suggests materials, climate, development, classification, presence of instability, limits of use, potential for change, etc.	
		SIGNIFICANCE (i) Suggests materials, conditions, limits of use, classification, potential for change, etc.	
		SIGNIFICANCE (i) Suggests properties, conditions, materials, development, subsurface characteristics, instability, limits of use, etc.	
		SIGNIFICANCE (i) Suggests development, climate, limits of use, potential for change, response to stress (natural and cultural), etc.	

*Denotes that the d and m procedures require a higher level of skill than normal.

TABLE 2. General Training and Experience Associated with Three Levels of Skill that Represent the Extremes and the Midpoint ¹

- 1 Minimum level of training – High school diploma, 4 weeks of specialized training, plus 4 weeks of on-the-job training for each specialty, and 12 weeks experience.

- 2 In addition to the above, this level requires 1 or 2 years of experience and considerable knowledge (college level) about at least one specialty, such as soils, geology, vegetation, land-form, drainage, land cover classification, some land use classification, bridges and road classifications, etc.

- 3 This level requires an unusual depth of knowledge (graduate level) about a specialty as well as a working knowledge of several disciplines, plus considerable working experience.

¹Based on material in:

J.N. Rinker, J. Ehlen, A.E. Krusinger, T.R. Currin, A.O. Poulin, P.B. McCracken. 1976. *Capabilities of Remote Sensors to Determine Environmental Information for Combat*. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, ETL-0081, AD-A035 139.

TABLE 3. A list of common photo analysis tasks and associated methods of information extraction and skill levels. The methods for extracting information are defined in table 1. Skill levels are described in table 3. Note that the first five tasks contain a large amount of the basic information needs and that they can be done by the lowest skill level group.

Task to be Done	Methods for Extracting Information	Skill Level
1. Detection/Identification – Simple. Mark, bound, and trace simple objects and pattern elements, e.g. roads, railroads, water bodies, structures, towns, airports, forest, cropland, barren, some landforms, some drainage patterns (subhumid and arid regions), etc.	d	1
2. Classification of some elements such as roads, bridges, etc., and simple land cover/land use.	d, m	1
3. Measurement – Plan. Dimensions, direction, orientation, etc.	d, m	1
4. Description – Simple. Layout, arrangement, orientation, and shape.	d, m	1
5. Measurement – Elevation. Heights, slopes, and measure or estimate areas and volumes.	d, m	1–2
6. Detection/Identification – Complex. Mark, bound, and trace complex objects and pattern elements, e.g. landform, drainage, profiles, cultural, vegetation.	d, m, i	2
7. Classification of land cover/land use patterns, vegetation patterns, cultural patterns, surficial materials.	d, m, i	2
8. Description – Complex. Shape, slope, structure, symmetry, areal and vertical homogeneity, etc.	d, m	2
9. Interpretation of data as applied to specific problems and prediction of simple forms of environmental impact.	d, m, i	2
10. Detection/Identification – Supplemental Features. Mark, trace, or indicate supplemental features such as bedding, joints/fractures, strike and dip, slips, tears, flows, etc.	d, m, i	2–3
11. Prediction of properties and conditions. Examples include resistance to erosion, hardness, stem spacing, stem diameter, presence of subsurface voids, and unstable materials and conditions.	d, m, i	2–3

TABLE 3. (Continued)

Task to be Done	Methods for Extracting Information	Skill Level
12. Significance of information elements, singly and collectively.	i	2-3
13. Classification of rocks, soils, and complex versions of landform, vegetation, land cover/land use, etc.	d, m, i	2-3
14. Preparation of environmental data base.	d, m, i	3
15. Interpretation of an environmental data base for construction site selection and evaluation, environmental impact, and prediction of responses to stress.	i	3

TABLE 4. Classification plans, methods of information extraction, and needed skill levels. None of the categories in any of the columns can be rigorously separated from the others. There is a transition. In general, however, the classification schemes that are needed for the preparation of any given data base determine the complexity of the photo analysis and the levels of skill and experience needed to complete the task.

Types of Identification and Classification	Example	Methods for Extracting Information	Skill Level
Generic	forest, tree, shrub, grassland, cultivated land, road, bridge, hill, bare soil, etc.	d	1
Specific	rain forest, oak tree, closed evergreen, broadleaf shrubland, cereal grain crop, interstate, truss bridge, barchane hill, windblown silt	d, m, i	2
Composition	mixed hardwood forest, cement concrete road, wooden bridge, sand hill	i	2
Use	Recreational forest, rangeland, cropland, railroad bridge, quarry, etc.	d, i	1-2
Property	closed canopy forest, thorny shrubland, impermeable soil, 30% slope, average stem spacing, etc.	d, m, i	2-3
Conditions	Gypsy moth infested forest, diseased crops, saturated soil, unstable slopes, potable water, etc.	d, i	2-3
Origin	residual soils, transported soils (aeolian, glacial, fluvial, etc.)	i	2-3

TABLE 5. Land cover and land use categories that should be identifiable by skill level 1 individuals, i.e. the lower of the three skill levels. This is based on using stereo aerial photography within the 1:20,000 to 1:100,000 scale range. Although these items form a simple land cover/land use data base, such information is directly applicable to many stated needs. If supplied with suitable Air Photo Indicator Sheets, this same group should be able to classify within some of these categories, e.g. amount of canopy closure, road type, bridge type, crop type, dam type or purpose, structure type and probable use, landform type, etc.

- Trees
- Brush
- Grassland
- Mixed
- Cropland
- Barren
- Water bodies
- Drainage-plan
- Roads
- Railroads
- Airports
- Bridges
- Dams
- Rights of way
 - Power lines
 - Pipelines
- Fence lines, hedgerows
- Structures
- Collections of structures (strip, town, etc.)
- Mixes of trees and structures
- Some landform and slope classes

TABLE 6. Data base information obtainable from air photos. Some of the direct observation type of information abstracted from the photos can be portrayed in the form of tracing, or other notation, directly on transparent material covering the photos. These are Direct Factor Overlays. Other types of information, i.e. observations and measurements, are recorded as notes and sketches. Information that is derived by inference and judgment can also be presented on overlays keyed to the air photos. These are Derived Factor Overlays, and usually consist of classification terms assigned to bounded areas and special identifications. These overlays, notes, and sketches form an environmental data base that can be evaluated with respect to a given problem or task.

AIR PHOTO PATTERN ELEMENTS

Landform
Drainage-Plan
Drainage-Elevation
Indicators of erosion
Indicators of deposition
Vegetation
Cultural
Tone and texture
Special

OBSERVATIONS, SKETCHES, AND NOTES

Information obtained by direct observation but which cannot be mapped or traced in place on the photos

1. Landform: profiles, shape characteristics, cross sections
2. Drainage-Elevation: gully cross section and gradient
3. Indicators of erosion
4. Indicators of deposition
5. Tone and texture

EXAMPLES OF INFORMATION THAT CAN BE MEASURED, OR APPROXIMATED

1. Dimensions of objects
2. Radius of curvature
3. Areas and volumes
4. Tree height and density
5. Canopy closure
6. Stream width
7. Slope
8. Spacing and orientation

DIRECT FACTOR OVERLAYS

Patterns and features traced or marked in place by direct observation

1. Drainage-Plan
2. Ridgelines
3. Lineations
4. Dip and strike
5. Pattern boundaries
 - landform
 - drainage
 - vegetation units
 - vegetation damage
 - land cover
 - land use
 - flood damage
 - structures
 - tone and texture
6. Cultural objects: roads, railroads, trails, canals, airports, pipelines, power lines, towers, buildings, bridges, some property boundaries
7. Special features: locations of slumps, tears, gradient changes, cross section changes

DERIVED FACTOR OVERLAYS

Examples of classifications and predictions based on inference and evaluation of the stereo photos, Direct Factor Overlays, sketches, and descriptive material

1. Geology: rock type, distribution, structure, properties, cross sections
2. Soils: type, distribution, depth, properties, conditions
3. Vegetation: type, distribution, properties (closure, spacing, diameter, vigor)
4. Slope classes
5. Land cover/land use identities
6. Critical areas: sites of potentially unstable soils, rocks, slopes, etc.
7. Probable locations of subsurface voids, ground water, minerals, contamination points, etc.
8. Change (needs sequential imagery): land use, population, economics, landform, etc.

PRODUCTS AND IMAGE ANALYSIS DOCUMENTATION

J. N. Rinker and P.A. Corl

If this manual procedure of analysis is to be improved, be more routinely applied, be involved in technology transfer, or be a guide to help develop computer-assisted techniques, it is a prerequisite that its logic and information elements be tested, certified, and documented in a readily usable and reliable manner.

There are but two sources of information for such documentation. One is the review, evaluation, and acceptance or rejection of existing information, including our own reservoir of knowledge, experience, field data, and imagery. The other is the discovery, testing, and establishing of new information. At ETL, the Center for Remote Sensing (CRS) is actively working on both aspects, i.e. the evaluation and refinement of existing knowledge, and the search for and development of new knowledge. Aside from the technical papers in the open literature, much of the CRS documentation is being put into formats designed to present and relate small single elements of information. In the case of manual image analysis (photo, radar, LANDSAT), the information unit is a pattern element that has proven to be an indicator of some aspect of the terrain. In the case of LANDSAT digital analysis, our information elements to date are spectral reflectance measurements and band intensity measurements associated with certain materials and conditions, or combinations of materials. The spectral reflectance measurements include information about pure materials, i.e. a material uniformly filling a field of view, as well as combined responses, such as varying ratios of vegetation and soils within a field of view. In the case of infrared thermal radiation, the information units contain specifications of time, bandpass, and meteorological conditions associated with feature/background contrast ratios. At present, the air photo pattern elements are receiving more attention than are the others. Each element, regardless of source, must be tested. Is it false, or is it true? If true, is it always true, or true only under certain conditions, and if so, what are the conditions? In order to answer these questions, it is necessary to consider ground observations, and measurements, as well as the pattern elements in the aerial photography or other imagery. Only by such a procedure of image analysis, field checking, arguing, and technical critique can one separate opinion from fact, establish validity, and set the basis for subsequently putting the material into a printed form.

Of the elements from the literature that have gone through the test and critique cycle, many have fallen by the wayside because they were proven to be either inaccurate or of too limited an application. Many others, including our own, have needed extensive modification. Very few have made it through to the final product without alteration. Of necessity, a large amount of printed material has been, and is being, collected and reviewed. This includes Army manuals, the open literature, internal reports, data bases, classification schemes, etc. Many of these items had what proved to be a surficial plausibility that read well, but which fell apart upon testing and critical review. Additional

complications included inconsistencies within the internal logic, contradictions within and between documents, and a noticeable lack of clarity. As a final test, one must be able to sit down with the images and the associated document, do what is said, see what is claimed can be seen, deduce what is claimed to be possible, and then go to the field and find that the results are correct. If this cannot be done, then that element or procedure must either be modified to make it true, or discarded. Before progress can be made in all of the ramifications associated with the applications of air photo and image analysis and their potential transition into a machine-assisted procedure, the bits and pieces, and the logic that binds them together, must be documented, and it is equally important that the documentation be correct.

In addition to conventional research reports, the information about patterns, materials, conditions, procedures, and radiometric characteristics is being expressed in a series of related documents that can be expanded or otherwise modified in the future. As field work, laboratory work, and literature review progress, deletions, alterations, and additions will be made. At present the proposed series consists of

Summary Sheets

Factor

Materials

Air Photo Patterns

Air Photo Indicator Sheets

Photo Interpretation Logic Sheets

Spectrophotometric Data Sheets

Radiance Data Sheets

Classification Schemes

Soils

Vegetation

Land Cover/Land Use

Application Summaries

Ground Water

Minerals

Soils Mapping

In general, the items in the top group are in formats that, in addition to other uses, can provide a means for selecting and transferring information into programs associated with machine-assisted or interactive procedures, such as a knowledge-based expert system, or into programs associated with digital feature extraction. Items in the middle

group are associated with data base preparation. Items in the lower group are meant to outline sequences of pattern elements associated with a given task. Those products in the upper group entitled "Materials, Air Photo Patterns, Air Photo Indicator Sheets, and Photo Interpretation Logic Sheets" are part of the documentation for the manual procedure of air photo analysis. In addition, they serve to evaluate the applicability of machine processes and to supply information in a form that can be incorporated into knowledge-based expert systems.

These documents supplement each other and, as a set, are designed to portray and illustrate the reasoning processes that an expert in air photo analysis would follow in making decisions and predictions about the nature of the terrain in terms of its identities, composition, conditions, practical utilization, and response to stress or cultural impact. This information can then be codified into rules and some form of logic network based on sequential questions and answers. With the rules and the yes/no answers, the non-expert can be led through the reasoning steps by a sequence of "If yes, then . . ." type of statement that leads to some conclusion. At any point, the user should be able to query the system as to the why of the statement.

It was mentioned earlier that the state of the art for obtaining detailed terrain information was the manual procedure of air photo analysis. This will continue to be true, even if one assumes the existence of a perfectly designed interactive system. In order to make use of the stored rules so that predictions can be made, a series of direct questions must be answered, and the answers to these questions come from the photos. For such questions as "Is the gully bottom flat?" (yes or no), "Is the gully gradient uniform?" (yes or no), "Do the walls of the gully have uniform slopes?" (yes or no), etc., the answers can come only from an analysis of the stereo photo, and this is a manual procedure, except for those features that can be identified by automatic machine recognition techniques. Nevertheless, an interactive system can direct the analyst to consider pattern elements that might have been overlooked and into paths of reasoning that were missed and, of more importance, to enable the nonexpert to produce results similar to those of an expert analyst. There is, however, this basic division of labor: the analysis of the photos is manual, and the interpretation of these results is by the computer. An example of a question and answer sequence of a type associated with knowledge-based systems is in appendix I.

SUMMARY SHEETS

Factor Summary Sheets. These are single sheet descriptions of each of the pattern element groups of landform, drainage-plan, drainage-elevation, erosion, deposition, vegetation, cultural, photo tones and texture, and special. Where appropriate, a first-order classification is, or will be, included. These represent a first draft, and changes will be made as work and discussion continue. Insofar as earth surface materials are concerned, the more important members of this group are landform, drainage (plan and elevation), erosion, deposition, and tone and texture. These groups are easier to organize and illustrate than are the other pattern elements. In any event, it may turn out that this sort of information is better presented in text form rather than as a series of summary statements. If so, these sheets will be dropped. The Factor Summary Sheets completed to date are in appendix A.

Materials Summary Sheets. These are single sheet descriptions of general characteristics and properties of earth materials. Because the physical and chemical properties of any material set the bases for the kinds of patterns that erosion and weathering can develop in that material, an understanding of these properties is of help in making judgments about patterns, pattern variations, and significance. The list of materials that will be treated in this section includes members of the igneous, metamorphic, and sedimentary rocks, and some soils. Examples of sheets completed to date are in appendix A.

Air Photo Patterns Summary Sheets. These single sheet summaries serve as reference guides to the photo pattern elements associated with a given material, in a given condition, and in a given climate. Each sheet is for a specific material and climate relation. As an example, one sheet is entitled "limestone, flat-lying, humid and subhumid areas." Each summary describes the characteristic landforms one can expect to find, the patterns associated with drainage (plan and elevation), the indicators of erosion that one should look for, depositional patterns that can form, vegetation associated with the material, typical cultural patterns that can occur, the nature of the tones and textural patterns, and special pattern elements that are uniquely related to the subject. These sheets provide basic relations that can be codified into rules for an interactive system. The materials to be described in this manner include members of the igneous and metamorphic rocks; the sedimentary rocks in the forms of massive pure beds, thin beds, and interbedded units; and some soils and surficial deposits. Air Photo Indicator Sheets will be used to illustrate the pattern elements that are discussed. Examples of these sheets are in appendix A.

AIR PHOTO INDICATOR SHEETS

These single sheet guides illustrate and describe specific pattern elements that are related to or indicative of a given material or condition. The pattern elements to be presented are those within the factors of landform, drainage (plan and elevation), erosion, deposition, vegetation, cultural, tones and texture, and special. Each sheet contains an air photo example, stereo if needed, plus ground photography when available. Along with each indicator are given the condition or the material that it indicates, the geographic location, the climatic zone (based on Trewartha, 1957), comments about the pattern, how the relation was verified, sensors that can detect the pattern, limitations in terms of film/filters, season, etc., and the engineering significance where appropriate. The pattern elements listed in the Air Photo Patterns Summary Sheets as well as the dominant and supportive indicators in the Photo Interpretation Logic Sheets will be illustrated with this form of indicator. Because these sheets illustrate the basis for making a judgment, or a decision about a pattern element and its relations to terrain components, they form a portion of the knowledge-base part of an interactive system. Specifically, they are meant to illustrate questions in the analytical sequence (refer to appendix I). These sheets can also serve as general reference material, as image keys, and as training aids. Indicator Sheets completed to date are in appendix B. Whether or not a similar approach will be taken with other forms of imagery remains to be determined.

PHOTO INTERPRETATION LOGIC SHEETS

The original purpose of these sheets was to provide a means for evaluating the manual procedure of photo analysis and determine what steps, if any, lent themselves to machine procedures, interactive systems, etc. Although the sheets do serve this purpose, they have been arranged to meet other goals as well. They provide a sequential listing of the pattern elements used in photo analysis. Next to each element are listed the dominant and supportive pattern indicators that the "expert" uses to identify or gain information about the specific element. Each of these pattern indicators is judged in terms of stereoscopic aerial photography, monoscopic aerial photography, automatic pattern recognition, and interactive systems. Adjacent to these evaluation columns is a column for comments. As many as possible of the dominant and supportive pattern indicators will be cross referenced to appropriate Air Photo Indicator Sheets. The pattern elements listed are from the factor groups of landform, drainage (plan and elevation), erosion, etc. At present, work will be restricted to landform and drainage (plan and elevation). When these are completed to some acceptable level and if it is still the intent to continue, then attention will be turned to erosion, deposition, and tone and texture. At this point, the evaluation columns for manual and machine procedures will be eliminated to provide space for additional comments and for cross-referencing the pattern indicators into appropriate data bases, e.g. MGI, Digital Land Mass System (DLMS), Tactical Terrain Products Data Base (TTPDB), etc. These sheets, along with the Air

Photo Indicator Sheets, provide the data units and basic elements of logic for incorporation into an interactive system. Specifically, they are the source of the questions that guide the analysis (refer to appendix I). Examples of the Photo Interpretation Logic Sheets are in appendix C.

SPECTROPHOTOMETRIC DATA SHEETS

Although there are several uses for these sheets, including camouflage and signature studies, they are oriented towards feature extraction based on supervised digital classification of LANDSAT scenes. An absolute spectral reflectance curve also enables one to estimate emissivities and thereby predict spectral emittance. Many materials have reflectance curves that are identical over some portion of the electromagnetic spectrum, but which differ in other parts. In this instance, one sensor would depict them as the same and another sensor would note a difference. The use of various film/filter combinations and multiband sensors to separate different materials is based on these relations.

The LANDSAT Multispectral Scanner (MSS) is perhaps the best known and most frequently used of the multiband techniques. It collects reflected sunlight from each instantaneous field of view (IFOV), which is about 70 by 70 m, and records the intensities in each of four spectral bands. The bands, which for LANDSAT 1 through 3 are numbered 4, 5, 6, and 7, have the respective wavelength passes of 0.5–0.6 μm (green), 0.6–0.7 μm (red), 0.7–0.8 μm (infrared), and 0.8–1.1 μm (infrared). On LANDSAT D, the new Thematic Mapper on board provides six more bandpasses. The approximate wavelength ranges are 0.45–0.52 μm , 0.52–0.60 μm , 0.63–0.69 μm , 1.55–1.75 μm , 2.08–2.35 μm , and 10.4–12.5 μm . The latter bandpass is commonly used in infrared thermal techniques. If one considers satellite systems other than LANDSAT,¹¹ then a variety of reflectance and emittance data are becoming available throughout the visible, photo infrared, thermal infrared, and microwave regions of the spectrum. Aside from conventional manual analysis of the imagery, such data can be manipulated by digital techniques, and a variety of programs have been developed for this purpose, most notably for the LANDSAT MSS.

Successes in digital classification, or at least in digital discrimination, are most frequently associated with features that have strong and unique spectral differences from their surroundings. Such features include damaged vegetation, vegetation units, exposed zones of alteration in soils and rocks, lakes, sediment loads, snowfields, etc. Discrimination and identification are, of course, two different things and the latter is the more difficult task. Even for discrimination, however, a program developed for one scene will not necessarily work on another scene of the same area or for the same type of terrain

¹¹NOSS National Oceanic Satellite Systems, 23 March 1979. A joint effort by National Aeronautics and Space Administration, Department of Commerce (National Oceanic and Atmospheric Administration), and Department of Defense (Navy, Air Force, and Army).

components in a different area. Nevertheless, a supervised classification, i.e. a classification procedure wherein the analyst is directly involved and can correct or eliminate obvious misclassifications and otherwise modify selection rules, is increasingly being used. Although a nonsupervised, or automatic, classification might work for a few features, such is not yet applicable for deriving general terrain information. There are several problems associated with classifying digital spectral information, including (1) variations in the quality and quantity of incoming sunlight as a result of atmospheric changes and seasonal changes, (2) variations in surface orientation, (3) lack of baseline spectral reflectance measurements, and (4) the IFOV being frequently composed of different surfaces.

Because of the obvious importance of spectral relations to many scientific needs, as well as the continual improvement of airborne and satellite systems to record spectral intensities in narrower and more numerous bandpasses, the abilities to discriminate and, in some cases, to identify, will be improved. Consequently, there will be an increasing use of digital analysis and digital classification techniques. Because in such procedures detection and identification are based on differences in spectral characteristics, it is important to establish the relations between cause and effect, determine the variances within scenes, and gain an understanding of the practical limits of reliability. Towards these ends, we are collecting from soils and plants a variety of laboratory and field spectral measurements (reflectance, fluorescence, absorptance) as functions of age, moisture, salinity, mineral content, stress, illumination characteristics, season, and percent cover in an IFOV. With reference to reflectance studies, the experiments include spectral, diffuse, and total hemispheric measurements, with the latter being done by means of integrating spheres. In some cases, the vegetation and soil samples are chemically analyzed to find out if there are any relations between the spectral reflectance, vegetation composition, and soil composition. Results of this research have been presented in the open literature, as well as via internal reports.^{12,13,14,15} A single sheet format is being developed at ETL to display this type of information on a feature-by-feature basis. In addition to the spectral data, regression equations will be included where appropriate. Such a data sheet might help in making decisions about LANDSAT band choice and band ratioing for digital classification, as well as provide information for photographic detection. A sample sheet is in appendix H.

¹²M.B. Satterwhite. "Changes in Soil Spectral Reflectance by Vegetative Cover." *Proceedings, Am. Soc. of Photogrammetry*. 1981 Annual Meeting, Washington, DC, February 1981.

¹³M.B. Satterwhite, J.P. Henley, and M. Treiber. 1982. *Vegetation Cover Effects on Soil Spectral Reflectance*. U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, Virginia, 1982, ETL-0284, AD-A125 817.

¹⁴M.B. Satterwhite. 1982. *Vegetation and Terrain Effects on Digital Classification of LANDSAT Imagery*. U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. ETL-0292, AD-A124 236.

¹⁵M.B. Satterwhite and J.W. Eastes. 1981. *Spectral Reflectance of Plant Indicators of Saline and Nonsaline Soils*. ILIR No. 1191D010091 Final Report, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

RADIANCE DATA SHEETS

Infrared Thermal. Research at the CRS-instrumented test site at ETL has generated a large amount of data associated with infrared thermal techniques, and some of these results have been released in the form of scientific reports.^{16,17,18,19} Single sheet summaries can be prepared that show radiation characteristics of various features/background combinations. Such sheets could include radiation variances as a function of time, meteorological conditions, physical conditions (material type, temperature, moisture, etc.), time of maximum contrast between feature and background, etc.

Microwave (Active and Passive). Cooperative research efforts with the Naval Research Laboratory (NRL), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and National Aeronautics and Space Administration (NASA) include evaluating passive microwave radiometers, a microwave imager, and radar with reference to vegetation type, canopy closure, soil, canopy contribution, canopy masking of ground radiation, and canopy obscuration of the terrain to radar. As these flights are infrequent, the data accumulate slowly. Variations in the recordings from the passive systems have shown some correlation with vegetation patterns, but whether these are due to differences in vegetation radiation properties, changes in soil type, or soil moisture is not yet known. Chemical analysis of the vegetation, especially for metallic elements, will be done to find out if there are any relations between such data and microwave emittance and reflectance. The research into the spectrophotometric, radiometric, and chemical characteristics of vegetation, soils, and rocks helps to develop knowledge applicable to specific feature extraction and to data base preparation in general. Figure 1 shows the ways in which this type of research supports the overall problem of data base generation and feature extraction. At present, we do not know if the results of these studies will lend themselves to summary sheet presentation.

¹⁶A.O. Poulin and A.E. Krusinger. 1980. "Instrumented Test Site for Infrared Backgrounds." *Presented at Meeting of the IRIS Specialty Group on Targets, Backgrounds and Discrimination.* 26, 27 August 1980.

¹⁷A.O. Poulin, A.E. Krusinger, M.B. Satterwhite, and L.K. Balick. "Observations of the Nocturnal Thermal Characteristics of an Isolated Conifer." ILIR No. 1091D010085 Report, October 1980, unpublished.

¹⁸A.O. Poulin and A.E. Krusinger. "Thermal Structure of Point-Source Vegetation Targets." ILIR No. 1191D010090 Final Report, 1 October 1981, unpublished.

¹⁹A.O. Poulin and A.E. Krusinger. *The Nocturnal Relationship of Isolated Tree and Air Temperature.* U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. Report in progress.

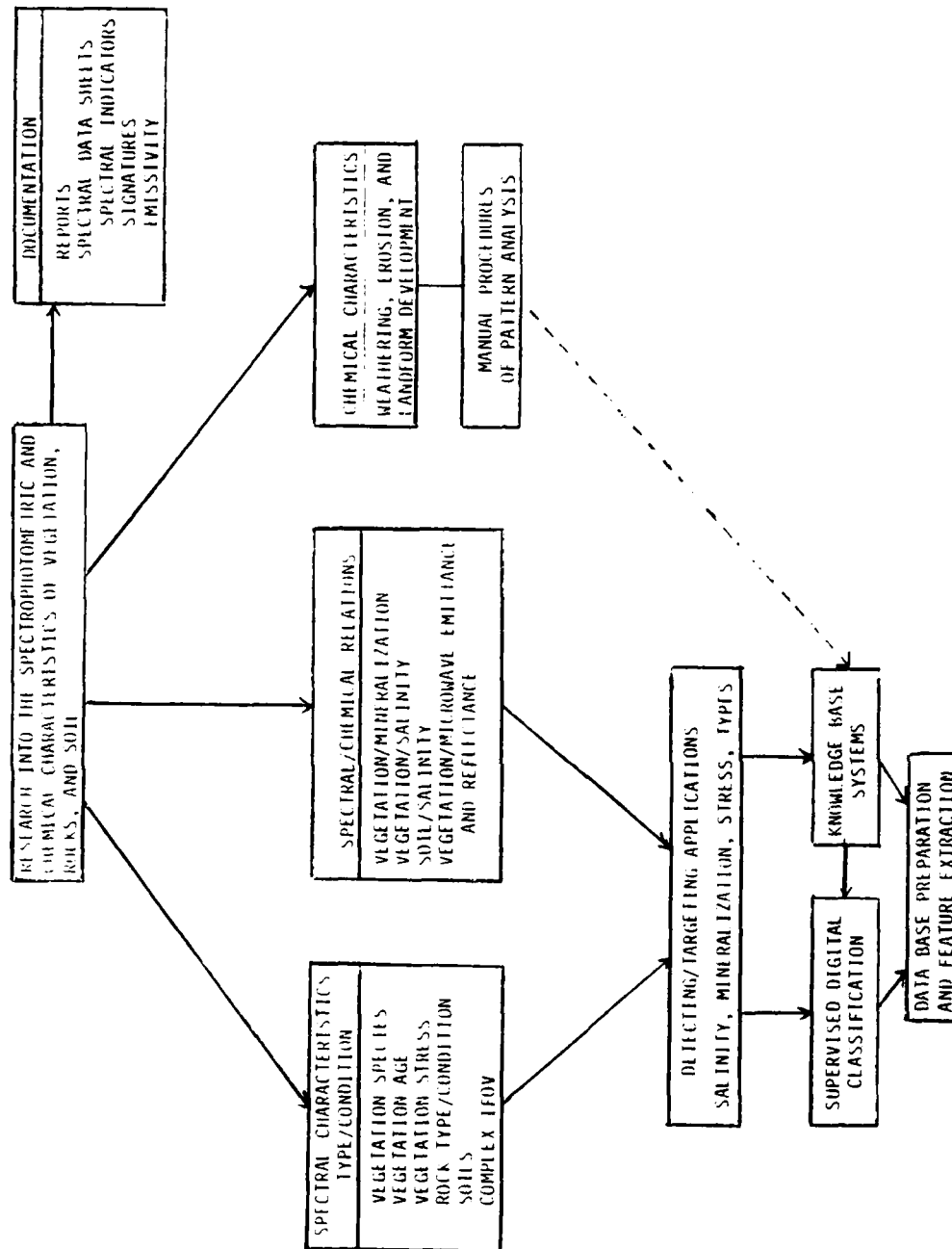


FIGURE 1. Diagram showing the ways in which research into the spectrophotometric, radiometric, and chemical characteristics of vegetation, soils, and rocks interact to develop knowledge applicable to specific feature extraction, or to data base preparation in general.

CLASSIFICATION SCHEMES

Whenever a large assortment of information elements is to be presented in a data base, some sort of classification system is needed to relate the pieces to each other and to establish a hierarchy. By and large, classification systems that are usable with photo analysis and that are directed towards, or at least include, information elements related to Army needs are not readily available. Consequently, effort has gone into developing classification systems for soils mapping, land cover/land use, and vegetation.

With reference to soils mapping, existing classification systems are based on laboratory or field measurements, not on photo patterns. Within ETL, a scheme has been developed that is based on the manual procedure of photo analysis and that has been critiqued but not tested. With reference to land cover/land use, 20 classification systems were evaluated, one of which was tested by photo analysis. None of the systems were satisfactory, either in being usable with imagery or in supplying sufficient amounts of terrain information needed by the Army. In view of the fact that the systems were designed around economic considerations, the latter finding is not surprising. Within ETL, work is continuing on developing a system that meets three goals: first, it must be applicable to manual techniques of image analysis, at least at the first level; second, it must be able to assimilate other sources of information at higher levels of classification without the need of altering the basic structure; and, third, it must include Army information needs. A similar situation exists with reference to the vegetation classification and a scheme has been developed that is based, in part, on work in ETL Report 0058, "Study of Classification and Nomenclature of Vegetation." This scheme has been critiqued, partially tested, and is being modified.

There are some characteristics that all classification schemes should share. A report by Liu lists qualifications that a soil classification system should have.²⁰ Because these comments apply equally to other subjects, they are paraphrased below.

1. Use of distinct attributes, but as few as possible, as the basis for forming groups.
2. Develop a logical, simple, and concise scheme that is easily remembered.

²⁰T.K. Liu. 1970. "A Review of Engineering Soil Classification Systems." In: *Special Procedures for Testing Soil and Rock for Engineering Purposes*. ASTM Special Technical Publication 479. Am. Soc. for Testing and Materials, 1916 Race St., Philadelphia, Pennsylvania 19103.

3. Groups should have meaning, i.e. the grouping of the elements should provide an indication of the general broad properties or behavior of the members.
4. Terminology should consist of descriptive, easily understood, and commonly used terms.
5. Symbols cannot properly substitute for descriptive names, but when they must be used they should have specific meaning and be easily associated with the element in question, i.e. avoid codes that have meaning only to a specialist or that require constant reference to tables for translation.
6. Flexibility. The scheme should be capable of adsorbing additions, deletions, or the creation of subdivisions without affecting the basic structure.
7. At least in the early levels of classification, the system should be capable of being used by relatively unskilled personnel.

To these qualifications we have added the following:

1. The scheme must lend itself to photo analysis techniques.
2. It must be able to absorb information from other sources.
3. It must include information elements required by the Army.

Summaries of the work on classification systems for soils, vegetation, and land cover/land use are in appendixes D, E, and F.

APPLICATION SUMMARIES

These are to be basic outlines that show the sequence of steps and the important pattern elements associated with an image analysis directed towards a specific task, such as finding the most probable areas for locating minerals, ground water, or sub-surface voids, etc. Accompanied by indicator sheets, they could be of use with an interactive system. There are interactive programs that are analogous in concept, ranging from early ones in chemistry and diagnostic medicine up to more recent ones in exploration geology. This is a low priority item, and furthermore work cannot start on it until more of the photo analysis documentation is done.

In figures 2 and 3, the relations among the topics that have been discussed are summarized. Figure 2 shows the general relations between the research work and the forms of documentation with respect to an analytical procedure, i.e. based on inductive and deductive reasoning. Figure 3 shows the relations of the various types of documentation and their intended uses with respect to manual analysis, supervised digital classification, and knowledge-based systems for interactive procedures of analysis.

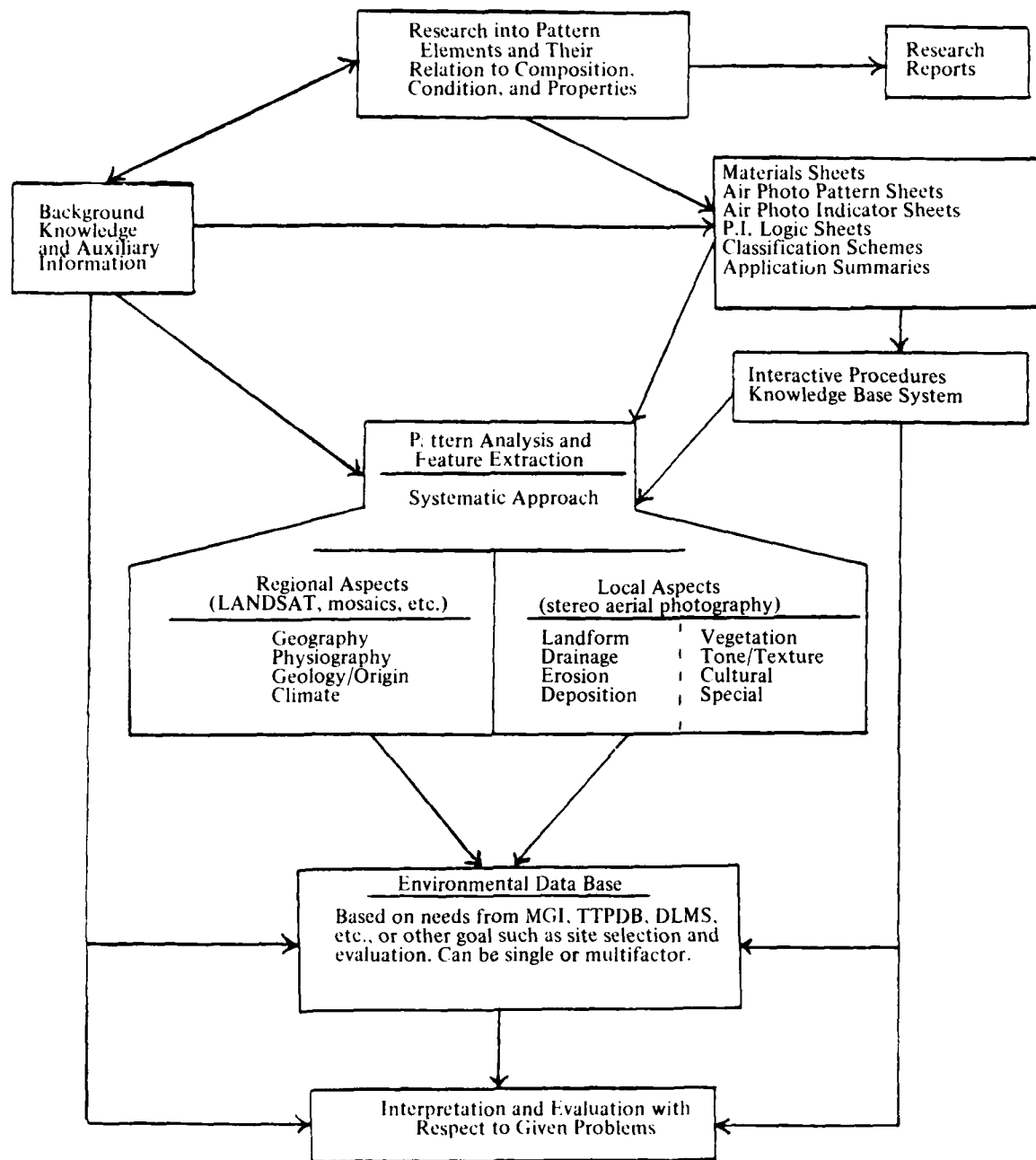


FIGURE 2. Relations between background knowledge, research, and documentation in the development of analytical procedures based on deductive and inductive reasoning.

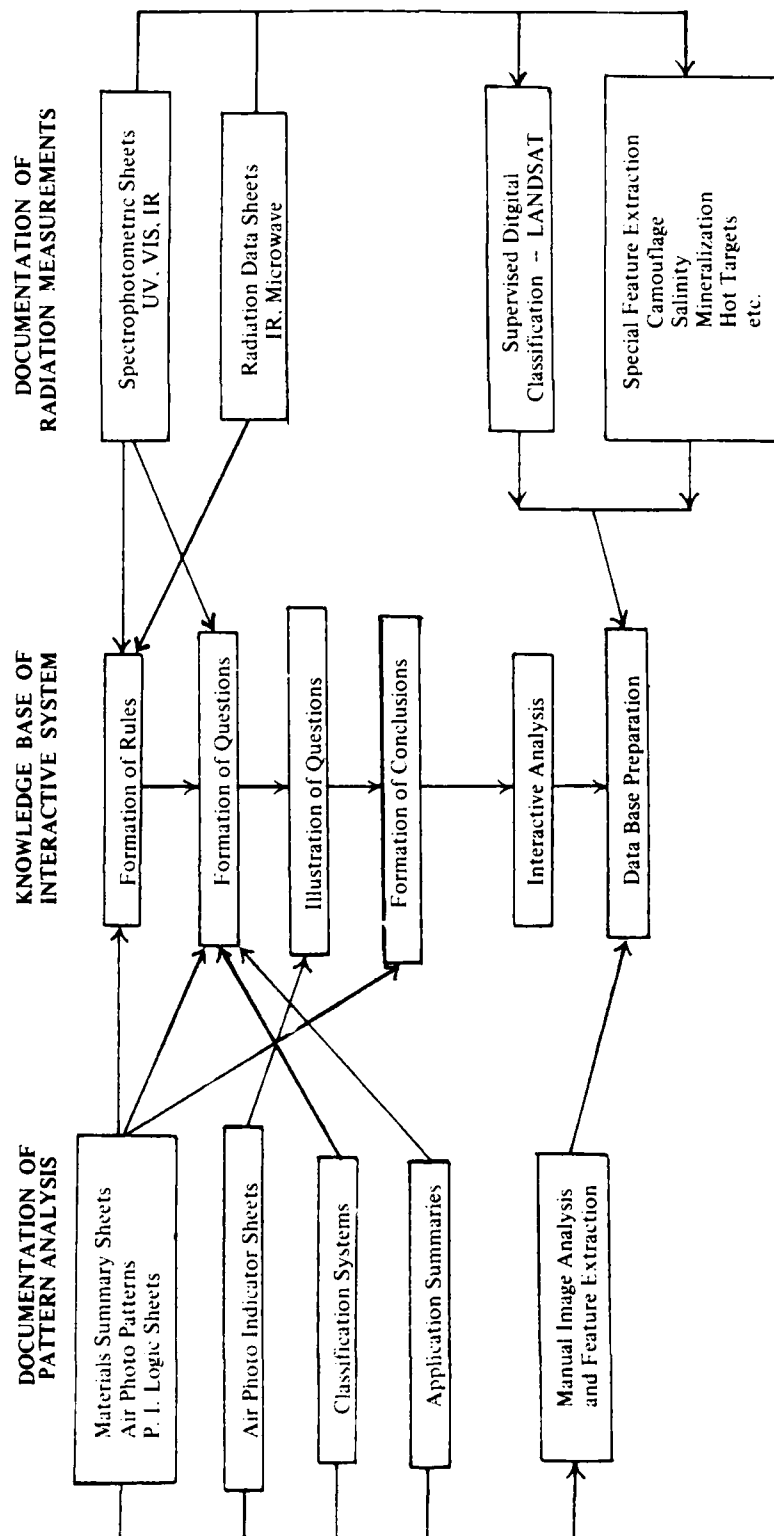


FIGURE 3. Documentation Uses. Documentation forms associated with pattern analysis are listed at the upper left and those associated with spectroradiometric measurements and radiation characteristics (infrared and microwave) are listed at the upper right. Both types of documentation can be used to support specific projects, as shown in the lower part of the figure, or contribute a knowledge-based system that can be used for interactive analysis and subsequent data base preparation.

LANDFORM

Landform refers to the shape, size, and orientation of any given surface feature and its location within and its relation to the surrounding area. It is the most important pattern element because it is so closely associated with the origin of the material and the subsequent erosional history. An understanding of landforms and their origin makes it possible to bound areas of similar materials and predict their composition, textures, and physical characteristics. In this part of the photo analysis, areas are outlined in which the terrain elements within are uniform in shape, size, spacing, arrangement, and orientation. An area might contain but one item or one shape, for example a plain, or it might contain a collection of shapes, such as a group of similar hills. Each bounded area must be described in terms of shape, size, spacing, arrangement (vertical and horizontal), symmetry and asymmetry, dip, slope, angularity, roundedness, and ratio of top area to basal area (for hills). These pattern element items are indicative of materials and conditions, and they must be evaluated in terms of significance. For example, sharp angularity in the hills, or mountains, is descriptive of the shape. The significance of this pattern is that it suggests the presence of a hard resistant material. Conversely, where hills have soft, gently rounded shapes, it is indicative of a soft material. Climate modifies these aspects and must be taken into consideration. A clay shale can have gently rounded slopes in a moist temperate region, and rugged precipitous slopes in an arid region subjected to seasonal rains and flash flooding. Profiles should be drawn along several transects through the stereo field of view. Upon completion of the analysis the profiles can be converted into predicted cross sections. Classification decisions frequently depend on the purpose of the analysis, scale of the photography, and a definition of the minimum area to be mapped. The complexities of landform classification found in most texts are beyond the needs of air photo analysis; however complicated the shape, it can be assigned into one of four general categories.

Plains. Any relatively flat surface of sufficient extent to be a mappable unit at the scale of imagery used. This includes surfaces that are flat over large regions, such as the Great Plains; surfaces of valley floors, old lake bottoms, terraces, benches, large fans, etc.; and perched flat surfaces such as mesas or buttes. The significance of this shape is that it suggests sedimentation or deposition. Usually, this is indicative of clays, silts, sands, and gravels, either in the form of sedimentary rocks or as soils. Lava flows can form layered sequences, the surfaces of which are flat over extensive areas. These would be mapped as plains. Other pattern elements, however, would direct the chain of reasoning away from considering the material to be sedimentary. The surface of a plain can have variations in relief that lead to such descriptions as: a gently rolling plain, a pitted plain, a dissected plain, etc.

Hills and Mountains. Shapes that have significant positive relief within the area of study, i.e. variations beyond the range of the adjectives used to describe modifications of a plain. Such topography can result from dissection of a plain, doming, or local uplift caused by the intrusion of igneous material, volcanic activity, aeolian deposits, or uplift and folding of the crust. The patterns of hill shape, in plan and elevation, are indicative of the nature of the materials in terms of igneous, metamorphic, and sedimentary rocks and in terms of structure such as dipping, flat-lying, etc.

Basins. Shapes that have significant negative relief and size within the study area, i.e. a depression of some sort. These include old marine and lake beds, large river valleys, solution valleys and depressions, subsidence depressions, etc.

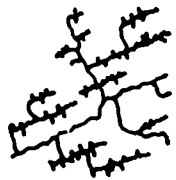
Escarpment. A significant and obvious boundary that separates landform units. When present it is most often as a steep and abrupt change in relief that is continuous over some distance.

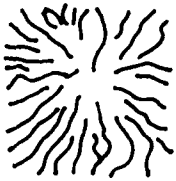
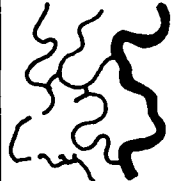
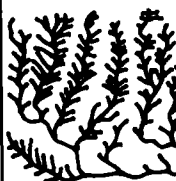
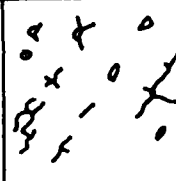
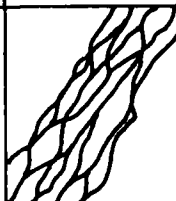
SUMMARY SHEET

FACTOR PATTERNS

DRAINAGE - PLAN

Drainage refers to the paths that water follows as it flows over a surface. It is next in importance after landform and provides information about general soil permeability, ground slope, relative depth of the soil mantle, presence of and type of rock, and dip of beds. Aside from forms of control such as caused by bedding, jointing, and fractures, drainage is a function of soil permeability and slope. Surface drainage patterns do not develop on highly permeable materials such as sand. In materials that are not permeable, such as plastic clays and silty clays, the water runs over the surface and develops an erosional scour or drainage pattern. In general, the finer or denser the drainage net the less the permeability and the finer the material. Parvis (1947) identified six basic patterns, dendritic, trellis, annular, parallel, radial, and rectangular. In addition, there are a few patterns that are uniquely related to a given material or to a given set of conditions. These are anastomotic (Zernitz, 1932), pinnate, discontinuous, and braided. There are many variations of the six basic types and it is seldom that one finds the ideal situation where a pure type forms the pattern.

NONE: The absence of a drainage pattern, or erosional scour, indicates that the material is permeable. Water falling on the surface drains down into the interior, rather than flowing over the surface. Such permeability is characteristic of granular materials.	
DENDRITIC: This tree-like pattern indicates homogeneity in composition and conditions and is frequently found on soils of very low permeability, large intrusive igneous masses, and flat-lying sedimentary rocks (sandstone, shales). A drainage pattern can be dendritic on a regional basis and exhibit other patterns at specific sites.	
TRELLIS: This pattern indicates bedrock control of drainage and is characteristic of strongly folded or dipping sedimentary rocks where the edges of the beds have been exposed at the surface, as the leaves of a book. The longer channels result from the erosion of weaker beds along the contact with a more resistant bed. Such channels follow the strike of the beds. The short channels are caused by erosion down the exposed surfaces of the beds.	
ANNULAR: This is a variation of the trellis pattern and is associated with maturely dissected domes. The arcuate paths result from erosion of a weak bed along the contact with a more resistant one.	
PARALLEL: This pattern indicates that the surface, though relatively flat, has a gentle but uniform slope in a given direction. This pattern can occur on the side slopes of valleys and alluvial fans, as well as on extensive areas of a plain underlain by slightly dipping sedimentary rocks.	

RADIAL: This pattern is associated with a central high (hill, dome, volcano), or a central low or basin. In the case of a central high, the water flows from the center outward and is called centrifugal drainage. In the case of a low, the water flows inward toward a central area and is called centripetal drainage. Depending on the size of the dome or basin and the photo scale or area covered, a segment of the radial pattern could be classified as parallel.	
RECTANGULAR: The angularity of this pattern is caused by joints and fractures within the rock or by changes in materials for flat-lying rocks.	
ANASTOMOTIC: This pattern of tortuous windings, interlocking channels, and ox bow lakes is characteristic of flood plains and deltas. It is indicative of a soil of smaller particle sizes than those associated with braided drainage.	
PINNATE: This feather-like pattern, with the relatively close spaced, uniform short gullies feeding into the tributaries is indicative of loessal material, that is, windblown silt. The regional pattern of the tributaries can be dendritic, parallel (as in this illustration), or even show evidence of bedrock control.	
DISCONTINUOUS: This pattern of isolated channel segments and small depressions is usually associated with limestone beds. Discontinuous or interrupted drainage can occur also in thermokarst areas and in permafrost areas.	
BRAIDED: This pattern results from the deposition of coarse-grained material (mostly sand and gravel) in the channels of a heavily loaded stream where stream speed suddenly decreases. As any one channel is filled, new channels develop. Such patterns occur on alluvial fans, desert washes, deltas, and outwash plains of receding glaciers.	

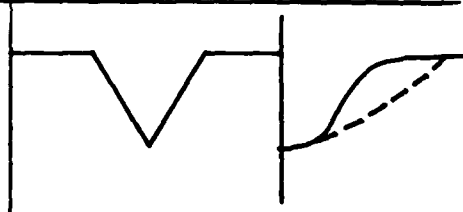
The dendritic, parallel, rectangular, trellis, annular, and radial patterns are from Parvis, M., 1948, *Regional Drainage Patterns in Indiana*, reprint No. 35, Engineering Experiment Station, Purdue University, Lafayette, Indiana. They can also be found in Frost, R.E., 1950, *Evaluation of Soil and Permafrost Conditions*, Vol. I, p.46c, Engineering Experiment Station, Purdue University, West Lafayette, Indiana. These, plus the pinnate pattern, are based on a thesis by Merle Parvis entitled *Regional Drainage Patterns*, 1947, School of Civil Engineering, Purdue University, West Lafayette, Indiana. The anastomotic pattern is based on Zernitz, E.R., 1932, *Drainage Patterns and Their Significance*. Jr. Geology 40(6):498-521.

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DRAINAGE-ELEVATION

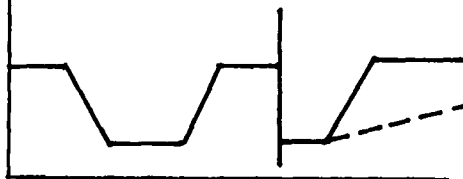
This pattern refers to the shapes of the gullies in cross section and in gradient. It is an important pattern element because soil textures and profile features can be interpreted directly from a detailed study of gully systems and gully characteristics. These features are closely associated with specific soil types and are not duplicated in unlike soils. For example, gullies with a nonuniform cross section and an interrupted gradient are indicative of changes in materials, e.g. stratified soil conditions, or a soil having a developed profile consisting of contrasting horizons. In general there are three basic gully cross section shapes that correspond to the three major textural groups of granular soils, silty soils, and clayey soils. In granular soils, erosion will develop gullies with a sharp V-shaped cross section and with a short, steep gradient. In silts, the gully cross sections tend to be V-shaped with flat bottoms or box-shaped with flat bottoms. Loessal materials, i.e. the windblown silts, develop very steep gully walls, but they are not usually vertical unless undercut by running water or cut in place during road construction. These soils are removed by headward erosion through flat-bottomed gullies of low gradient. Water-deposited silts tend to develop vertical box-shaped gullies. Although marine sand-clays of the eastern U.S. coastal plain also develop a box-like gully, other pattern elements can be used to separate and identify these materials. Nongranular, cohesive, and plastic soils, i.e. the clays, develop a gully whose cross section has a broad, softly rounded saucer shape and whose gradient is gentle and extends well back into the upland.

V-shaped gullies. These gullies are usually short and stubby with a short, steep gradient. In general, the coarser the material, the shorter and steeper the gully. Alluvial fans are frequently found at gully mouths.



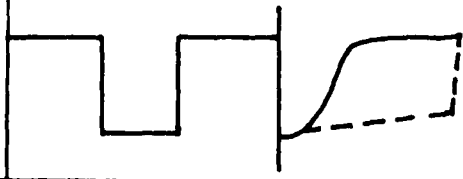
Granular and semigranular, nonplastic, noncohesive soils, i.e. sands, gravels, and combinations.

Flat-bottomed V-shaped gullies with a long gentle gradient ending in a steep face. Alluvial fans are not formed at the gully mouths.



These are indicators of loessal material (i.e. very fine sand and silt).

Box-shaped gullies with vertical sides, flat bottoms, and long gentle gradients.



These are indicators of water-deposited silts and sand/clay mixtures of the coastal plains, as well as indicators of subsurface drainage or ground water sapping.

Saucer-shaped gullies with gentle side slopes and broad cross sections. The gully gradient is gentle, and gullies extend for great distances, gradually feathering out to become indistinguishable.



Nongranular, cohesive, and plastic soils, e.g. clay, silty clay.

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SUMMARY SHEET

FACTOR PATTERNS

EROSION

The patterns of erosion provide information about the nature of the material, conditions, and climate. Each mechanism of erosion leaves a telltale pattern of shape or tone. In this part of the analysis one looks for indicators of the mechanism of erosion, describes them, and assesses their significance. For example, the occurrence of blowouts on a surface is suggestive of the presence of a granular or sandy material; the presence of sinkholes, a form of chemical erosion, is suggestive of limestone; the intensity of water erosional patterns suggests something about the nature of the resistance of the material to erosion. In general, these patterns are related to

- Water
- Wind
- Gravity
- Ice
- Chemical
- Thermal
- Man-Induced

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DEPOSITION

Material that is eroded away must be deposited elsewhere, and the resulting patterns are controlled by the nature of the material, conditions, and climate. Some depositional formations are so large that they can be classified as landform patterns, e.g. large deltas, fans, terraces, dunes, etc. Even so, their patterns are indicative of composition.

This part of the analysis serves as a checkpoint to review the imagery for indicators of deposition and assess their significance, e.g. examining gully mouths to see if fans are present, which, if found, would indicate that there must be a source of granular material someplace. In general, depositional patterns are caused by the following mechanisms:

Water (terraces, fans, braided channels, deltas, tone streaks, etc.)

Wind (dunes, sheet cover)

Gravity (talus)

Ice (glacial till, eskers, moraines, drumlins)

Man-induced (tailing piles, dredging piles)

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VEGETATION

The results derived from an analysis of vegetation patterns can be used to provide information about the vegetation itself in terms of type, density, vigor, stem diameter, etc., or to provide information about other terrain characteristics and climate. Air photo scales suitable for engineering soils evaluation and environmental data base preparation, i.e. in the 1:20,000 scale range, are too small for use in species identification. This task usually requires scales of 1:5,000 and larger. On the smaller scales, however, vegetation types or large pure stands can be identified and boundaries established between groups. These boundaries are frequently associated with changes in soil texture, soil moisture, topography, and orientation and give supportive information to factor boundaries established in earlier phases of the analysis. Knowledge of landform and soil within an area can frequently set the basis for a fairly accurate prediction of vegetation types. The vegetation patterns can also provide some information about climate. A mixed hardwood forest with a closed canopy and in a temperate region requires some 40-45 inches of rain per year. Progressively less rain means progressively less tree cover and an increase in other vegetation types. These relations are not exact but they can provide qualitative information about the area in question. Under certain conditions, usually in subhumid and arid regions, a vegetation type or species can be a unique indicator to such things as the soil mantle depth or soil type. Although there are several ways of classifying vegetation, some of them task oriented, a first-order breakdown based solely on photo patterns usually includes the following:

Forest	Closed Canopy Open Canopy	Sufficiently open to expose ground surface and subarbooreal layers to observation (50–75% trees).
Shrubs	Closed Canopy Open Canopy	
Mixed trees and grassland		About 50% of each.
Grasslands		
Agricultural	Plantations Cropland	
Wetlands		
Barren		

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CULTURAL

As in the case of vegetation the analysis of cultural patterns can be done for two purposes: to derive information about the culture itself and to use the cultural patterns to derive information about other factors. As an example of the first purpose, the economic characteristics of a given society can be deduced through an analysis of the cultural patterns. As an example of the second, a pattern of cultivated fields, such as the alternating tones of fallow farming on a flat surface, can provide clues as to soil texture and general climate. Cultural information is needed for many different purposes, e.g. economic evaluation, planning, military operations, etc. As a result, no single classification system satisfies all users. Classification systems are usually tailored to the problem at hand. Complicating the issue is the fact that most classification systems are some combination of land cover and land use categories. Land cover can be determined by image analysis. Identifying the land use, however, frequently rests on ground determination. Based solely on photo patterns, i.e. without auxiliary information, one can bound and trace the following first-level categories. Some second-level categories can also be obtained directly from imagery.

Structures. This includes patterns for all types of buildings, ranging from multibuilding farmsteads to metropolitan development.

Transportation and Communication. This includes highways, railroads, airports, canals, pipelines, transmitter towers, power lines, etc.

Agricultural and Livestock. This category includes cultivated fields, orchards, plantations, pasture, feed lots, etc.

Recreation. This includes those areas that have little or no structural development, but do show patterns that link them to some activity such as golf, skiing, camping, etc.

Special. This category is for cultural features that do not readily fit into other classifications, such as quarries (including gravel pits), cemeteries, transition zones, etc.

Natural. This classification is for those areas that do not show cultural patterns and which cannot therefore be assigned into any cultural category. Many of these areas will be identified on the factor patterns of drainage, vegetation, and surficial geology.

PHOTO TONES AND TEXTURE

Photo tones and textural patterns can provide information about specific materials or conditions, as well as provide information to support conclusions developed during the analysis of other factors. In most cases these patterns are associated with areas of relatively bare or exposed soil and rock, or with an area of uniform vegetation cover. Although photo tones and texture are important sources of information, care must be taken in evaluating them, especially those of soils, because climate and season greatly influence the development and detectability of these patterns. For instance, it is generally true that well-drained soils record as light tones or colors in a photograph and poorly drained, fine-textured soils tend to record as dark tones and colors. Under some conditions, however, these general statements are not true. A dry mound of sand on a sand plain in a humid region can show as a light tone against a darker background although the materials are the same for both the plain and the mound. The tone will be different due to the influence of topographic position of the mound on its drainage characteristics. The mound would probably show as a lighter tone than its background. In an arid region a sand dune on a sand plain will probably have tones very similar to those of the plain. Soil tone patterns can also alter their contrast, and even disappear, as a function of season or local weather conditions. With respect to soils, tones and textural patterns can provide information about identity, origin, uniformity, horizon development, moisture relations, etc. For instance, on panchromatic photography silt has a bright, uniform photo tone and a silky texture. Soils derived in glacial till generally show intricate patterns that are related to the complex character of the mantle. As examples, soils of the Wisconsin glacial till show an intricate mottling of light and dark gray tones that are related to different soil texture and moisture conditions; Illinoian till is characterized by a light fringing around the gullies, which is indicative of a soil profile development. Other tone patterns are associated with marks left as a result of wind action, or flowing water, which, in themselves are indicative of the nature of the surficial materials. With respect to rocks, tone and texture can provide supportive information as to type. In igneous rocks, for example, the mafic classes such as basalt and gabbro have dark photo tones. The silicic rocks such as granite tend to have lighter tones. In many subhumid and arid regions, however, the rock surfaces can be covered with another material such as lichens, desert varnish, or alterations produced by weathering which can darken or lighten the surfaces of the rock. The tones that are recorded by the sensor represent some unknown mixture of bare rocks, weathered surfaces, varnish surfaces, and lichen-covered surfaces. In some instances this cover can be as much as 80%, thereby causing a light colored granitic rock to have a very dark, almost black, photo tone. With respect to vegetation, tone and texture can provide information about composition or vegetation type.



SPECIAL

This pattern category includes items that do not easily fit under other factor headings or items that, though discussed elsewhere, are in themselves sufficiently direct indicators of identities and conditions that they warrant additional evaluation. Furthermore, this part of the analysis serves as one more checkpoint to examine the imagery for clues to support previous findings or suggest new relations or identities. Frequently these patterns depend on some inherent quality of the material or on some inherent nature of an action or force. When this is so, they can be important to such matters as evaluating construction sites, assessing potential instability, locating ground water, etc. For example, wind-blown silt deposits have an internal vertical structure that accounts for some patterns that serve as direct indicators of the presence of such material. These include the pinnate drainage pattern, flat-bottomed steep-sided gullies, terracettes and pinnacles on gully walls, and vertical road cuts. The pinnate drainage pattern, gully cross section, and road cuts would be evaluated under their respective sections. Terracettes and pinnacles, too small to be considered as landforms, would probably be evaluated within this category. As another example, slumps and tears in an otherwise smooth valley wall are indicative of instability and potential engineering problems. Patterns that merit special attention include joints, fractures, and faults; soil slumps, landslides, mudflows, and tears; certain landforms that are direct indicators of materials or conditions (barchan dunes, drumlins, colluvial slopes, etc.); and some patterns of drainage, erosion, and tones.

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SEDIMENTARY ROCKS

Sedimentary rocks are formed by the compaction and cementation of particulates, or grains, that have settled out of a transporting medium of water, wind, or ice. The grains that form these rocks are produced by the weathering and disintegration of pre-existing rocks or by chemical precipitation and are deposited as horizontal layers or beds, with the oldest deposit on the bottom and the most recent at the top. This bedding is characteristic of sedimentary rocks. There are two main types based on origin: clastic and chemical.

Clastic rocks. Clastic rocks are those formed by the weathered products of pre-existing rocks and are made up of particles ranging in size from boulders to clay. The common names given to these rocks are descriptive of the particle size, i.e. conglomerate (boulder to sand-sized particles), sandstone (sand-sized), silt stone (silt-sized), and shale (fine silt to clay-sized). The physical characteristics of these rocks, such as color and hardness, are determined by the mineralogy of the grains and the type and degree of cementation binding the grains together. Conglomerate and sandstone, for example, are usually composed of strongly cemented, resistant minerals such as quartz and are resistant to weathering, whereas shale is very weakly cemented and is softer.

Chemically deposited rocks. These rocks are formed by minerals precipitated from solution, secreted by organisms, or left as a residue from evaporation. They are more susceptible to chemical weathering and dissolution than the clastic rocks. The most common of the chemical sediments is limestone, which is composed of calcium carbonate in the form of calcite. Most limestones are of marine origin and were originally deposited as a limey mud on the ocean floor. Some limestones could be called clastic as they are composed of fragments of shells or coral cemented together. Dolomite is similar to limestone in appearance, but is somewhat more resistant to chemical weathering. Limestone and dolomite have the widest distribution of this group of rocks. Evaporites are formed by the evaporation of mineral bearing waters, usually in an arid environment. They are not as widely distributed or as abundant as limestone and dolomite, but are important from an economic standpoint. The evaporites are usually softer than other sedimentary rocks and are highly susceptible to chemical weathering. Gypsum and rock salt are the most common of the evaporites. As with most natural phenomena, sedimentary rocks do not always fall into clear-cut classes. It is possible, therefore, to have clastic sediments and chemical sediments being deposited at the same place and at the same time, giving rise to combinations such as sandy limestone, silty sandstone, gypsiferous sandstone, and so on for as many combinations as there are sizes and chemical classes.

COMPILER: J. Ponder Henley, USAETL.



**SEDIMENTARY ROCKS
SOLUBLE ROCKS**

Rocks formed from chemical sediments (precipitates or evaporites) are susceptible, in varying degrees, to dissolution. The rate of chemical weathering is dependent on the solubility of the rock, the presence of a solvent, and adequate drainage to remove the dissolved products. Limestones are the most widely distributed and recognized of the chemical sediments, and their spectacular cave systems with solutional and depositional features are well known. Most limestone is of marine origin, the calcium carbonate being deposited directly by chemical precipitation from sea water or deposited by organisms. Coral, bryozoans, and some algae have calcareous skeletons which form reefs, the voids of which can be filled with detritus or precipitated calcium carbonate to form a solid rock mass. All the shells of marine animals, such as gastropods, pelecypods, and brachiopods, contain calcium carbonate, and they can be cemented together into a limey matrix to form another type of limestone. In calm water very fine-grained limey mud can accumulate, forming a smooth compact limestone. In its purest form, limestone is composed of the mineral calcite (calcium carbonate). Many formations, however, contain varying amounts of impurities such as chert, sand, or clay minerals which can affect the weathering characteristics. The solvent available for the dissolution of limestone is water from atmospheric precipitation. Limestone is only slightly soluble in pure water. Rain and glacial melt water contain varying amounts of carbon dioxide, which produces a weak carbonic acid solution. This carbonic acid reacts with the calcium carbonate to produce calcium bicarbonate, which is soluble in water and is carried away. The chemical reactions and the changes in equilibrium are complex. Factors that influence the rate of dissolution include the presence of organic by-products and calcium dioxide in the soil, temperature of the solution, the amount of rainfall, and purity of the limestone. As impurities increase, especially the more granular types (sand and silt), weathering becomes a combination of mechanical and chemical.

Dolomite, a calcium magnesium carbonate rock, is similar to limestone in formation and appearance. Although it is generally considered to be less soluble than limestone, solution features are common in dolomite.

Evaporites. Gypsum (calcium sulfate) is the most abundant of the evaporite rocks at the surface, and is much more soluble than limestone or dolomite, especially in higher temperatures. Gypsum is usually more evident in arid areas, preserved because of the lack of rainfall.

The chloride rocks, the best known being halite (sodium chloride, or rock salt), are even more soluble and rarely persist as landforms.

COMPILER: J. Ponder Henley, USAETL.

SEDIMENTARY ROCKS
SHALE

Shale is a fine-grained clastic sedimentary rock and is the most common and widely distributed member of this group. It is formed by the compaction and induration of mud or silt and clay particles. Although shale contains silt, and at times larger particles, it always has an appreciable amount of the clay minerals. A fine silt represents the lower limit of particle sizes that can come from a grinding process, a size that is from about 0.002 mm to perhaps 0.005 mm (2–5 μm). Clay particles are the result of chemical reactions (alteration, decomposition, recrystallization) and have sizes less than 0.004 mm or 0.005 mm, depending on the classification used. Many of the particles are less than 0.002 mm. Being this small, the effects of surface charge are very large, and the particles cling together, a property called cohesiveness. Being a sedimentary rock, the structure of shale is a layered one, with the layers being finely stratified and having thicknesses that are but fractions of a millimeter. It has a fissility that is parallel to the bedding plane, i.e. it readily splits into thin sheets parallel to the bedding plane. If the rock is more massive and not fissile, it is a mudstone, siltstone, or a clay stone, depending on the grain size distribution. There are several classifications for shale, usually based on the relative percentages of clay, silt, and other material contained in them, but no one scheme is used universally. For example, there are argillaceous (clay) shales, arenaceous (sandy or siliceous) shales, calcareous (limey) shales, ferruginous (iron rich) shales, and carbonaceous (organic) shales. Clay shales are a valuable economic resource, and for commercial purposes are usually classified as kaolin, ball clay, fire clay, bentonite, fullers earth, and miscellaneous clay.

Because of the very small particle sizes and the resultant small pore size, shales are essentially impermeable, and intergranular cementation does not occur. Consequently, shales have little resistance to erosion and they are easily affected by mechanical weathering. Although shale can be indurated enough so that it does not fall apart when wet, it is usually relatively soft and easily broken. A shale can take on one of several different colors; for example, red, yellow, brown, blue/green, gray, black, and in some instances a very light gray. In general, shale is less durable than sandstone and limestone. Some clay shales and the residual soil covering them can absorb water and show a tendency to expand or shrink if they become wet or dry.

Engineering Characteristics and Problems. The residual soil mantle over a clay shale is plastic, cohesive, and has little or no dry strength. In general, the problems associated with clay shales are poor subgrade support, pumping, and poor natural drainage. Subgrade support and compaction of shale for fill present problems because of the expansive nature of clay shales when wet. Because of the poor natural drainage and the fissile nature, shales can also become a problem in stability. For example, ground water can collect on a shale's impervious surface, especially if located below an aquifer, and if this bed is dipping, this lubricated surface can cause sliding and slumping of the material above it.

COMPILER: J.N. Rinker, USAETL.



IGNEOUS ROCKS

Igneous rocks, formed from the cooling of molten material (magma), are divided into two groups: plutonic (intrusive), rocks that solidify deep within the earth's crust, and volcanic (extrusive), rocks that solidify on or near the surface of the earth. Chemical composition in both types of igneous rocks ranges from silicic to mafic, i.e. from rocks composed of light-colored minerals containing large amounts of silica to those composed of dark-colored minerals containing less silica and enriched in iron, magnesium, and calcium.

Plutonic Rocks. Plutonic rocks are formed from molten material that cools slowly deep within the earth's crust and are, therefore, coarse grained. Granitic magmas, for example, may be emplaced as deep as 20 kilometers below the surface; other magmas are emplaced at greater depths. Plutonic rocks appear on the surface of the earth only as the result of uplift and/or erosion. The most common forms of plutonic rocks are batholiths, dikes, and sills. Batholiths are very large bodies, usually formed of granitic rock, that are more than 100 sq. km. (40 sq. mi.) in diameter; dikes are narrow, relatively small linear bodies that cut across adjacent layers; and sills, similar to dikes in size and shape, parallel adjacent layers.

Common plutonic rocks are granite, diorite, monzonite, and gabbro. Granites, the most common, are composed of highly silicic, light-colored minerals, primarily quartz, light-colored plagioclase feldspars, potassium feldspars, and mica. In addition to forming from molten materials, granite can form as a result of metamorphic processes. Diorite and monzonite are medium grained and intermediate in color and composition, containing intermediate composition plagioclase, biotite, hornblende, and/or pyroxene and quartz. Diorite is intermediate in grain size, but usually is treated as a "granitic" rock. Monzonite can be coarse grained. Gabbro is dark in color, mafic in composition, and relatively rare; it consists primarily of dark-colored plagioclase, pyroxene, hornblende, and olivine. Pegmatites, very coarse grained rocks of granitic composition (crystals are often measured in meters), are also relatively rare. They usually occur as veins and form during the last stages of development of, and in association with, granitic batholiths.

Volcanic Rocks. Volcanic rocks are fine grained because they are formed from molten material that cools rapidly on or near the surface of the earth. Some volcanic material, such as obsidian (the most common volcanic glass), cools so rapidly that it is grainless. Volcanic rocks, forming as deep as several hundred meters below the surface of the earth, are divided into two groups: flow materials that result from quiet, non-explosive eruptions from volcanos and fissures; and pyroclastics that form from molten material explosively erupted into the air.



Flow Materials. Common flow materials are basalt, andesite, and rhyolite; basalt is the most common. The primary mineral constituents in basalts are dark in color, and include dark-colored plagioclase, pyroxene, and olivine. Andesite, the fine-grained equivalent of diorite, is intermediate in color and composition. The light-colored silicic rhyolite is the fine-grained equivalent of granite.

Pyroclastics. Pyroclastic rocks are usually fine grained. The most common are volcanic ash, pumice, and tuff. Pyroclastic rocks usually are intermediate to highly silicic in composition, but can also be mafic (volcanic bombs). They often contain large amounts of volcanic glass, and are normally medium to light in color. Pyroclastics, much less common than flow materials, are carried and deposited by wind and water and often form layered sequences.

Igneous rocks are important economically because the fluids associated with them during formation contain high concentrations of valuable elements. For example, gold, silver, copper, and uranium occur in veins associated with igneous rocks, and rare metals, such as lithium and beryllium, commonly occur in pegmatite minerals.

COMPILER: J. Ehlen, USAETL.

References:

Turner, Francis J. and Verhoogen, John. *Igneous and Metamorphic Petrology*. 2nd edition. New York: Mc Graw-Hill Book Company, Inc., 1960, pp 1-449.

Pirsson, Louis V. *Rocks and Rock Minerals*. 3rd edition. Revised by Alfred Knopf. New York: John Wiley and Sons, Inc., 1956, pp 103-226.

**TRANSPORTED - AEOLIAN
LOESS (WINDBLOWN SILT)**

Loess is an unconsolidated, or weakly consolidated, deposit of windblown soil that comes mostly from river flood plains. These deposits, which occur mostly in plain or plateau regions, range in thickness from a few centimeters to as much as 200 meters. Usually they are calcareous in nature (either calcium or magnesium carbonate) and consist mostly of angular grains of silt-sized particles (approximately 0.075 to 0.002 mm) with lesser amounts of very fine sand and clay. In general, the particle sizes decrease with increasing distance from the source. Most frequently the silt-size particles are quartz, i.e. quartz is common to all loessal deposits.

Debate continues as to the mode of emplacement, as well as the origin of loess. The prevailing view is that the sediment was produced by the grinding action of glaciers on underlying rocks. Later, the particles were deposited downstream from runoff from melting glaciers, and subsequently reworked and carried by the wind to be deposited on downwind upland surfaces.

Loess has a vertical microtubular structure which supports a capillary rise of as much as 9 m (30 feet), and which is responsible for forming the characteristic steep erosional faces. Loess that has not been deeply weathered has a high porosity (50-60%),¹ and an in-place dry density that ranges from 66-104 pounds per cubic foot.² It is usually well drained internally, with the vertical permeability being several times greater than the horizontal permeability. It is remarkably uniform in physical properties, easily eroded when exposed to running water, and forms a fertile soil.

Loessal deposits are distributed throughout the world. Within the United States loess can be found in Washington, Idaho, South Dakota, Nebraska, Iowa, Kansas, Illinois, Kentucky, Tennessee, Mississippi, Indiana, and Ohio. There are deposits in Europe that constitute an irregularly shaped rich farming belt through northeastern France, Belgium, Germany, Hungary, Poland, Czechoslovakia, Rumania, and into southeastern Russia. There are deposits in north China and throughout the basin of the Yalu River. In South America deposits can be found in Argentina, Paraguay, and to some extent Uruguay. There are also deposits in northern Africa, Israel, Australia, and New Zealand.

Engineering Characteristics and Problems. Although of low density, this material, when dry has a fairly high strength because of the clay binder. This strength can be lost because of wetting. Remolded loess has a greatly reduced permeability, is only moderately compressible, and has a low cohesive strength.³ Road cuts, other than near vertical, will be unstable and gradually erode back to the stable steep configuration, unless preventative measures are taken. The supportive properties are usually good if the material is compacted properly. Once the vertical structure is destroyed, which is easy to do, the material takes on other characteristics, and presents the engineer with a different set of problems. For example, when dry, the material is loose, impossible to compact, and easily removed by wind; and when saturated, it can become quick. These latter characteristics are also of concern when considering problems associated with cross-country mobility.

COMPILER: J.N. Rinker, USAETL.

¹Nyle C. Brady. 1974. *The Nature and Properties of Soils*. 8th ed., Macmillan Publishing Co., Inc., New York.

²J.B. Sheeler. 1968. "Summarization and Comparison of Engineering Properties of Loess in the United States." Highway Research Record No. 212, Conference on Loess: Design and Construction. Nat. Res. Council, Nat. Acad. of Sci. - Nat. Acad. of Engineering. Washington, DC, Pub. No. 1557.

³U.S. Dept. of Interior, Bureau of Reclamation. 1968. *Earth Manual*.

WATER DEPOSITS

Water-deposited materials are formed from sediments eroded and weathered from earth surface materials (rocks, soils, and other deposits). They cover a large portion of the world's land area and are important because they provide excellent sites for highways, airports, and other construction projects, and because of their economic value as sources for granular material. They range from minor deposits associated with the beds and banks of small streams to very large deposits such as the outwash plains formed from the erosion of adjacent mountains. The Great Plains of the United States are of this latter type. The depositing medium is flowing water, which has the ability to sort material by particle size as a function of the speed of the current. Furthermore, the telltale clues left by flowing water, i.e. ridges, channels, and current marks in the form of linear and curvilinear tone streaks are important indicators of these deposits.

These materials can become indurated, consolidated, or cemented, which alters both the structural characteristics of the mass, as well as the identifying surficial patterns. In many places, water-deposited materials of the Great Plains and the Coastal Plain of the U.S. have become rock-like through long periods of time, and no longer exhibit the surface patterns associated with water deposits. The air photo interpretation of water-deposited materials depends on relative age and erosional history; texture of the material and of the overburden; degree of induration, cementation, or consolidation; topographic position; climate; and the nature of the original topography covered by the material. There are several ways to classify water-deposited materials and we have elected to start on the one based on information in Frost (1953)¹ because it is oriented towards the use of air photo patterns.

Alluvial Deposits

- Fluviatile Plains
- Intermontaine Basins
- Stream Flood Plains
- Stream Terraces
- Deltas

Marine Deposits

- Coastal Plains (Estuarian Plains, Tidal Flats, Terraces)
- Miscellaneous Shore Features
 - (Beaches, Spits, Bars, Tidal Marshes, Reefs,
 - Barrier Beaches, Beach Ridges)

Lacustrine Deposits (Nonglacial Lakebeds)

- Tertiary
- Pleistocene
- Recent

Glacio-Fluviatile Deposits

COMPILER: J.N. Rinker, USAETL.

¹R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes*. School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.



**ORGANIC SOIL
PEAT AND MUCK**

Organic soils are formed by the sequential deposition of vegetative remains on the bottoms of shallow ponds, bogs, marshes, and swamps, where they slowly undergo anaerobic decay. Structure of organic deposits is that of a layered system that varies in the nature of the original plant tissue and in the extent of decomposition. These layers can later become soil horizons. Organic soils are differentiated on the state of decomposition. Nondecayed and slightly decayed deposits are called peat, and those deposits that are fully decomposed or nearly so are called muck. In peat deposits one can identify plant parts and plant species. The texture of these soils ranges from fine to coarse as a function of the nature of the plant residue. In muck deposits plant parts cannot be identified and the soils are fine.

Organic soils are dark brown to black and are light in weight when dry, having about one-sixth the bulk density of a mineral soil. They have a high water holding capacity, holding three to four times their dry weight in moisture. Some slightly decomposed peats can hold 12-20 times their dry weights in water.¹ On the other hand, dry mineral soils can usually hold only one-fifth to two-fifths of their dry weights as water. Organic soils have a much larger surface area than even mineral soils such as clay, and consequently, they have a more pronounced colloidal nature. Plasticity, however, is low. In general, these soils are porous and easy to cultivate when dry; and if the structure has been destroyed, these soils are easily eroded by the wind. In dry seasons peat and muck deposits can burn for weeks if they catch fire, and such fires are difficult to extinguish. In addition to being valuable agricultural soils, these materials are used in greenhouses, in nurseries, on lawns, and as a fuel.

Although the organic soils are nowhere near as extensive as the mineral soils, they can be found throughout the world where conditions are favorable. A great portion of the world's deposits (60%) occur in Russia.² Within the U.S., these deposits are scattered throughout the country, although the vast majority are in glaciated areas. The Pleistocene glaciation set the stage for the development of shallow ponds, bogs, and swamps by leaving a suitable topography and by impeding, if not blocking, drainage-ways.

Engineering Characteristics and Problems. Because these soils are highly compressible, they should be avoided as foundation materials. If this cannot be done, compensatory techniques must be used, e.g. excavation and backfill, use of piles and bridges, or causing compaction by surcharging.³

COMPILER: J.N. Rinker, USAETL.

¹Nyle C. Brady. 1974. *The Nature and Properties of Soils*, 8th Ed. Macmillan Publishing Co., Inc., New York.

²"United States Mineral Resources," Geological Survey Professional Paper 820, 1973.

³R.E. Frost, J.G. Johnstone, O.W. Mintzer, M. Parvis, P. Montano, R.D. Miles, and J.R. Shepard. 1953. *A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes*. School of Civil Engineering and Engineering Mechanics, Purdue University, West Lafayette, Indiana.

**SEDIMENTARY ROCKS
SANDSTONE — FLAT-LYING**

Sandstone is composed of sand-sized particles cemented together. Most frequently the particles are quartz, and the cementing agent can be calcium carbonate, iron, or silica. The characteristics of sandstone depend on the origin of the sand and on the type of deposition, i.e. aeolian, alluvial, or marine. The beds can be massive or thin, and cross bedding is common. The relative strength and resistance to weathering of sandstone are determined by the mineral composition of the grains, the type of binder, and the thickness of the beds caused by depositional variation. For example, sandstone cemented by silica is resistant to erosion and weathering. Other sandstones can be so weakly cemented that they easily break apart into their component grains. Sandstones that are cemented with calcium carbonate develop deeper soil mantles than sandstones having a siliceous binder. As the calcium carbonate content increases, such rocks take on the patterns of limestone. On exposed sandstones with rough topography, surface water carries away many of the particles, resulting in a thin soil mantle. Because sandstones can be porous, they are important reservoirs of water. Although they usually occur interbedded with other sedimentary rocks, one can find massive units up to 130 meters (approx. 400 feet) thick.

Landform. The resultant landform depends on the climate, as well as the thickness of beds. In arid regions, sandstone is a mesa former and the landform is blocky, flat-topped with vertical sides, and contains box-like canyons and gullies with vertical walls. Pinnacle rock forms are common and talus piles are usually found at the base of cliffs. Wind abrasion can carve the blocks into unusual shapes. In humid regions, the landform associated with massive beds is slightly crested, with a vertical face and talus piles at the base of the face. Dense vegetation can cause a rounding or smoothing effect. Soft sandstones have sharply crested ridges and V-shaped valleys. Thinly bedded sandstones also tend towards this type of landform.

Drainage-Plan. Dendritic on a broad regional basis. The local pattern can vary in its arrangement from dendritic to rectangular with many right angle turns in the streams caused by jointing in the rock. The angles between gullies, tributaries, and major streams are relatively sharp, i.e. they are not rounded as in the case of limestone.

Drainage-Elevation. In cross section the gullies are long, straight, steep, and V-shaped, and the valleys containing them are V-shaped. Areas between closely spaced gullies are sharply crested. Gullies developed in a soil mantle on soft sandstone are sharply V-shaped. A residual soil of sand and clay produces U-shaped gullies, whereas one of silty clay produces broader and softer V shapes.

Erosion. By water, wind, and gravity. Sandstone is fairly resistant and not easily eroded by running water. Depending on the climate, sandstone weathers to blocky pieces which are slowly reduced to sand, or it weathers directly to sand. This sand is removed by running water or by wind action. Weathering is easier along joints and fractures, especially in arid climates, and can form a series of widened grooves on the surface. Wind erosion or, more accurately, sand blasting can cause an outcrop to appear "honey combed" or "moth eaten." Unless precautions are taken, shallow residual soils are easily erodible in farming areas. Talus accumulations attest to the gravitational influence.

Deposition. Usually in the form of talus slopes in both arid and humid regions. The eroded sand can be deposited as fans at gully mouths, as valley fill, or carried out to form deposits in a basin.

Vegetation. A forest cover in humid regions. Because sandstone is often a water-bearing rock, it will support some vegetation even in subhumid areas, and provides a basis for separating sandstone from other sedimentary units. In arid regions vegetation is sparse and is usually concentrated along drainageways and in joints.

Cultural. Orchards are common in humid areas. The shallow soils are not usually suitable for tillage. Where farming does occur contour plowing is frequently practiced as a means of reducing surface erosion.

Tone and Texture. If not obscured by vegetation the tones of sandstone and residual sandy soils tend to be light. The tones tend to be slightly darker with increased clay and silt content.

COMPILERS: Robert E. Frost and J. Ponder Henley, USAETL, 1980.

**SEDIMENTARY ROCKS
LIMESTONE — FLAT-LYING
HUMID, SUBHUMID AREAS**

Limestone is made principally of calcium carbonate, a substance that is slightly soluble in the weak carbonic acid formed from atmospheric carbon dioxide and rain-water. In areas of sufficient rainfall, the slightly acid runoff trickles down through and along joints and fractures, slowly dissolving the limestone and gradually enlarging the cracks. Intersections of vertical fractures are gradually enlarged into sinkholes. Caves and passages can become so large that the rock roof collapses from its own weight. With time the sinkholes, voids, and passages become ever larger, and eventually coalesce to form interconnected solution valleys. As the limestone is dissolved away, particulate matter that settled out during the formation process is deposited as a residual soil.

Landform. Plain. In youth the landform is a sinkhole-studded plain with poorly developed sinkholes in early youth and well-developed ones later. Relief can be as much as 25 meters (refer to Indicator 0019). In maturity the form is a karst plain with large, deep sinkholes, collapse features, and vertically walled solution valleys that are usually flat-bottomed, and with relief ranging from 100 to 200 meters (refer to Indicator 0021). Tributaries to the main solution valley are short and stubby. In the plan view of youthful and mature forms, the intersections of drainageways are well rounded, appearing scalloped in places. In old age the landform is a mound-covered plain. The dome-shaped mounds are remnants of the former sinkhole divides. In tropical regions limestone frequently shows a knobby surface.

Drainage—Plan. Discontinuous in youth and maturity. Although some drainage occurs through the porous soil and into the joints and fractures, most of the drainage is by way of the sinkholes, which are circular in horizontal beds. If a sinkhole drainageway becomes clogged, a pond results. As the landscape matures and solution valleys merge, areas of connected drainage develop which are usually dendritic in pattern.

Drainage—Elevation. Surface gullies rarely exist. Sinkholes are gently rounded depressions in youthful terrain, and gradually evolve into deep, steep-sided, funnel-shaped holes.

Erosion. Degradation occurs by chemical solutioning, scouring by running water, and gravitational collapse.

Deposition. Other than the accumulation of the residual soil, depositional patterns are not developed.

Vegetation. A closed forest canopy in humid regions. In cleared areas of the youthful landform trees are frequently left in many of the sinkholes.

Cultural. The residual soil that accumulates is a very good soil and can support a variety of agricultural practices, topography permitting. Quarries are frequently evident.

Tone and Texture. The rock color usually ranges from a light to a dark gray, and the soil color from yellowish-brown to red. In humid areas vegetation obscures both the soil and the rock. In less humid or cleared areas the soil shows as a light photo tone with darker circles or spots for the sinkholes.

Special. Fractures and joints are apparent on aerial photography as surficial line traces, as segments of drainage, and as flat walls of sinks and collapse features. Sinkholes tend to align with the fracture pattern.

Engineering Characteristics and Problems. The weathering of limestone can produce a relatively deep residual soil mantle. In humid areas a typical soil profile would show a top horizon consisting of a yellowish-brown silty soil of some 50 cm (2 feet) thickness; a relatively thick bright red B horizon of clay and silty clay; and a rather whitish C horizon of plastic clay containing limestone fragments. The more important engineering problems are associated with road cuts, the need to avoid or fill sinkholes, the possibility of subsurface voids, and varying subgrade conditions. Even though the top horizon soils are well drained internally, they become poorly drained when their structure is destroyed by compaction.

COMPILERS: Jack N. Rinker and Robert E. Frost, USAETL.

**SEDIMENTARY ROCKS
LIMESTONES AND SHALES
FLAT-LYING — HUMID**

In many places sedimentary rocks exist as alternating beds of limestone and shale. Differential weathering of interbedded hard resistant limestones and soft shales can develop several patterns, depending on the thickness of the beds. If the beds are thin, the slopes tend to be smooth. Thicker beds can show as slope changes, as well as tone changes that are in the form of contour-like bands that outline the hills. In 1:20,000 scale aerial photography slopes appear relatively smooth where the beds are less than half a meter in thickness. The combination of weathering, erosion, impervious and hard limestone, and impervious and soft shale units, tends to develop a compound slope with the upper section steeper than the lower. The lower slope is mantled with a colluvium of limestone fragments embedded in plastic clay. This mantle, which becomes thicker towards the toe, tends to protect the in-place rock from further degradation.

Landform. A flat-topped dissected plain with softly rounded slopes in both plan and elevation. In humid areas angularity is absent. Hill slopes are not uniform but are steeper in the top one-half to two-thirds and flare out in the bottom portion. The upper, steeper slope represents rock in place; the lower, gentler slope represents colluvial material; and the break in slope marks the transition. Spurs, uniform in height and general slope, extend out from the upland areas. The contour that represents the base of the hills is rounded, arcuate, and in places, scallop-like.

Drainage—Plan. Although the overall regional pattern appears dendritic in form, a close examination will usually reveal the influence of joints and fractures. Larger streams and whole valleys tend to meander. The upland surface can show tones, and sometimes depressions, associated with sinkholes. On the hill slopes many straight parallel gullies can be found on the colluvium. These cannot be detected if there is much vegetation. The angles between gullies and tributaries are rounded.

Drainage—Elevation. Large gullies that are tributary to important collector valleys have a cross section profile that resembles a broad, open, and rounded "V." In humid regions, gully shapes are difficult to observe because of vegetation.

Erosion. By abrasive scouring, weathering, and gravity. Landslides can occur in the colluvial material.

Deposition. None.

Vegetation. In humid areas such a region will be tree covered or cleared for farming. In semiarid regions it will usually be grass covered.

Cultural. Farming in humid regions and grazing in semiarid locations. In arid regions the soils are usually too thin for crops. Contour farming practices are frequently followed. Highway alinement usually follows ridges or valley bottoms where possible. Because colluvium is an unstable material, landslides are a constant problem to construction and engineering efforts.

Tone and Texture. In humid regions vegetation masks the tones and color of the underlying material. In arid regions, and if the beds are thick enough, a contour-like banding can be seen. The lighter banding marks the limestone beds, and the darker banding indicates the shale layers.

Special. The flaring out of the lower slopes in what is known to be a series of sedimentary rocks is an indicator that points to the likely presence of interbedded limestone and shale. This is also a direct clue to the existence of colluvial material and to the engineering problems associated with its instability.

Engineering Characteristics and Problems. Insofar as construction operations are concerned, several problems are associated with this type of area. Usually these problems are in terms of drainage, compaction, subgrade conditions, and landslides. The colluvial mantle can become unstable from excess water, cutting the toe, loading the surface, etc., any of which can induce landslide activity.

COMPILERS: Robert E. Frost and Jack N. Rinker, USAETL.

**SEDIMENTARY ROCKS
SHALE — FLAT-LYING**

Shales are fine-grained (less than 0.005 mm) clastic sedimentary rocks produced by the compaction and induration of silt and clay-sized particles. They are the most common and widely distributed sedimentary rocks. Shale has a wide range in chemical composition as a function of the clay minerals within it. In terms of particle size distribution it can also include a wide range of nonclay components. For example, there are argillaceous (clay) shales, arenaceous (sandy or siliceous) shales, calcareous (limey) shales, ferruginous (iron-rich) shales, and carbonaceous (organic) shales. The structure is of the bedded type, with the beds ranging from very thin to thick. Shales are usually fissile, that is, they are easily split into thin layers parallel to the original bedding planes. In general, shales are not as durable as sandstone and limestone. Because shale is made of an impermeable material, intergranular cementation does not occur, and as a result it readily succumbs to simple mechanical weathering. Clay shales absorb water and have a tendency to expand and shrink as they become wet or dry.

Landform. Because there are many varieties of shale, there are many varieties of landform. Climate is also an important factor. In general, shales occupy troughs, or can be maturely dissected to form a softly rounded topography in humid climates; or rugged, severely dissected terrain in arid regions that have few, but torrential, rainstorms. Hard shales will have steeper slopes, but retain a rounded aspect. These landforms are not as controlled by geologic structure as are those developed on other sedimentary rocks.

Drainage-Plan. Dendritic. If the shales are soft, the intersections of branches and gullies will be rounded. Only when the shales are relatively hard will angularity appear in the plan view. In general, the finer the drainage net, i.e. the closer the spacing of the gullies, the finer the particle size distribution of the material. Thus, clay shales usually have a relatively dense or closely spaced drainage net. The basic pattern is modified by climatic conditions. In an area subjected to bursts of intense rainfall and flash flooding the drainage pattern is denser than for a similar clay shale in a region where the rain is more uniformly distributed throughout the year.

Drainage-Elevation. In cross section the gullies are rounded, almost saucer-shaped, and have long, uniform gradients. In sandy shales the gullies tend to have a cross section that is more of a broad V shape. In arid regions the slopes can be angular and steep because of scouring caused by flash flooding.

Erosion. By water primarily. The fine texture and lack of cementing agents make shale susceptible to mechanical weathering and erosion by running water. It is easily eroded in arid regions because of the lack of vegetation and the flash flooding.

Deposition. In addition to forming a residual soil mantle, the silt and clay particles weathered from shales can be transported from the immediate area and redeposited elsewhere as alluvial or lacustrine sediments. Because of their small particle sizes, they do not form fans at gully mouths.

Vegetation. In humid climates, shales will support a dense vegetative cover if the residual soil is deep enough. Side slopes too steep for cultivation or with soil too shallow for agriculture will be forested. The uplands can be cultivated. In arid climates the land is barren or very sparsely vegetated with shrubs or grass if a soil is developed.

Cultural. The primary economic pursuit is agricultural, which is climate dependent. High quality shale is used in making fired clay products and in making cement; therefore, quarrying operations and kilns are frequently present.

Tone and Texture. In arid regions the coloring is usually of a yellowish-brown, which gives a light photo tone in panchromatic imagery. In flat lands where gullying has not occurred the depressions are dark and the highs are light. In humid regions tones are usually obscured by vegetation.

Engineering Characteristics and Problems. The residual soil mantle over a clay shale is plastic, cohesive, and has little or no dry strength. In general, the problems associated with clay shales are poor subgrade support, pumping, and poor natural drainage. Subgrade support and compaction of shale for fill present problems because of the expansive nature of clay shales when wet. Because of the poor natural drainage and the fissile nature, shales can also become a problem in stability. For example, ground water can collect on a shale's impervious surface, especially if located below an aquifer, and if this bed is dipping, this lubricated surface can cause sliding and slumping of the material above it.

COMPILERS: J. Ponder Henley, Jack N. Rinker, and Robert E. Frost, USAETL.

IGNEOUS ROCKS

Of the three groups of rocks, igneous, metamorphic, and sedimentary, only the igneous rocks can be considered "original," for they are formed from the cooling of molten material. Igneous rocks are divided into two groups: extrusive rocks, which solidify on or near the surface of the earth, and intrusive rocks, which solidify deeper within the earth's crust. Chemical composition in both types of igneous rocks ranges from silicic to mafic, i.e. from rocks composed of light-colored minerals containing large amounts of silica to those composed of dark-colored minerals containing less silica and enriched in iron, magnesium, and calcium. The mafic rocks tend to be mechanically stronger than the silicic rocks because of their composition. Because their mineral components react more readily with water than do the mineral components of the silicic rock, the mafic rocks are less resistant to weathering in climates where water is abundant. In short, the mode of emplacement, the chemical properties, climate, weathering, and tectonic activity determine the characteristics of the photo patterns found on igneous rocks.

Landform. The air photo pattern produced by igneous rocks is more complex than the patterns of sedimentary and some metamorphic rocks because of the greater range in igneous rock composition and the tendency of such rocks to form random patterns. With the exception of such landforms as lava flows, the topography in areas of exposed igneous rocks tends to be that of rugged mountains and hills; escarpments and plains, however, are common. Depressions such as calderas and craters are characteristic of volcanic igneous landforms.

Drainage—Plan. The most common drainage patterns on igneous rocks are dendritic, indicating homogeneous composition over large areas, and radial, indicating the shape of the typical hill or mountain landform. Stream alignments usually are highly irregular, and straight stream segments are short. Stream density is generally low.

Drainage—Elevation. Stream channels in igneous rocks usually are V-shaped and quite deep, providing the high relief typical of igneous terrains. Waterfalls are common.

Erosion. Mechanical weathering of igneous rock predominates, but is often accompanied by chemical weathering, particularly in humid climates. Weathering in hot arid regions is almost exclusively mechanical. Erosion is concentrated along fractures.

Deposition. Areas of igneous rocks (excluding pyroclastics) usually form highlands, and are not, therefore, areas of deposition; most eroded material is carried out of the igneous region.

Vegetation. Vegetative cover on igneous rocks is more sparse than on metamorphic or sedimentary rocks in the same area; the less weathered and younger the surface exposure, the sparser will be the vegetation.

Cultural. Areas of igneous rocks are usually culturally unexploited, except where plains are formed. In these areas, agriculture is commonly the major activity. The most common use of other igneous terrain is for recreation.

Tone and Texture. Dark-colored rocks are composed of low silica minerals enriched in iron, magnesium, and calcium and appear dark gray to black in photo tone on panchromatic aerial photography. Light-colored rocks are high in silica and sodium and, as a result, appear light gray to white in photo tone on panchromatic aerial photography. Photo texture is related to grain size: the coarser grained the rock, the rougher and blockier the texture. Texture is also related to the density, direction, and attitude of joints.

Special. Almost all igneous rocks are jointed. Certain types of joints are characteristic of certain types of rocks, i.e. columnar joints are characteristic of basalt, and curvilinear sheeting joints are characteristic of granite.

COMPILER: Judy Ehlen, USAETL.

**IGNEOUS ROCKS
PYROCLASTICS**

Pyroclastic igneous rocks are formed from particles ejected from the crater of a volcano or a fissure. Particles range in size from silt (ash fragments) to boulders (volcanic bombs) that can be more than 4 meters in some dimension. The photo patterns of pyroclastic rocks are therefore distinctly different from those formed on flow materials.

Landform. Pyroclastics usually form low, rounded hills and plains. Two types of volcanos are formed of pyroclastic material: cinder cones and spatter cones. Cinder cones are small- to medium-sized volcanos formed of cinders (lava with a high gas content). Lava flows often extrude from the bases and sides of cinder cones. Spatter cones are small hills usually less than 20 meters (65 feet) high, and are formed of basaltic material with a low gas content. This material is ejected over short distances as small globs that stick together upon landing. Cinder cones and spatter cones often form lines along the fissure from which they are derived. Resistant pyroclastic rocks, such as tuff and welded tuff (tuff hardened by heat and/or pressure) cap the hills. In addition, welded tuff sometimes occurs in rings called maars, which are formed by underwater eruptions. Extensive fairly flat areas covered with pumice to a depth of at least several inches are relatively common near volcanos that have a history of violent explosive eruptions. Such plains are called pumice plains. Pumice is a highly silicic, glassy lava.

Drainage-Plan. Excluding the fine-grained ash deposits, drainage patterns on pyroclastics are usually subdendritic, rectangular, or radial. Surficial drainage is usually absent on the more porous pyroclastic materials, such as pumice, particularly when they are relatively young. The very dense dendritic drainage patterns on ash deposits are similar to those formed on fine-grained sedimentary rocks (e.g. shale), making differentiation between ash and shale difficult on aerial photography unless there are other volcanic features in the area. Radial patterns develop on cinder cones and spatter cones.

Drainage-Elevation. Stream channels in the finer-grained pyroclastics are often steep-sided and V-shaped, whereas in the more resistant pyroclastic materials, such as welded tuff, they are more irregular and angular, without the sharp V-shaped cross section.

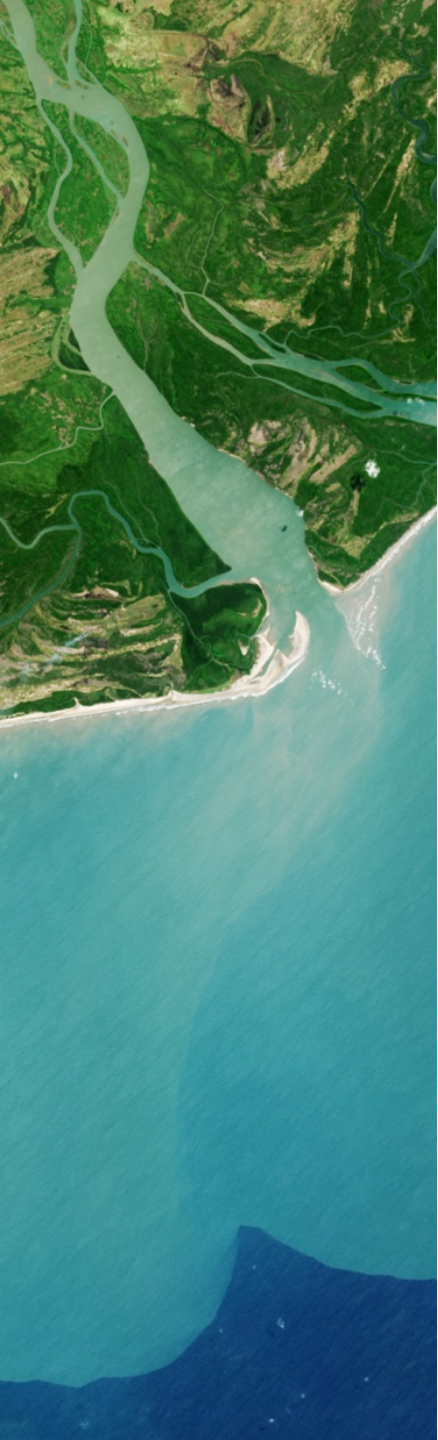
Erosion. Fine-grained volcanic material that has been deposited by wind or water will erode in a pattern similar to that of any fine-grained sedimentary material. Because of the softness of such materials, they are easily eroded. Consequently, badlands-type topography is common. Material that has been welded is more resistant to erosion and will develop vertical slopes, often with pinnacles and fins (narrow, sharp ridges). Although water is the primary agent of erosion, it is possible that the wind plays some role in the formation of fins and pinnacles.

Deposition. Pyroclastic materials are either deposited near their source by gravity or are carried some distance by the wind. The average distance that fine-grained volcanic ash is carried is usually measured in kilometers, whereas volcanic bombs are usually deposited within a few meters of the vent. They are subsequently moved downslope by running water.

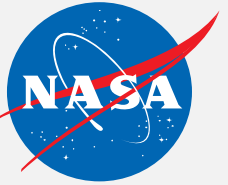
Tone and Texture. Pyroclastic material is usually silicic in composition, and is light in color and photo tone. Tuffs, ash deposits, and pumice are highly variable in color, ranging from pink, green, and buff, to gray and white. Volcanic bombs, which are basaltic in composition, are dark in photo tone, as are cinder cones and spatter cones. The textures of pyroclastic materials differ greatly. The most common pyroclastics are tuff and ash deposits, which appear smooth on aerial photography. Welded tuff appears coarse in texture because smaller particles have been welded together to form large, blocky aggregates. Cinder cones and spatter cones are usually rough and blocky in photo texture.

COMPILER: Judy Ehlen, USAETL.

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National Aeronautics and
Space Administration



ARSET

Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

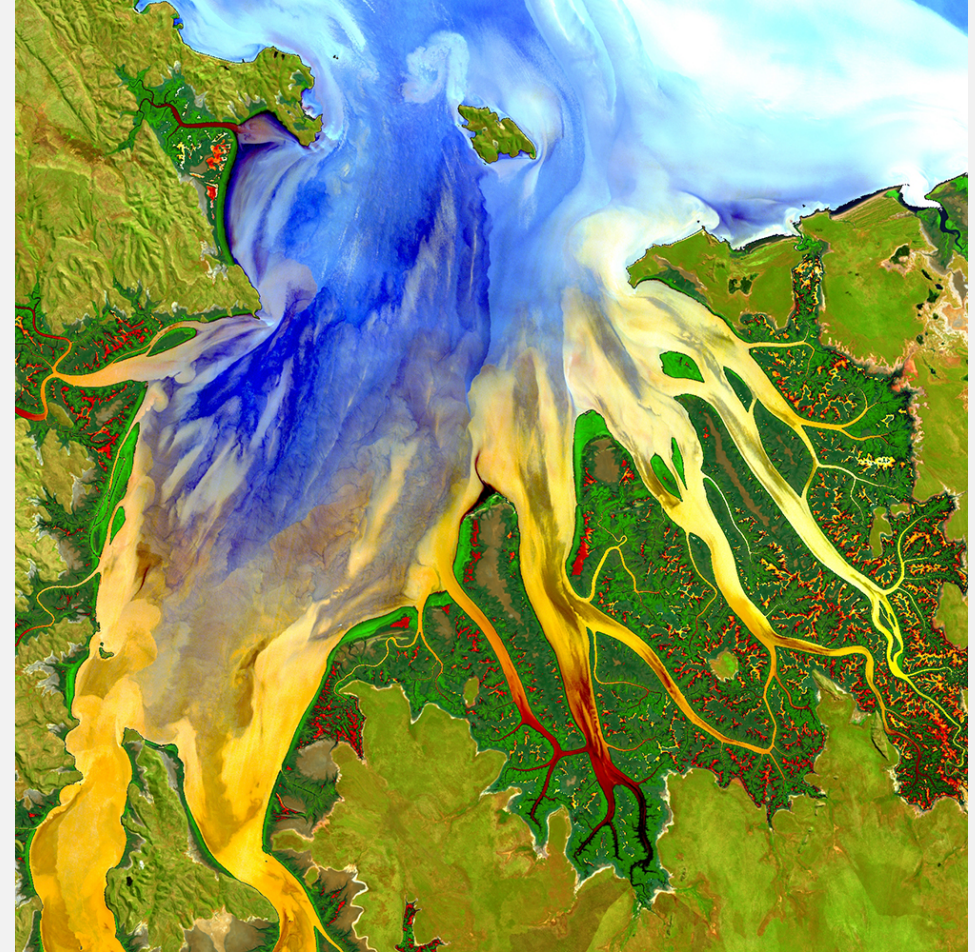
 @NASAARSET

Fundamentals of Aquatic Remote Sensing

Sherry L. Palacios, Ph.D.

Course Objective

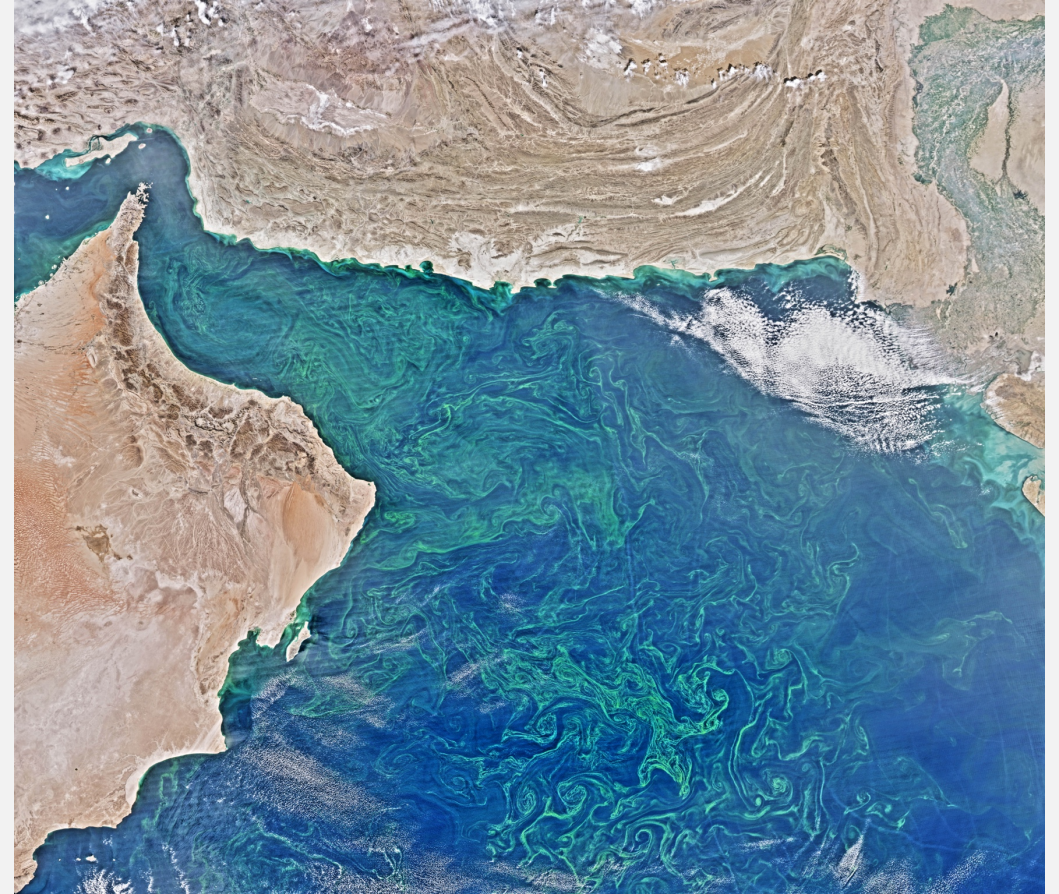
- Provide an overview of aquatic optics, the remote sensing of water targets, and NASA Earth observation resources available for aquatic applications.



Credit: NASA/USGS Landsat; Geoscience Australis

Agenda

- Light and Water
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools

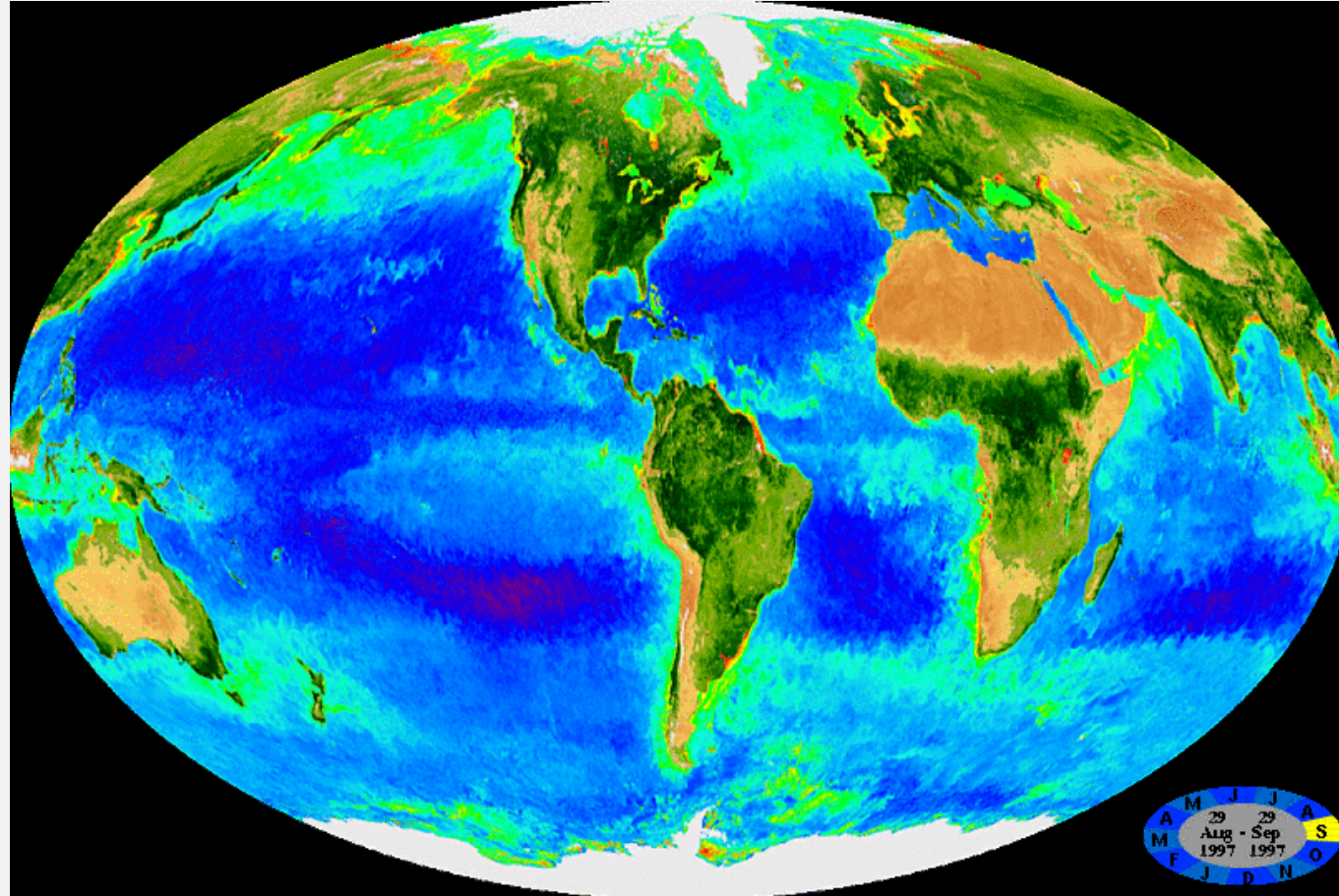


Phytoplankton Bloom in the Arabian Sea

Credit: N. Kuring, <http://earthobservatory.nasa.gov/IOTD/view.php?id=85718>

Why Do We Observe from Space?

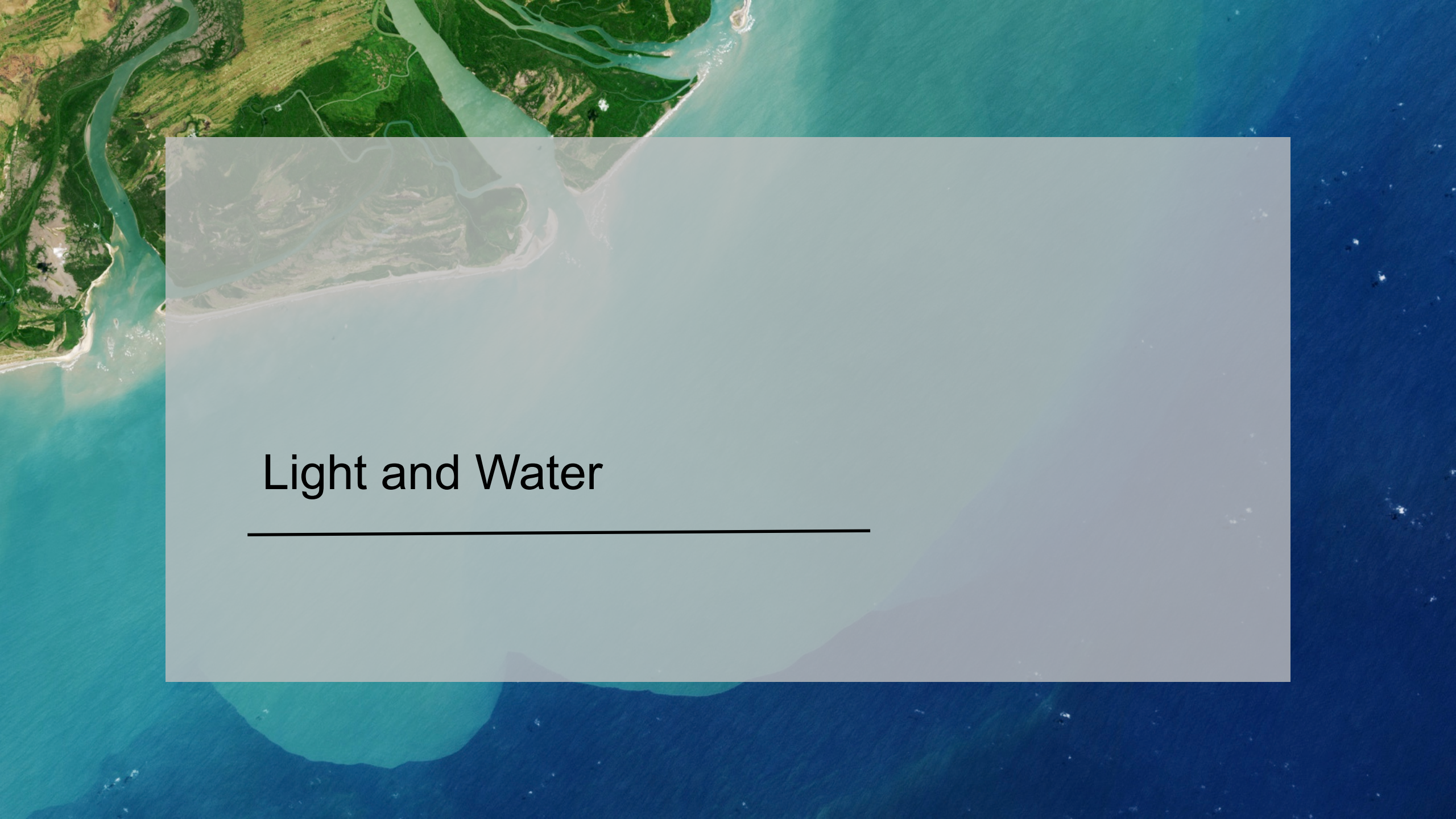
To Understand Earth's Processes on a Global Scale



SeaWiFS Chlorophyll
Credit: OBPB, NASA Goddard

Advantages of Remote Sensing of Aquatic Environments

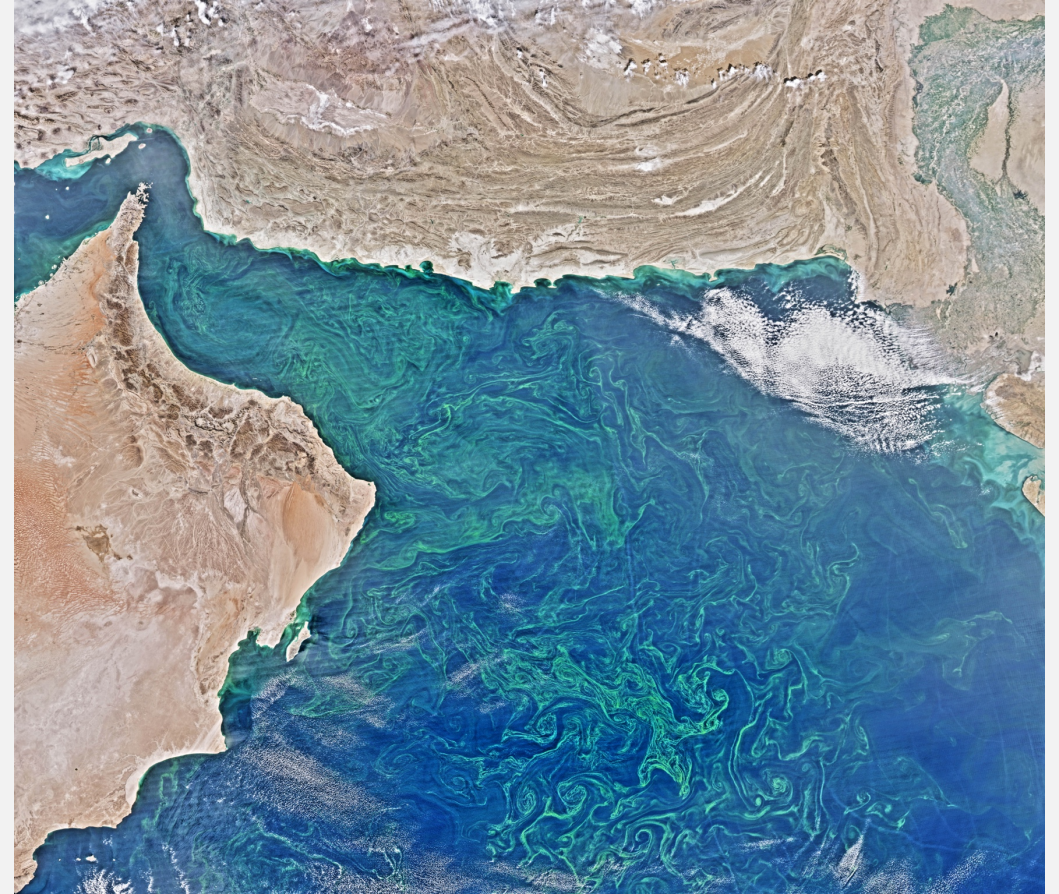
- Synoptic coverage
- Temporal frequency needed to capture dynamic aquatic processes
- Observations of remote ocean locations, infrequently accessed by sea-based platforms

An aerial photograph of a coastal region. On the left, a river with a complex delta system flows into the sea. The land is green with some brown patches, possibly indicating different vegetation or soil types. The water near the shore is a light turquoise color, while the deeper ocean is a dark blue. A large, semi-transparent white rectangle is overlaid on the right side of the image, containing the title text.

Light and Water

Agenda

- Light and Water
 - How light propagates through the atmosphere and water column, and back to sensor
 - Constituents of the water column and their inherent optical properties
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools

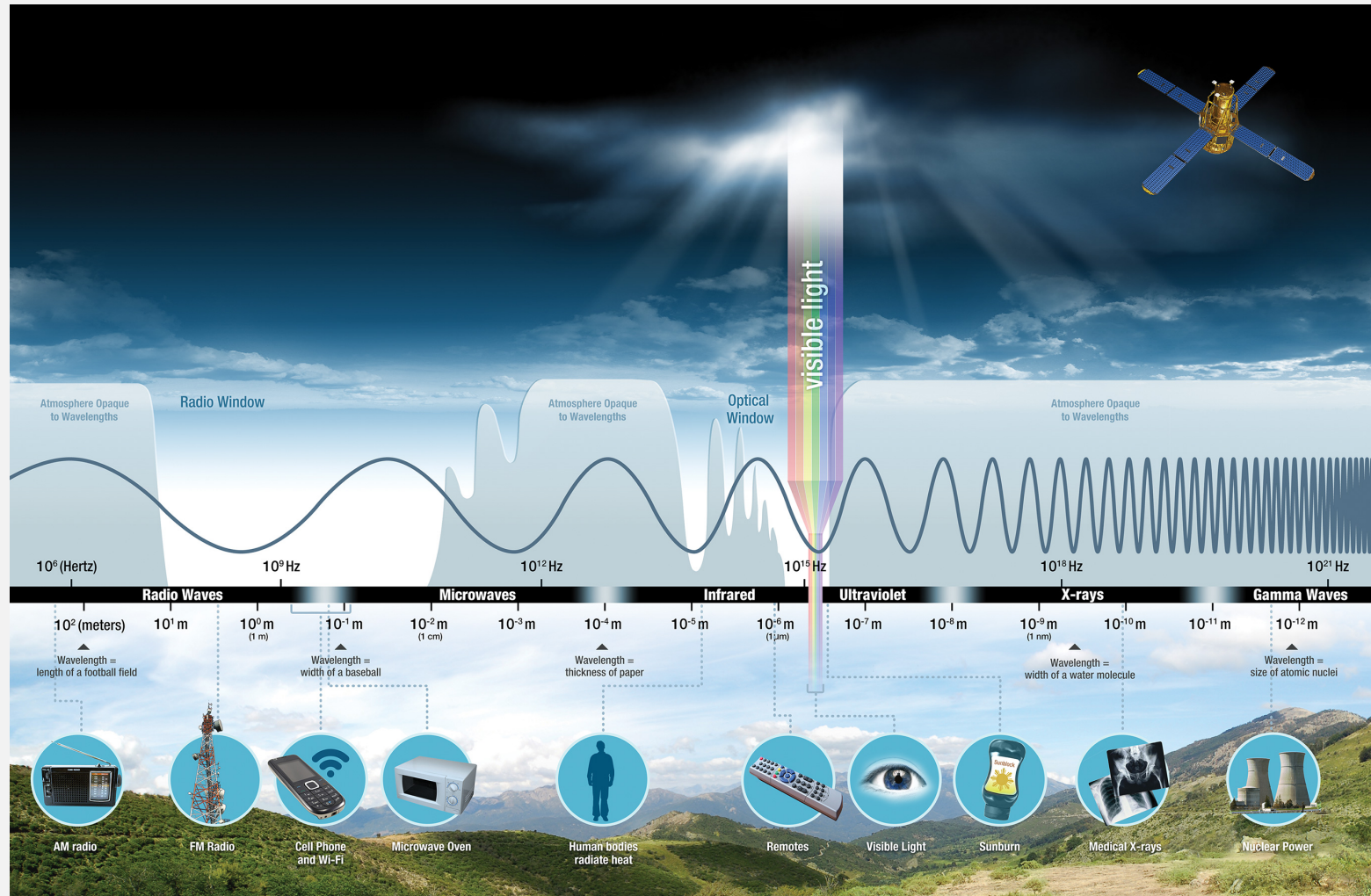


Phytoplankton Bloom in the Arabian Sea

Credit: N. Kuring, <http://earthobservatory.nasa.gov/IOTD/view.php?id=85718>

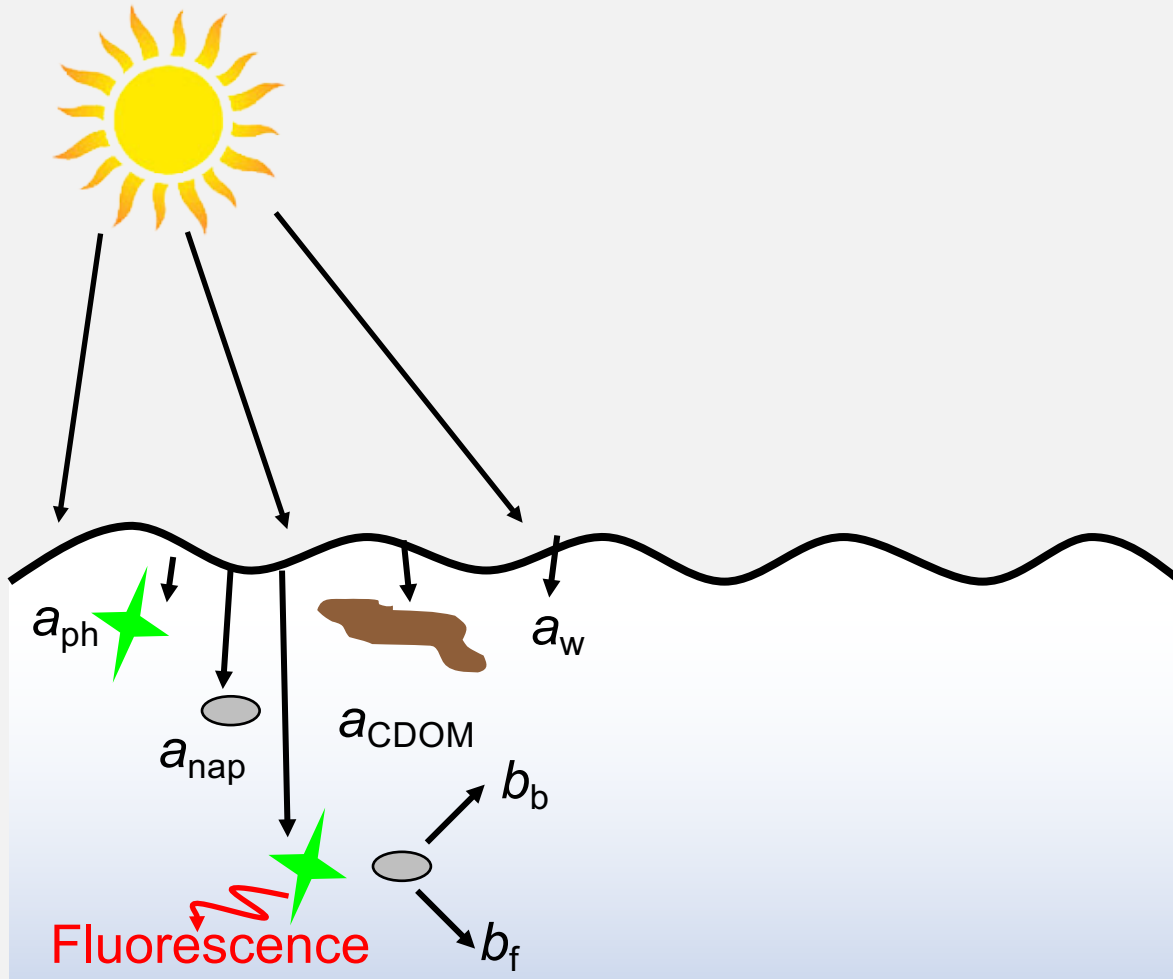
First, an Aquatic Optics Primer...

The Electromagnetic Spectrum



How Light Interacts with Water

Defining Remote Sensing Reflectance (R_{rs}) – or ‘Ocean Color’



$$R_{rs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Inherent Optical Properties

a = absorption by...

phytoplankton (ph)

non-algal particles (nap)

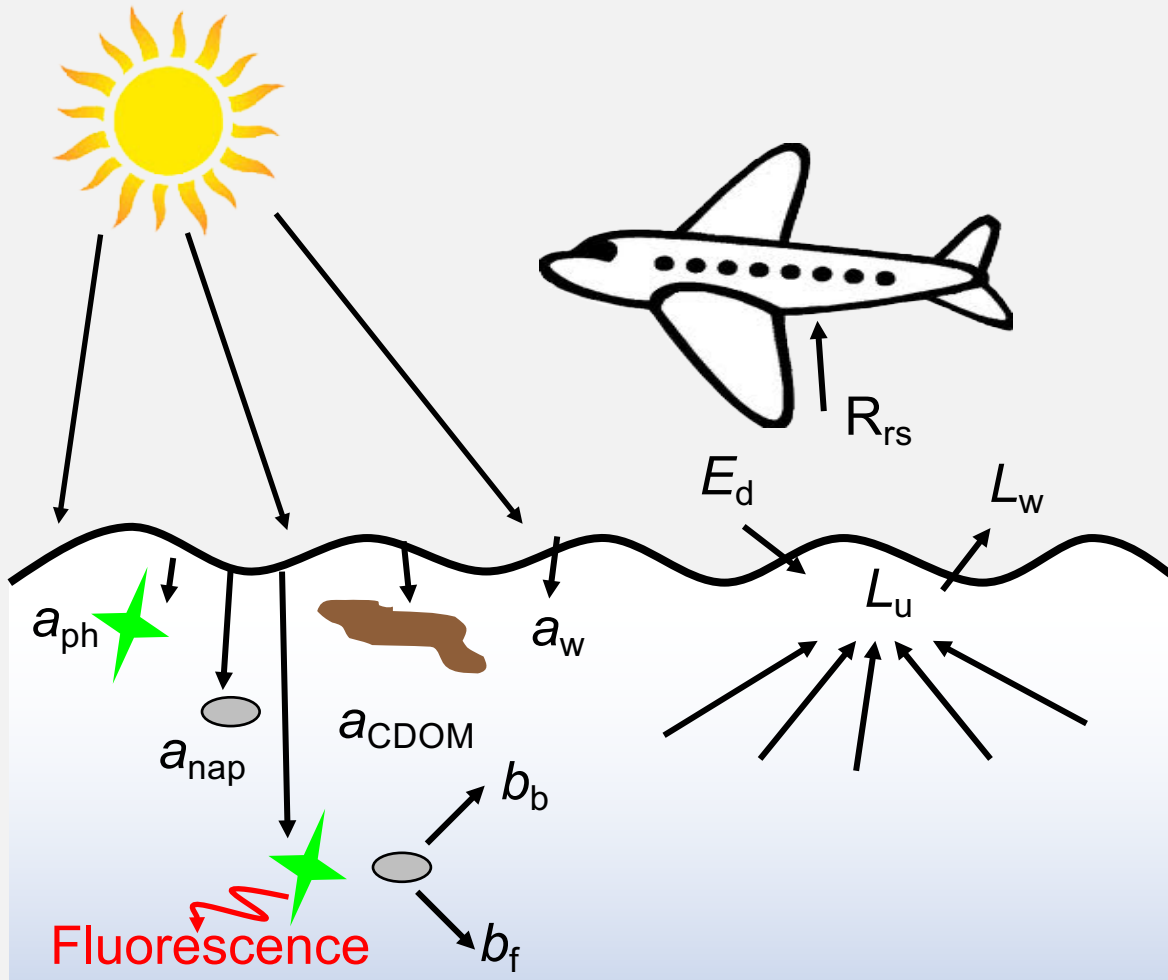
colored dissolved organic matter (CDOM)

water (w)

b = scattering in forward (f) and backward (b) directions

How Light Interacts with Water

Defining Remote Sensing Reflectance (R_{rs}) – or ‘Ocean Color’



$$R_{rs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} = \frac{L_w(\lambda)}{E_d(\lambda, 0^+)}$$

Inherent Optical Properties

a = absorption

b = scattering

Apparent Optical Properties

L_w = water leaving radiance

L_u = upwelling radiance

E_d = downwelling irradiance

R_{rs} = remote sensing (rs) reflectance

Inherent Optical Properties (IOPs) and the 'Color' of Water

$$R_{rs}(\lambda, 0^+) \cong C \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Light absorption (a) by phytoplankton (ph), non-algal particles (nap), water (w), and colored dissolved organic matter (CDOM)

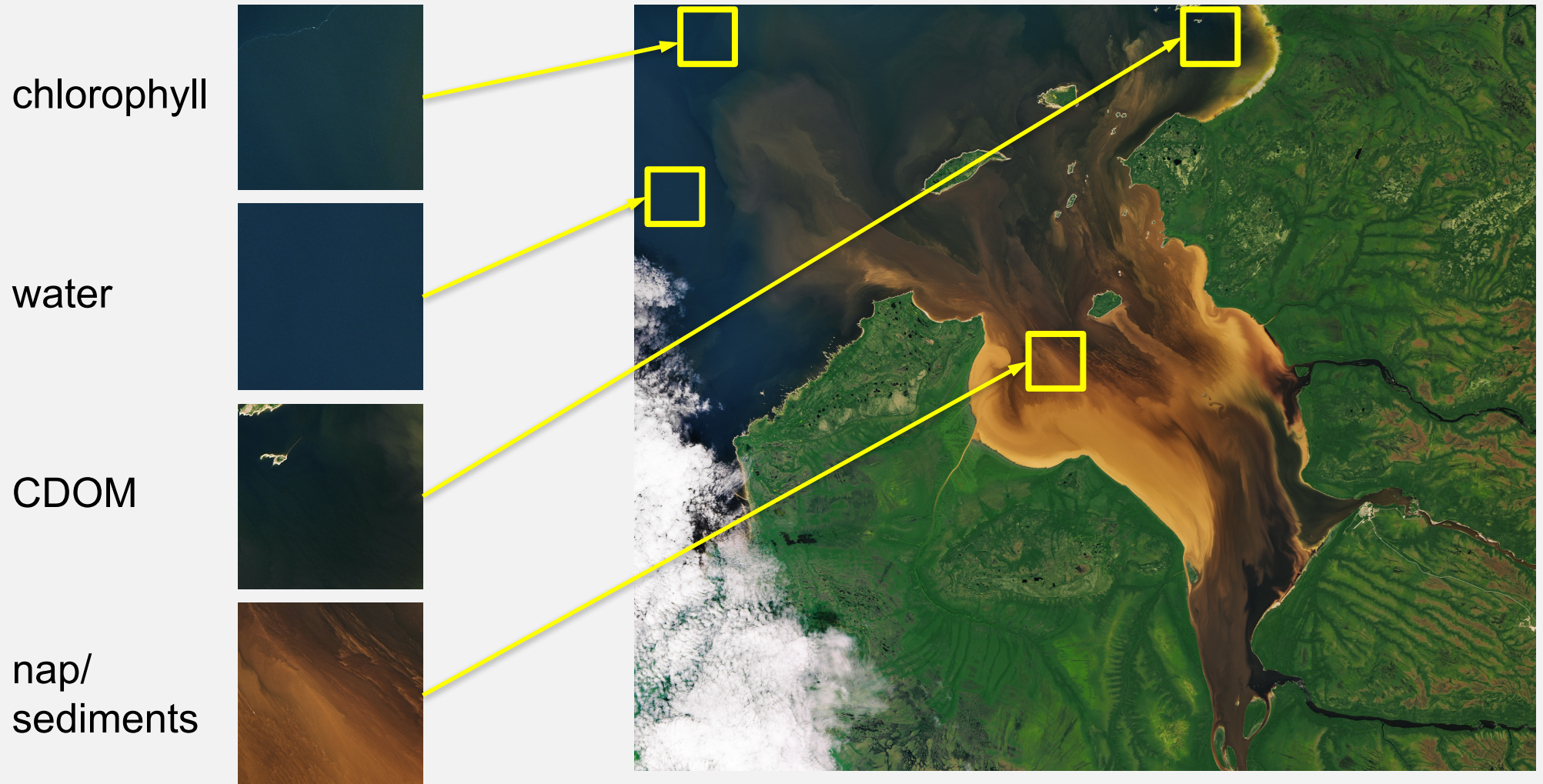
$$a = a_{ph} + a_{nap} + a_{CDOM} + a_w$$

Light scattering (b) by particles in forward (b_f) and backward (b_b) direction

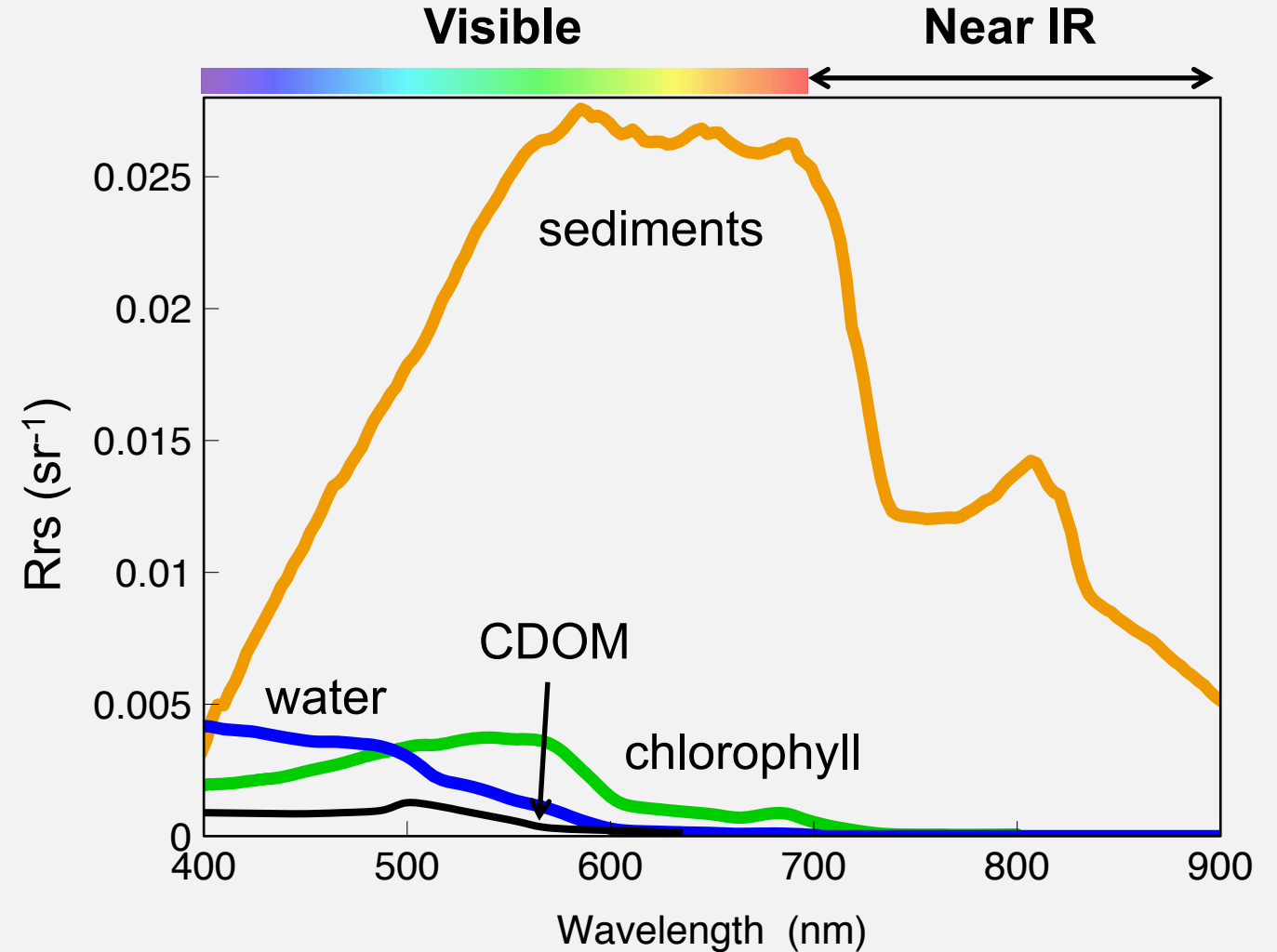
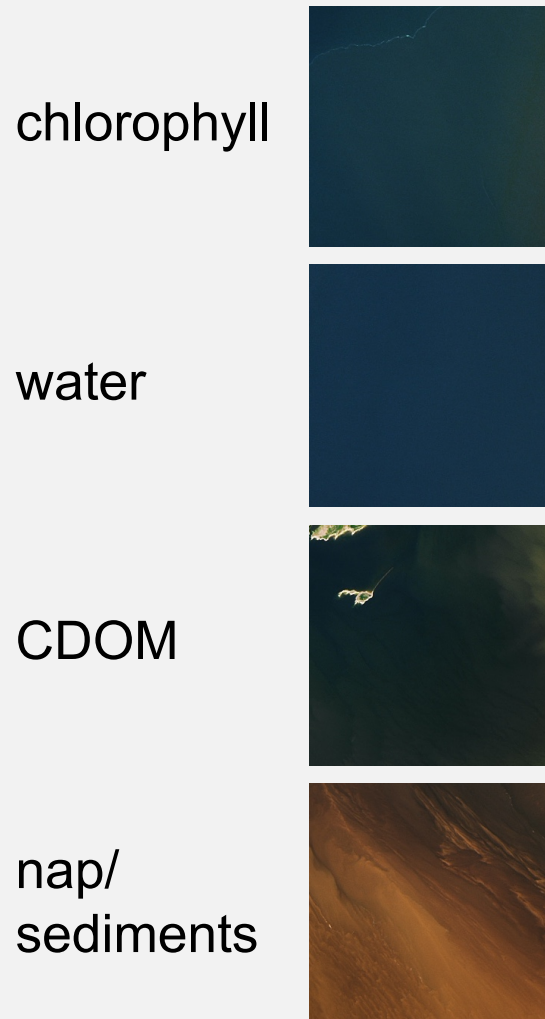
$$b = b_f + b_b$$



Inherent Optical Properties (IOPs) and the 'Color' of Water

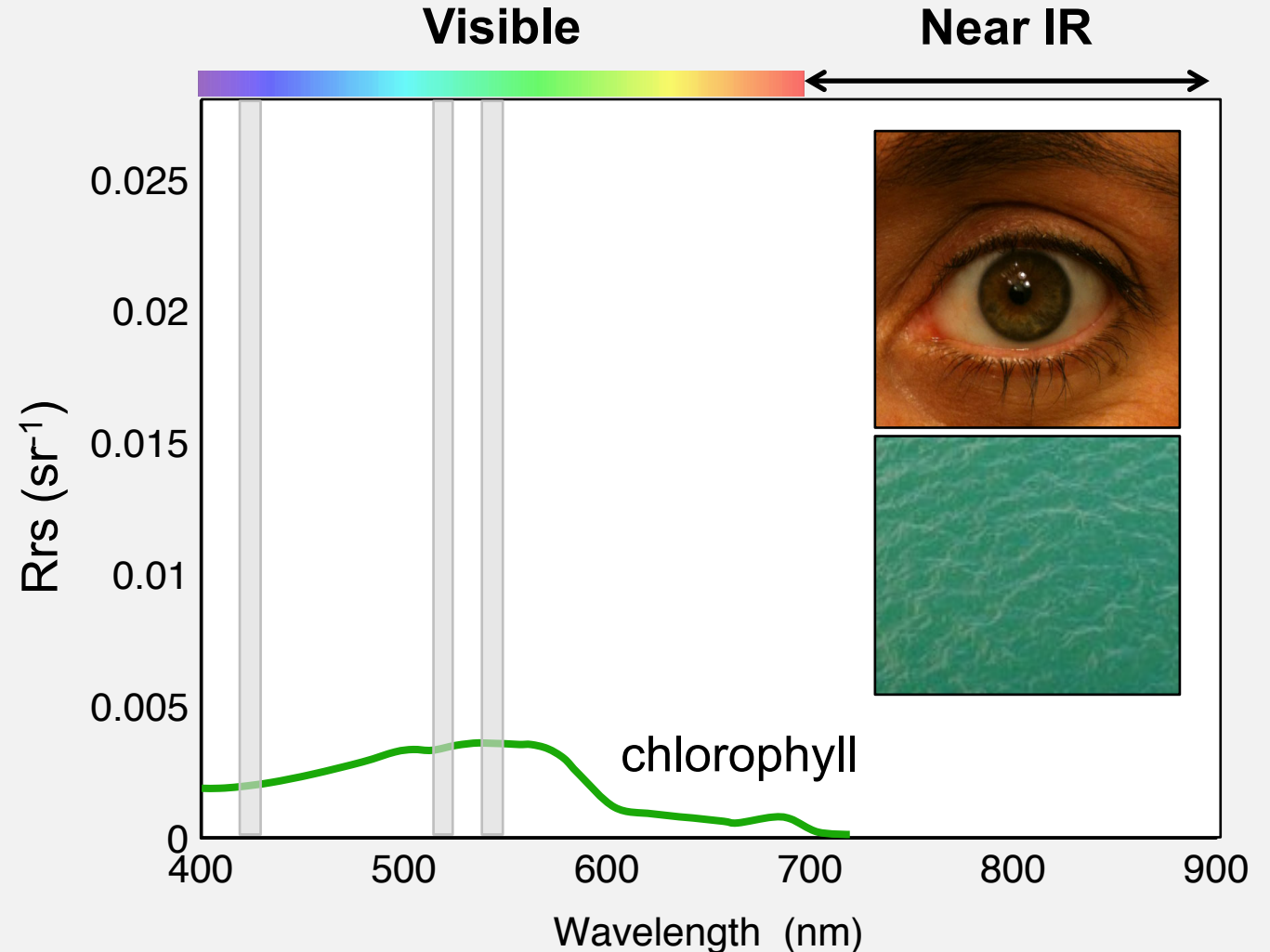


Inherent Optical Properties (IOPs) and the 'Color' of Water



Inherent Optical Properties (IOPs) and the 'Color' of Water

- The typical human eye has color-detecting receptors that sense light at:
 - 420-440 nm 'blue'
 - 534-555 nm 'green'
 - 564-580 nm 'red'
- Water with high chlorophyll content looks green because it reflects strongly in the green part of the spectrum

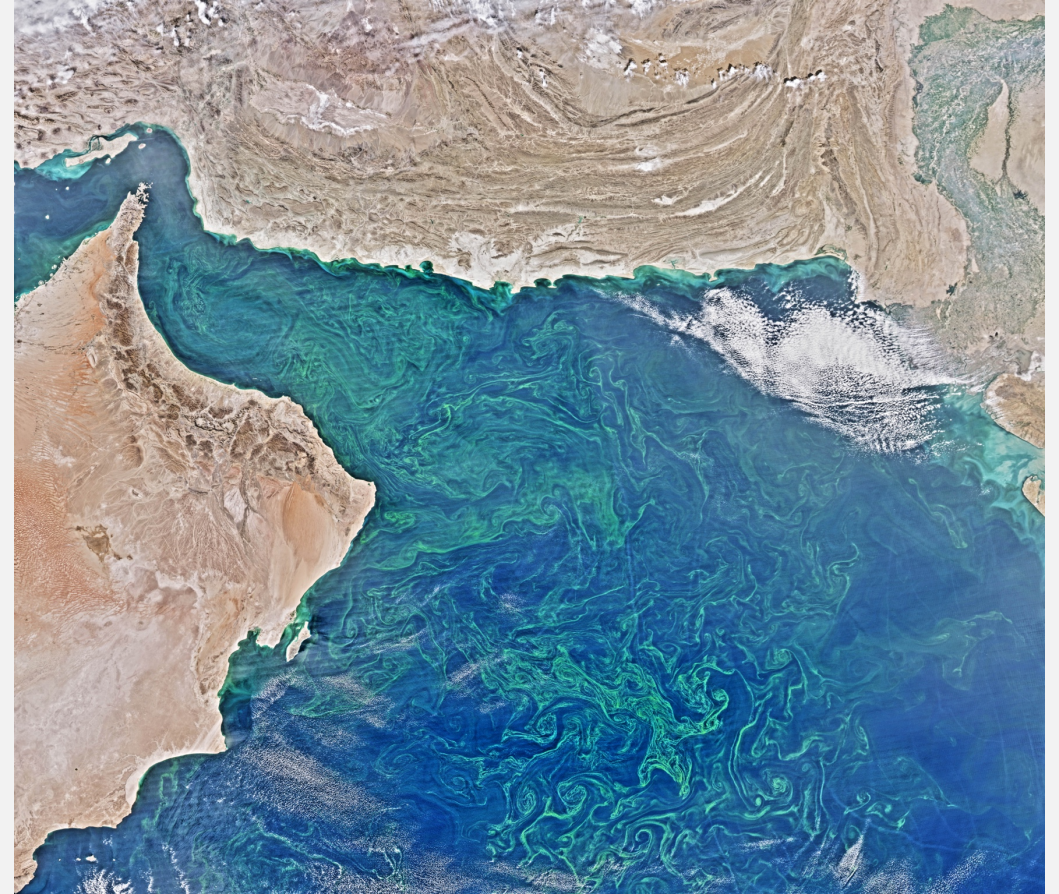


An aerial photograph of a coastal landscape. A river with a light-colored, sandy delta flows into the ocean. The water near the shore is a vibrant turquoise, while the deeper ocean is a dark blue. The land is covered in green vegetation. A semi-transparent white rectangle is overlaid on the right side of the image, containing the title text.

Fundamentals of Remote Sensing

Agenda

- Light and Water
- Fundamentals of Remote Sensing
 - Spatial, Temporal, Spectral Resolution
 - NASA Satellites and Sensors for Aquatic Applications
 - Image “Correction”
 - Satellite Data Processing Levels
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools



Phytoplankton Bloom in the Arabian Sea

Credit: N. Kuring, <http://earthobservatory.nasa.gov/IOTD/view.php?id=85718>

Types of Resolution

Spatial Resolution

- Decided by its pixel size
- Pixel: smallest unit measured by a sensor

Temporal Resolution

- How frequently a satellite observes the same area of the Earth

Spectral Resolution

- Ability of a sensor to define fine wavelength intervals
- Finer spectral channels enable remote sensing of different parts of the atmosphere

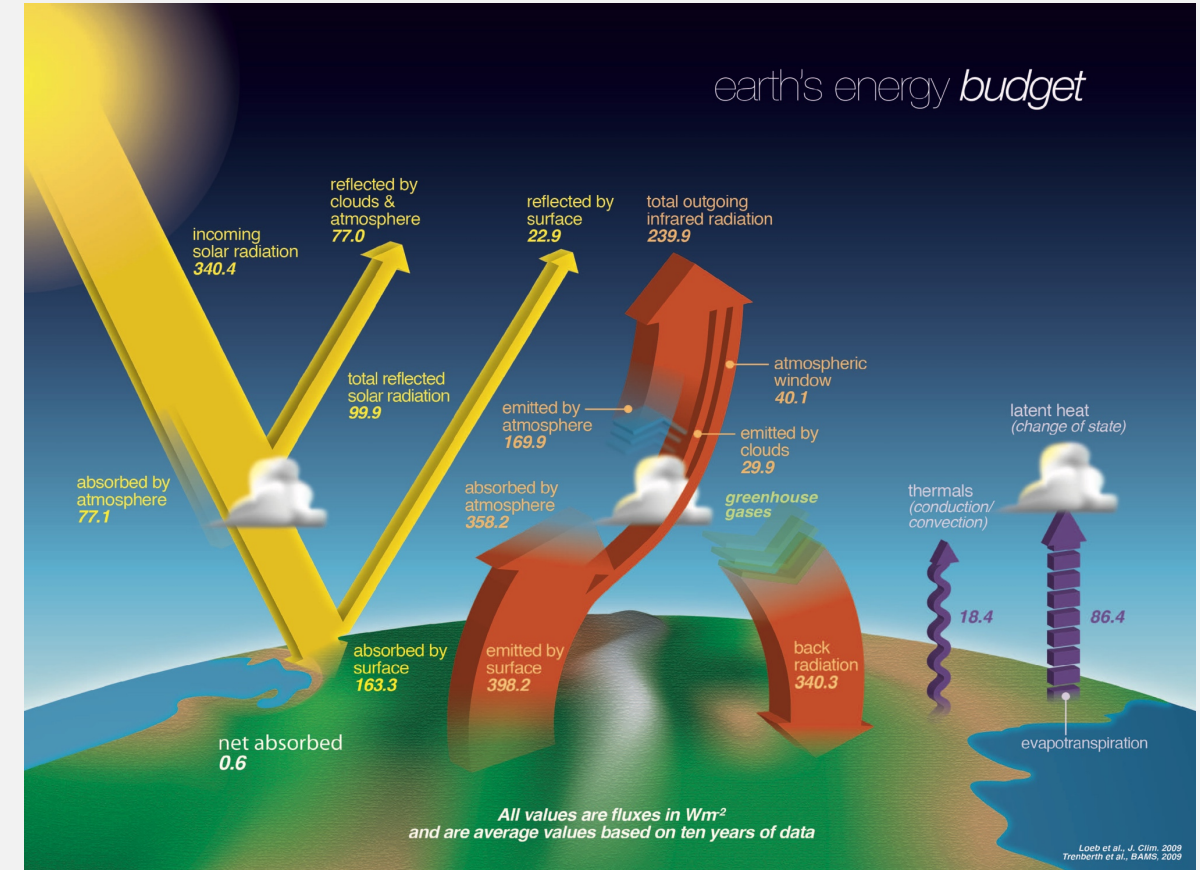
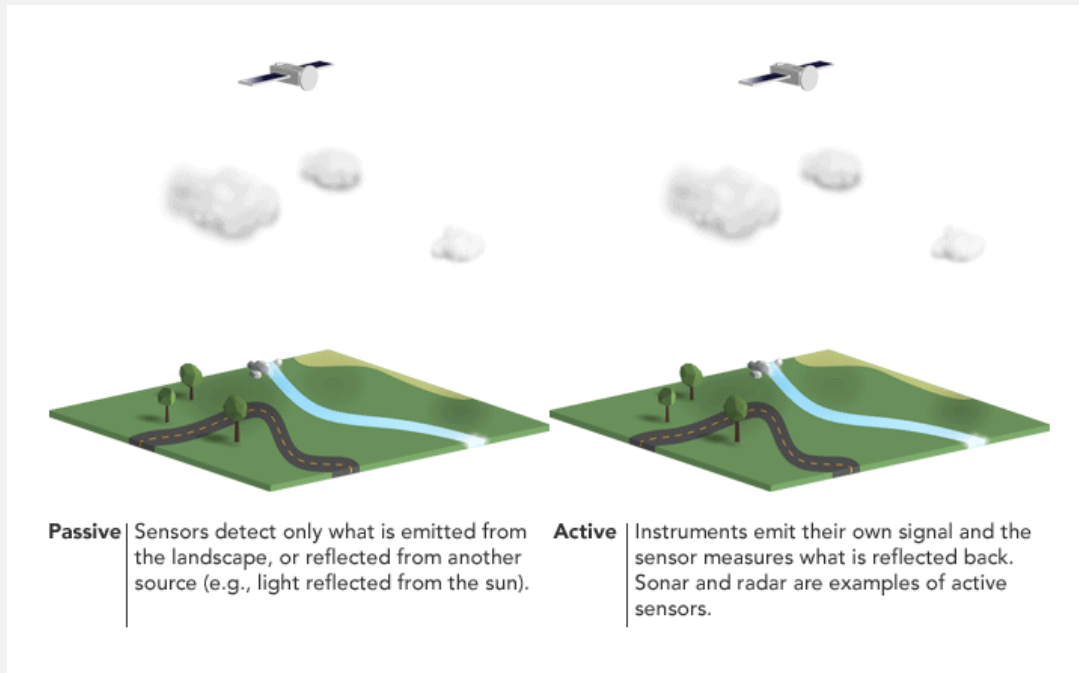
*Credit: Natural Resources Canada

Satellite (Sensor)	Spatial Resolution	Temporal Resolution	Spectral Bands
Landsat 8 (OLI)	15 m, 30 m	16 day revisit	9 bands (blue-green, green, red, near IR, shortwave and thermal IR)
Terra, Aqua (MODIS)	250 m – 1 km	2 times per day	36 bands (red, blue, IR, NIR, MIR)

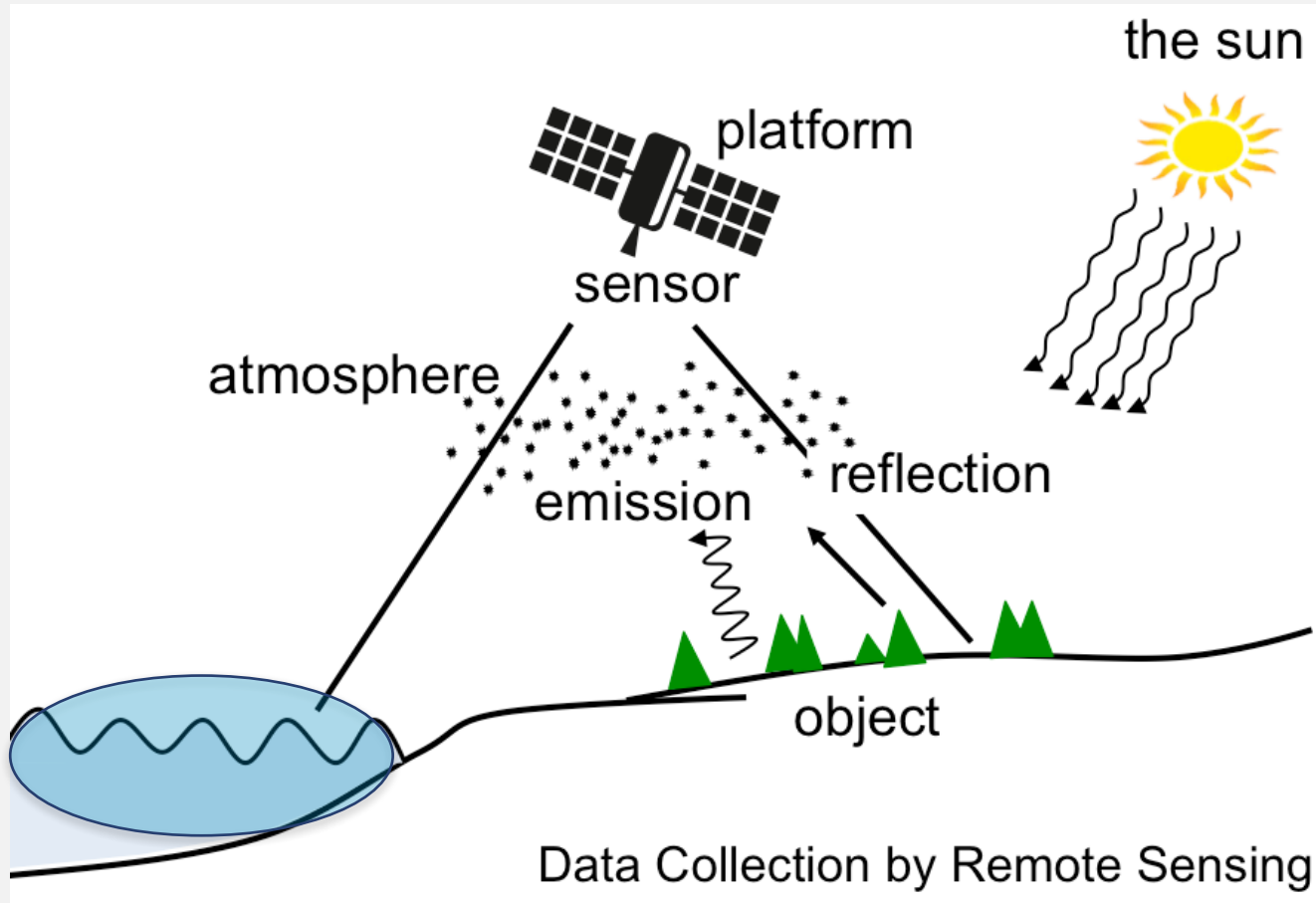
How Do We Observe From Space?

Overview of Active & Passive Remote Sensing

- Satellites carry instruments and sensors to measure:
 - reflected solar radiation
 - emitted infrared and microwave radiation



Data Collection by Satellites



Atmosphere

- Clouds
- Aerosols
- Gases

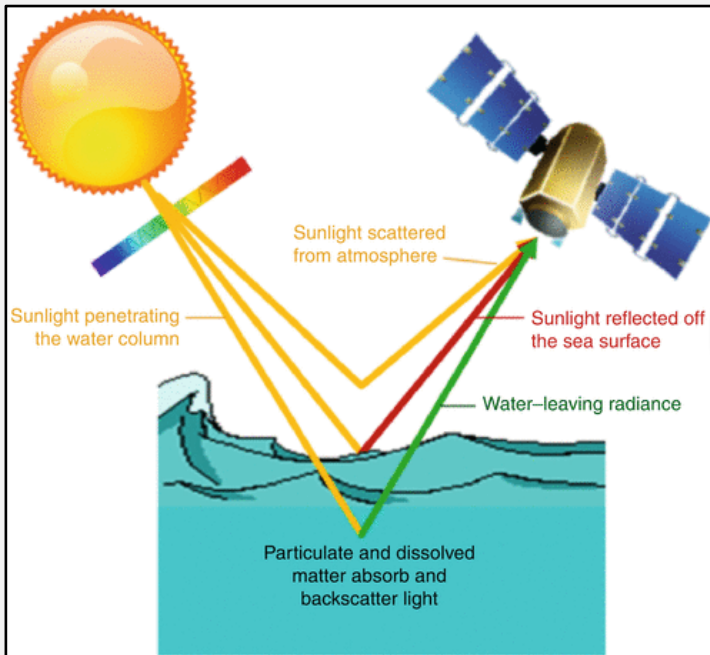
Earth's Surface

- Snow/Ice
- Land (land use, vegetation)
- **Water**

Remote Sensing of Water Bodies

Reflected Solar Radiation (~color of water)

- Measured by satellite sensors
- Used to derive the properties of optically-active water constituents



- Suspended Sediments
- Algae
- Colored Dissolved Organic Matter
- Detrital Organic Matter
- Submerged or floating vegetation
- Oil

- Contaminants
- Pathogens

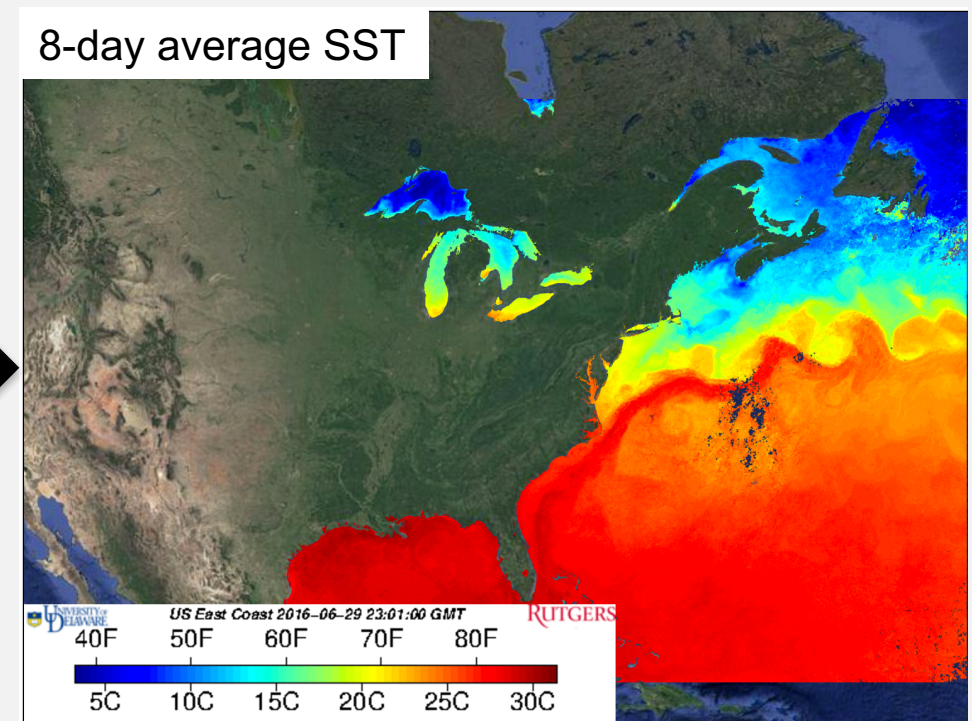
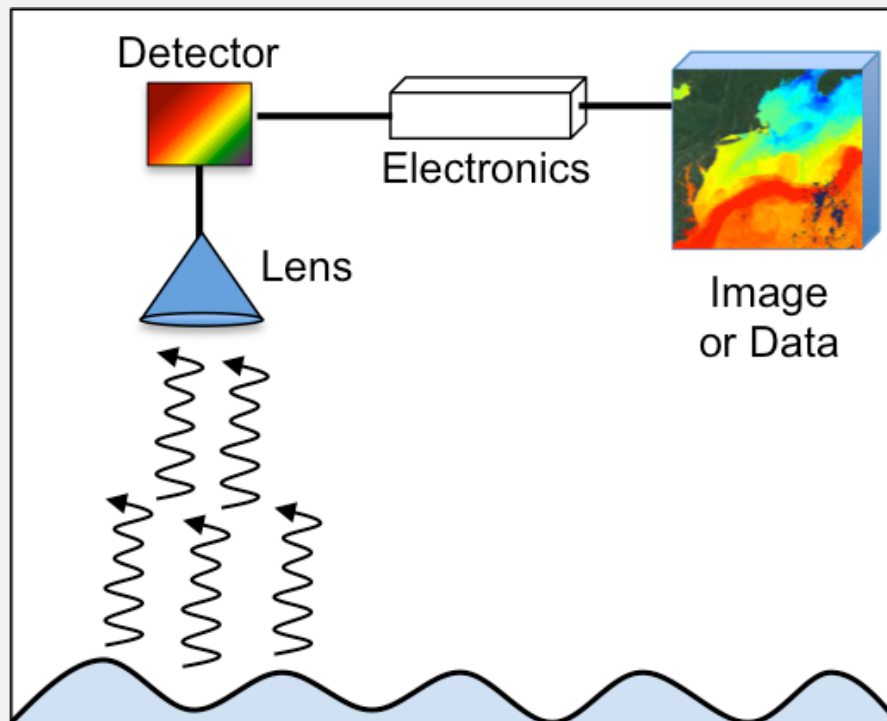


Coccolithophore Bloom, Norway

Remote Sensing of Water Bodies

Emitted Thermal Radiation

- Used to derive the surface temperature of water bodies



MARACOOS, ORB Lab, courtesy M. Oliver

A satellite image of a coastal region. On the left, a river with a complex delta system flows into the ocean. The land is green with some brown patches, indicating vegetation and possibly agricultural or natural terrain. The ocean is a deep blue, with a lighter turquoise area near the shore. A semi-transparent light blue rectangle is overlaid on the right side of the image, containing the title text.

NASA Satellites and Sensors for Aquatic Applications

Overview of NASA Satellites & Sensors for Water Quality Monitoring

- Currently several satellites observe water surface properties in:
 - the open ocean
 - coastal oceans and estuaries
 - many inland lakes
- A number of water quality parameters are operationally available from these satellites
 - e.g. temperature, chlorophyll-a



NASA Satellites & Sensors for Ocean and Coastal Systems

Satellite	Sensor	Parameter
Landsat Series (7/1972 - present)	• Thematic Mapper (TM) • Enhanced Thematic Mapper (ETM+) • Operational Land Imager (OLI)	• Spectral Reflectance
Terra (12/1999 - present)	Moderate Resolution Imaging Spectroradiometer (MODIS)	• Spectral Reflectance • Chlorophyll-a Concentration • Temperature • Colored Dissolved Organic Matter (CDOM) • Turbidity • Euphotic Depth
Aqua (5/2002 - present)		
Terra (12/1999 – present)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	• Spectral Reflectance • Temperature

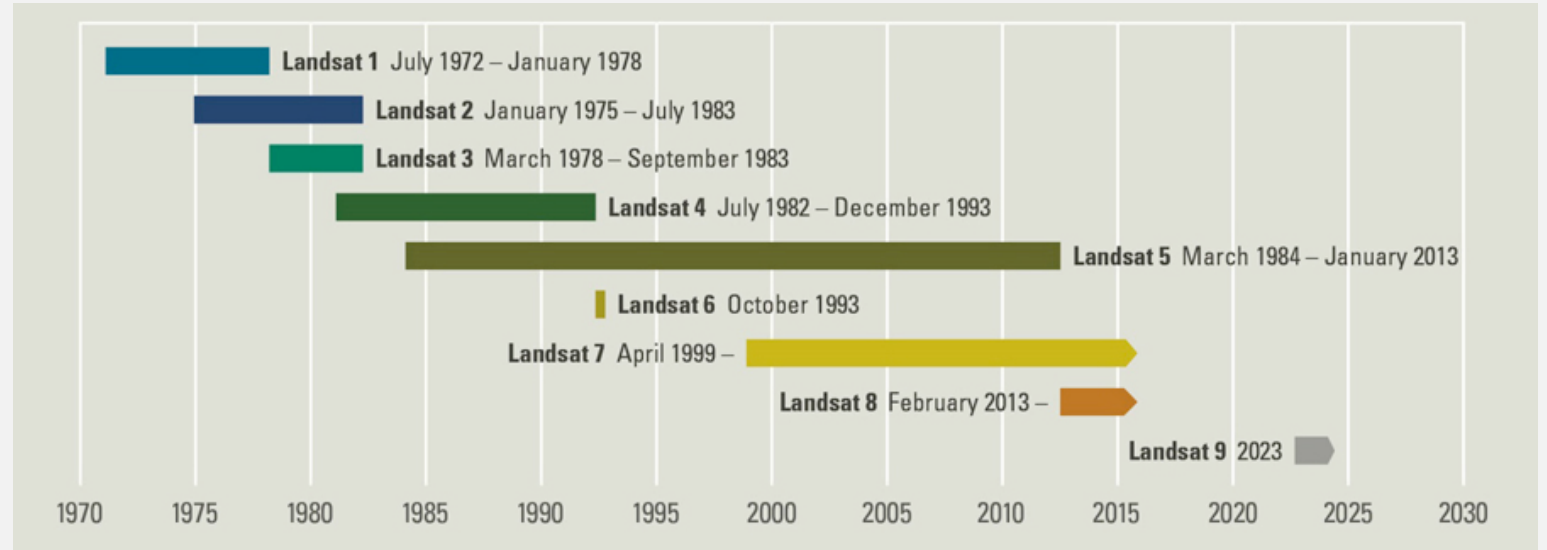
NASA Satellites & Sensors for Ocean and Coastal Systems

Satellite	Sensor	Parameter
National Polar Partnership (NPP) (11/2011-present)	Visible Infrared Imaging Radiometer Suite (VIIRS)	• Spectral Reflectance • Chlorophyll Concentration
International Space Station	Hyperspectral Imager for the Coastal Ocean (HICO) (2009 – 2014)	• Spectral Radiance • Spectral Remote Sensing Reflectance
Plankton, Aerosols, Clouds, ocean Ecosystems (PACE) (proposed for 2022 or 2023)	Ocean Color Instrument	• Spectral Reflectance • Optional Polarimeter being considered

Landsat Satellites and Sensors

<http://landsat.gsfc.nasa.gov/>

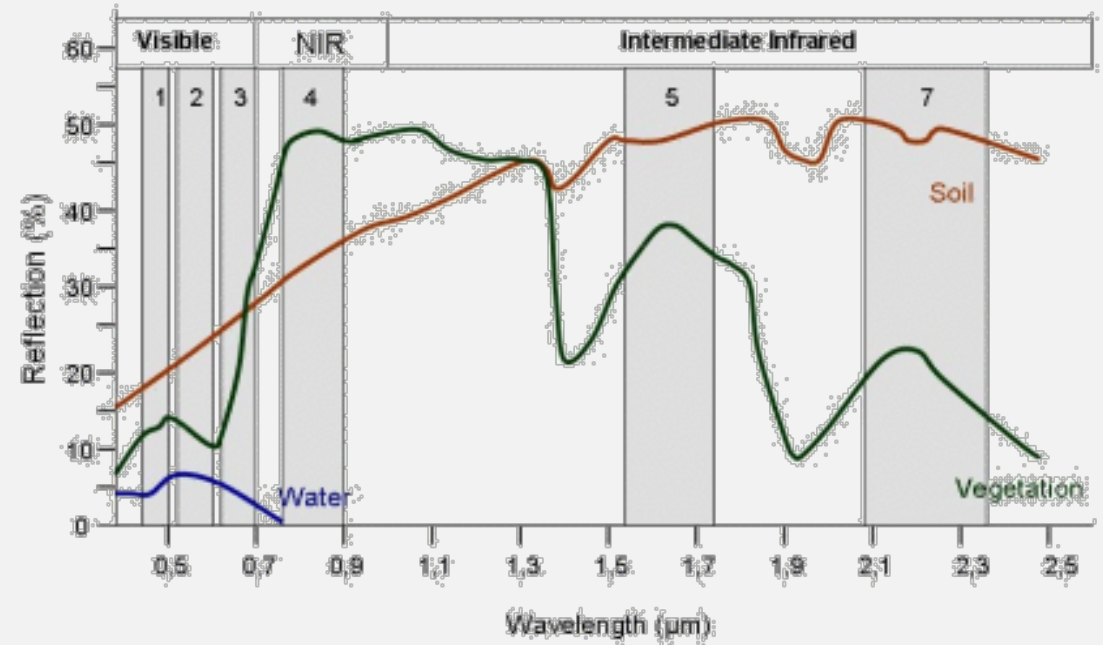
- Near-polar orbit
- 10 a.m. equator crossing time
- Global coverage
- July 1972 – present
- 16 day revisit time
- Sensors:
 - MSS
 - TM
 - ETM+
 - OLI
 - TIRS



Landsat-7 Enhanced Thematic Mapper (ETM+)

<http://geo.arc.nasa.gov/sgc/landsat/l7.html>

- Flying on-board Landsat 7 polar orbiting satellites
- Spatial Coverage and Resolution:
 - Global, swath 185 km
 - Spatial Resolution: 15 m, 30 m, 60 m
- Temporal Coverage and Resolution
 - April 15, 1999 – present
 - 16 day revisit time
- Spectral Bands
 - 8 bands (major bands include: blue-green, green, red, reflected and thermal IR, and panchromatic)

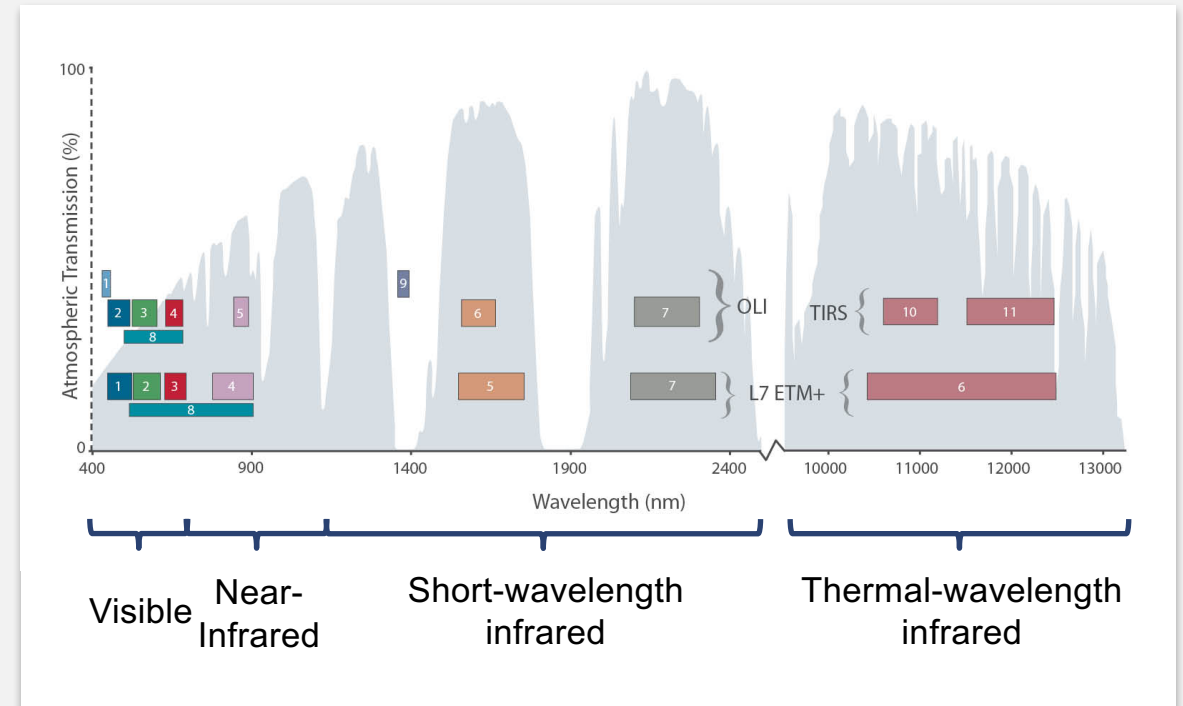


- Spectral Bands
 - Bands 1-5, 7: 30 m
 - Band 6: 60 m
 - Band 8: 15 m

Landsat-8 Operational Land Imager (OLI)

<http://landsat.usgs.gov/landsat8.php>; <http://landsat.gsfc.nasa.gov/?p=5779>

- Flying on-board Landsat 8 (Landsat Data Continuity Mission – LDCM) polar orbiting satellite
- Spatial Coverage & Resolution:
 - Global, Swath 185 km
 - Spatial Resolution: 15 m, 30 m
- Temporal Coverage & Resolution:
 - February 11, 2013 – present
 - 16 day revisit time
- Spectral Bands
 - 9 bands (major bands include blue-green, red, near IR, shortwave and thermal IR, panchromatic)

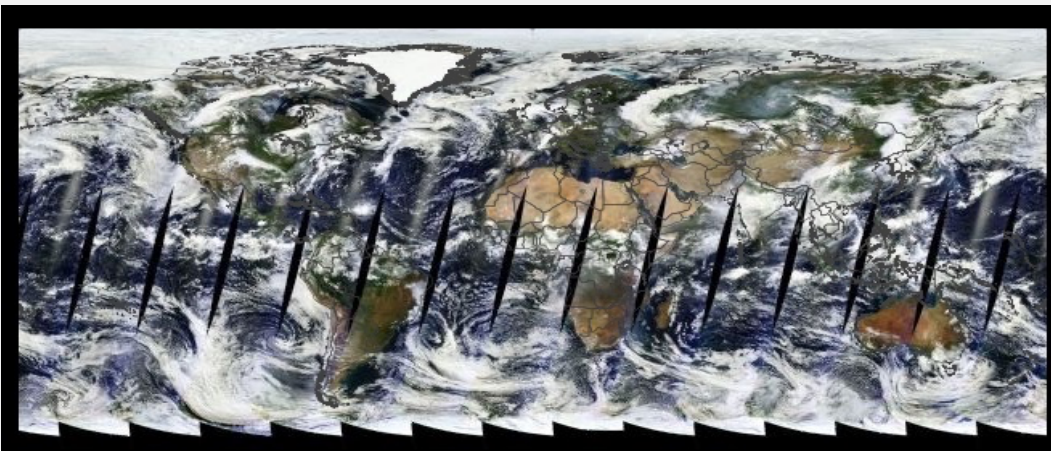


Terra and Aqua

<http://terra.nasa.gov/>; <http://aqua.nasa.gov/>

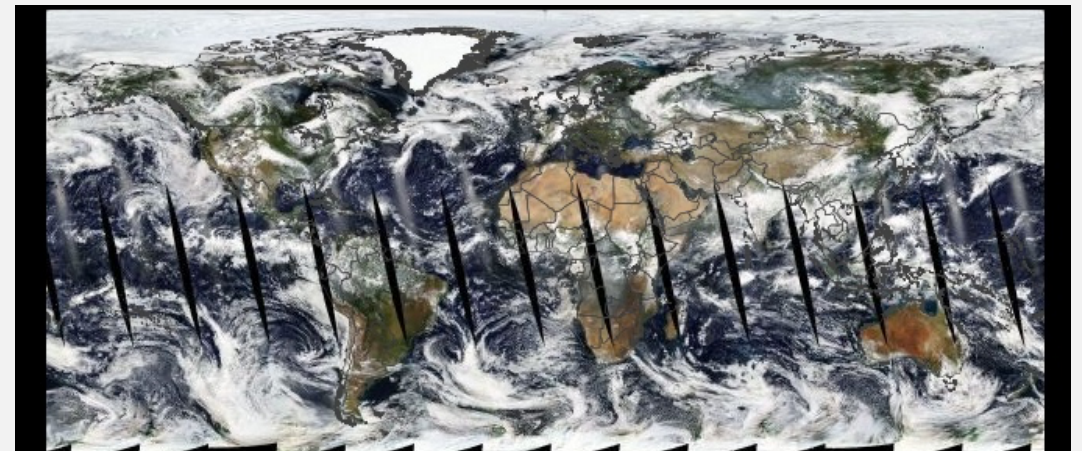
Terra

- Polar orbit, 10:30 a.m. equator crossing time
- Global Coverage
- December 18, 1999 – present
- 1-2 observations per day
- Sensors:
 - ASTER, CERES, MISR, MODIS, MOPITT



Aqua

- Polar orbit, 1:30 p.m. equator crossing time
- Global Coverage
- May 4, 2002 – present
- 1-2 observations per day
- Sensors:
 - AIRS, AMSU, CERES, MODIS, AMSR-E



MODerate Resolution Imaging Spectroradiometer (MODIS)

<http://modis.gsfc.nasa.gov>

- On board Terra and Aqua
- Designed for land, atmosphere, ocean, and cryosphere observations
- Spatial Coverage and Resolution:
 - Global, Swath: 2,330 km
 - Spatial Resolution Varies: 250 m, 500 m, 1 km
- Temporal Coverage and Resolution:
 - 2000 – present
 - 2 times per day

Spectral Bands

- 36 bands (red, blue, IR, NIR, MIR)
 - Bands 1-2: 250 m
 - Bands 3-7: 500 m
 - Bands 8-16: 1000 m

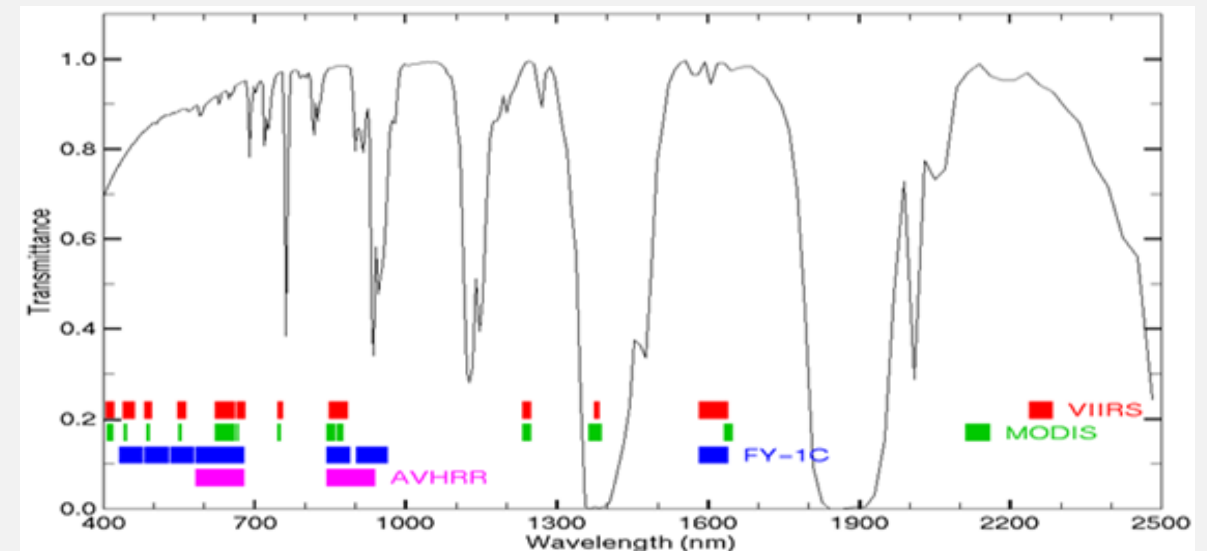
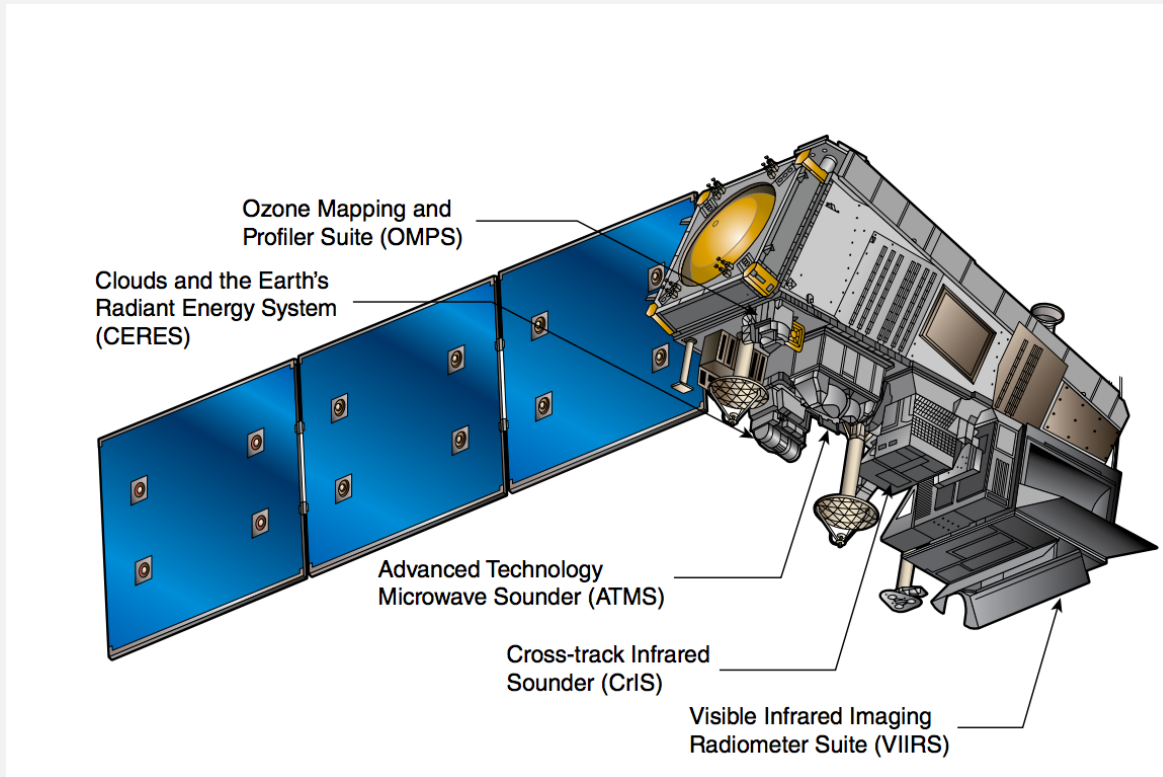


Image Credit: <http://cimss.ssec.wisc.edu/>

National Polar Partnership (NPP)

http://www.nasa.gov/mission_pages/NPP



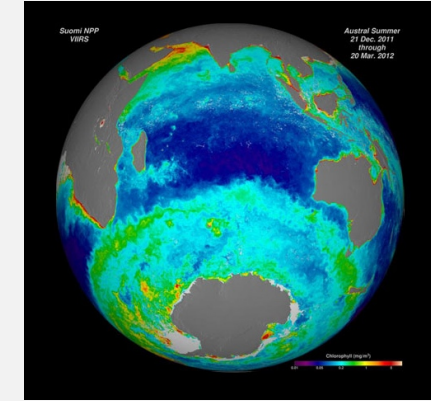
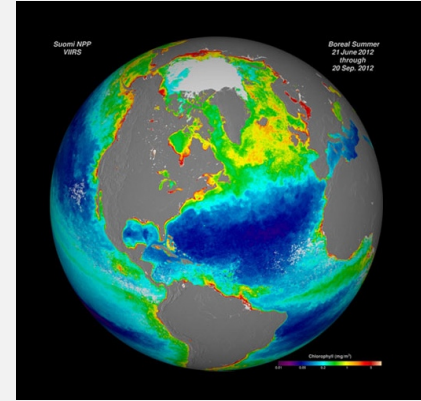
NASA/NOAA

- Polar orbit
- 1:30 p.m. equator crossing time
- Global coverage
- November 21, 2011 – present
- 1-2 observations per day
- Sensors:
 - VIIRS
 - ATMS
 - CrIS
 - OMPS
 - CERES

Visible Infrared Imaging Radiometer Suite (VIIRS)

<http://npp.gsfc.nasa.gov/viirs.html>

- Flying on-board NPP, polar-orbiting satellite
- Designed to collect measurements of clouds, aerosols, ocean color, surface temperature, fires, and albedo
- Spatial Coverage and Resolution:
 - Global, swath width: 3,040 km
 - Spatial resolution: 375 m – 750 m
- Temporal Coverage
 - October 2011 – present
 - 2 times per day

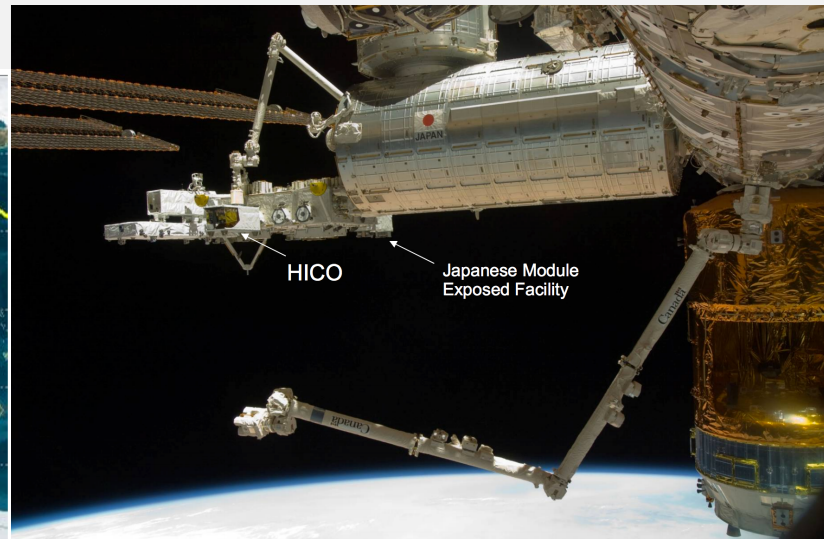
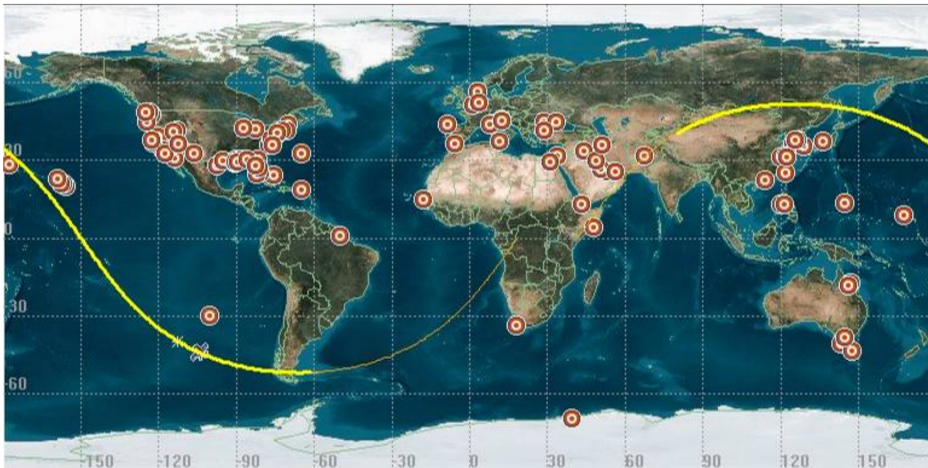


- Spectral Bands
 - 15 bands (major bands include visible, red, blue, green, short, middle, and long-wave IR)
 - Ocean Color Bands 1-7: 0.402 - 0.682 μm
 - Sea Surface Temperature Bands 12-13: 3.660 - 4.128 μm

Hyperspectral Imager for the Coastal Ocean (HICO)

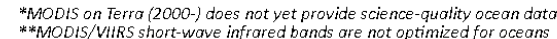
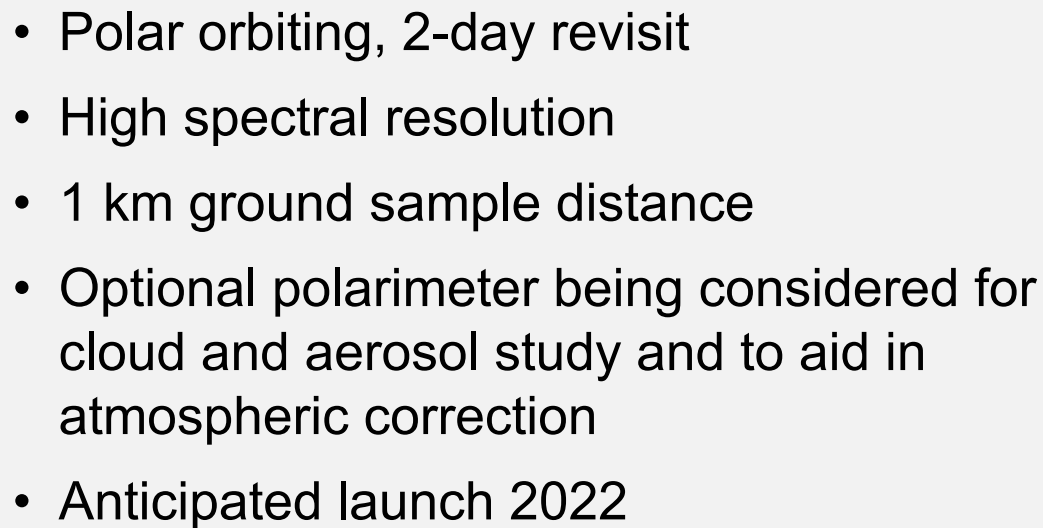
<http://hico.coas.oregonstate.edu/>; <http://oceancolor.gsfc.nasa.gov/cms/data/hico>

- Partnership with U.S. Naval Research Lab, Office of Naval Research, Oregon State University, and NASA
- Active 2009 – 2014 aboard the International Space Station (ISS)
- 380 nm to 960 nm at 5.7 nm spectral resolution
- 90 m² spatial resolution
- Targeted data collection



Davis, C. O. (n.d.). *The Hyperspectral Imager for the Coastal Ocean (HICO): Sensor and Data Processing Overview* [PDF]. International Ocean Colour Coordinating Group.

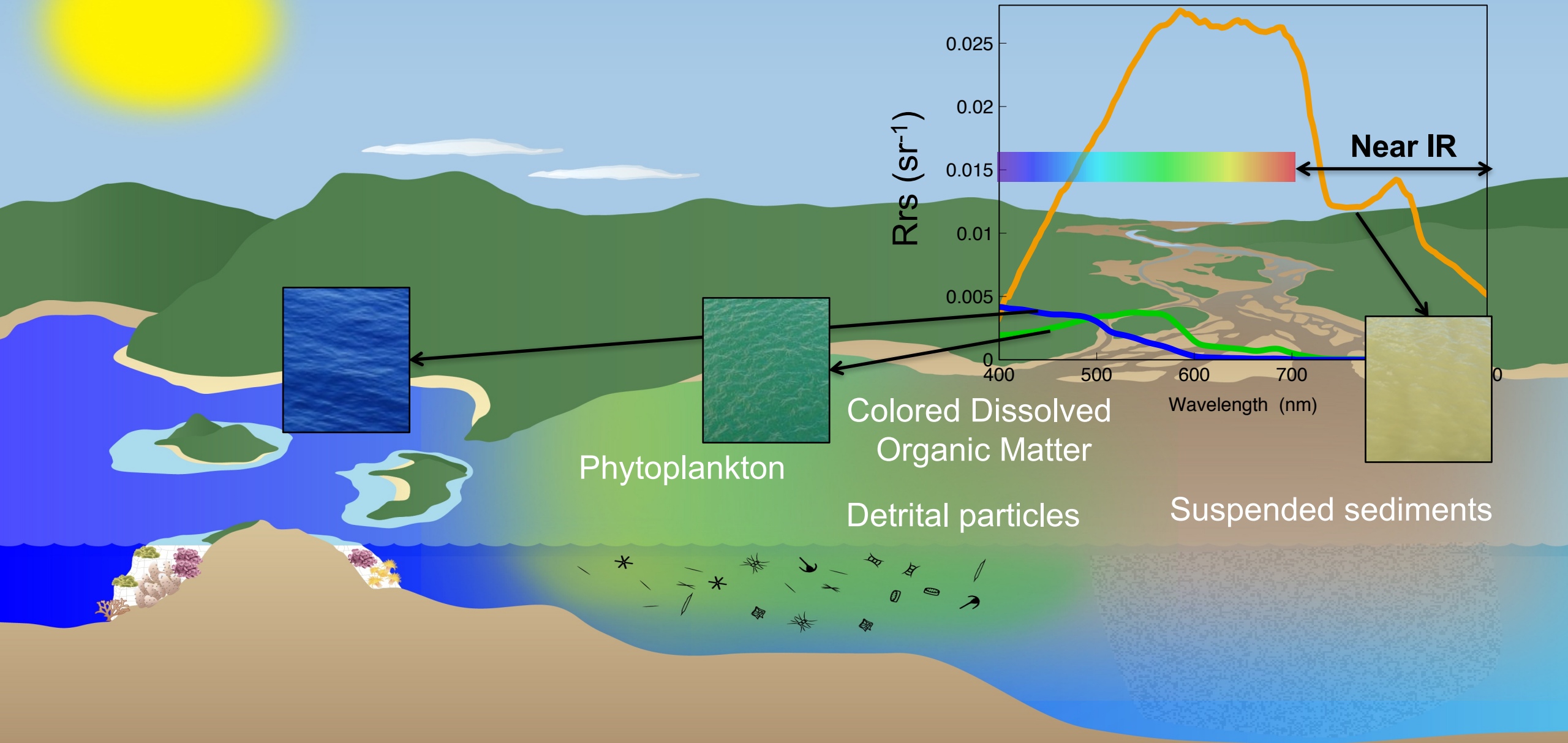
<http://pace.gsfc.nasa.gov/>



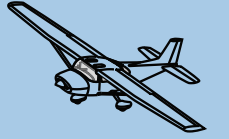
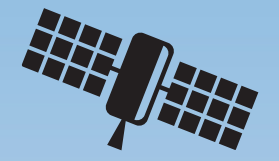
An aerial photograph of a coastal region. On the left, a river with a complex delta system flows into a body of water. The land is green with some brown patches, possibly indicating different vegetation or soil types. The water transitions from a light turquoise near the shore to a deep blue further out. A large, semi-transparent white rectangular box is overlaid on the right side of the image, containing the text "Image 'Correction'" and a horizontal line.

Image "Correction"

Remote Sensing of Water Bodies



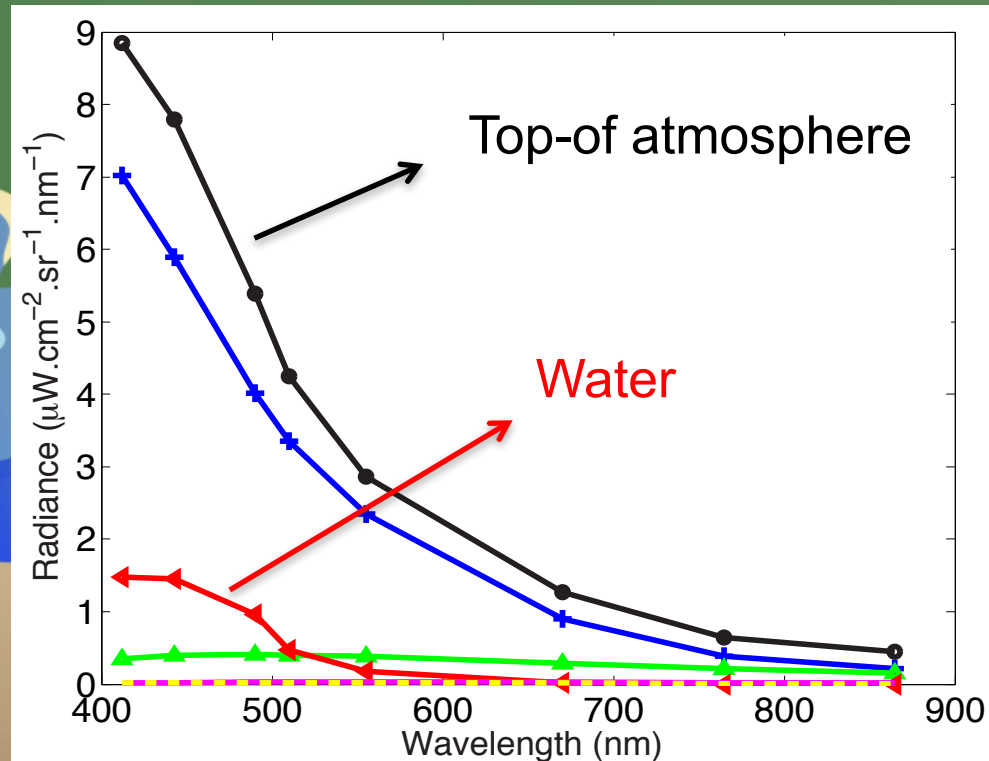
Atmospheric Correction



$$L_t(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T(\lambda, \theta)L_g(\lambda) + t(\lambda, \theta)L_{wc}(\lambda) + t(\lambda, \theta)L_w(\lambda)$$

>90%

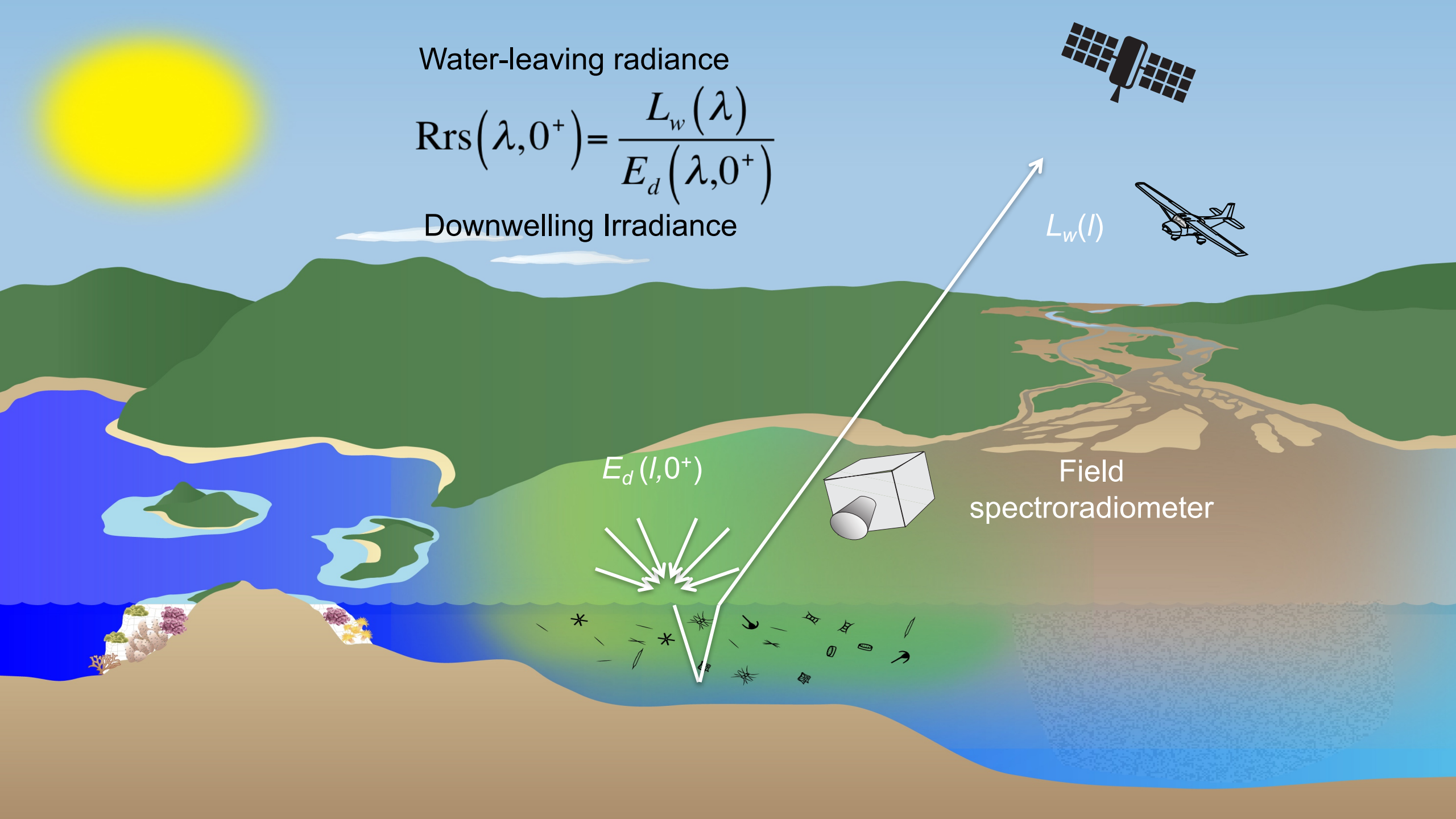
<10%



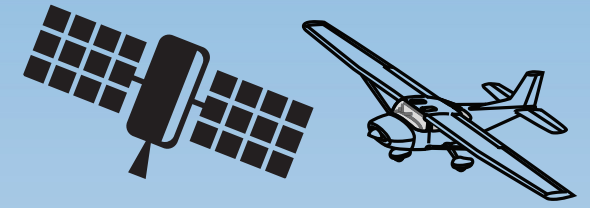
Water-leaving radiance

$$R_{rs}(\lambda, 0^+) = \frac{L_w(\lambda)}{E_d(\lambda, 0^+)}$$

Downwelling Irradiance



Atmospheric Correction



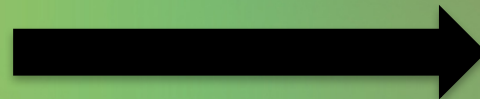
$$L_t(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T(\lambda, \theta)L_g(\lambda) + t(\lambda, \theta)L_{wc}(\lambda) + t(\lambda, \theta)L_w(\lambda)$$

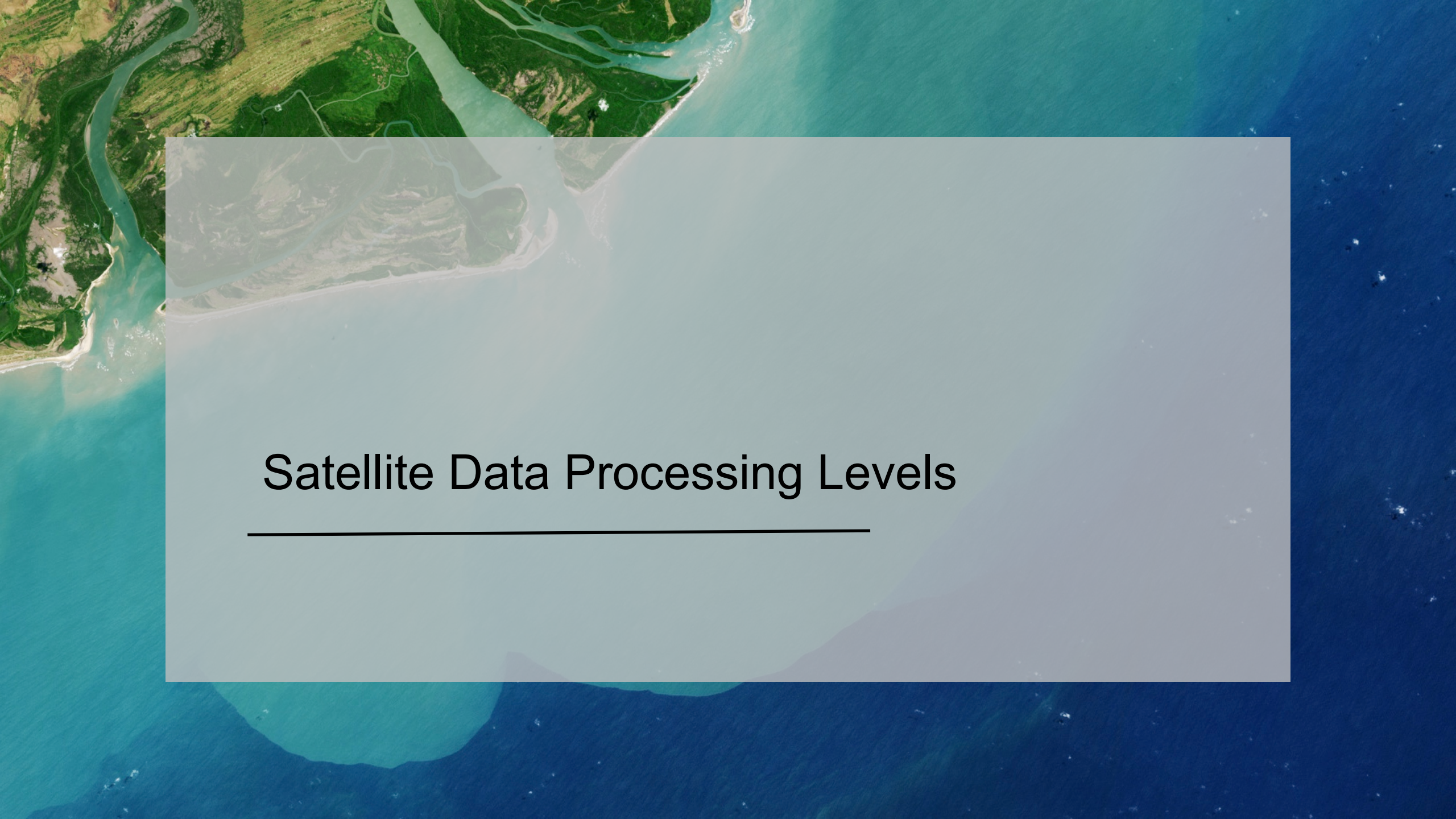
>90%

<10%



Atmospheric
correction



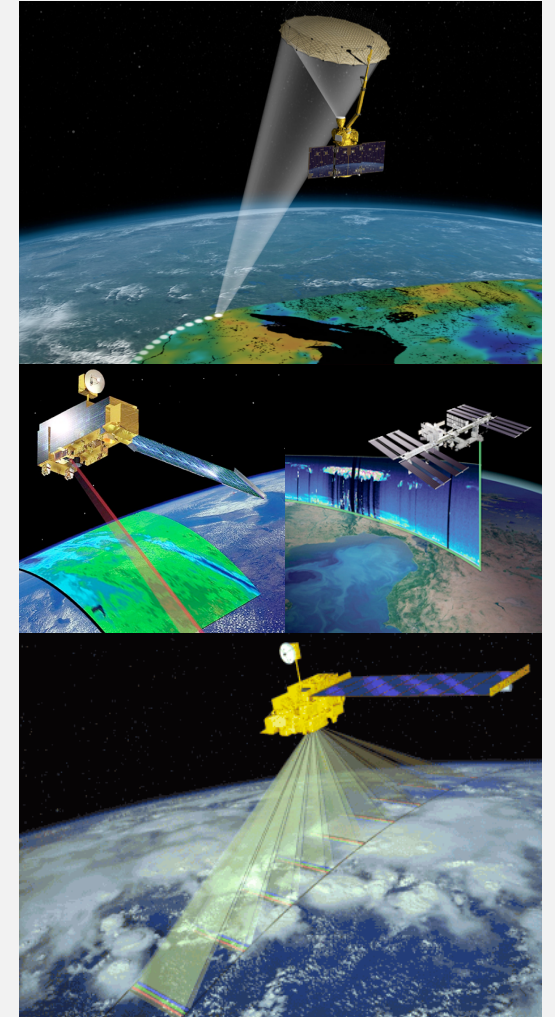
A satellite image of a coastal region, likely a river delta, showing a mix of green land, brownish water, and blue ocean. A semi-transparent light gray rectangular box is overlaid on the right side of the image, containing the title text.

Satellite Data Processing Levels

Levels of Data Processing

<http://oceancolor.gsfc.nasa.gov/cms/products>

- Level 0: unprocessed instrument data at full resolution, rawest format available
- Level 1A: reconstructed and unprocessed instrument data at full resolution
- Level 1B: L1A data with instrument/radiometric calibrations applied
- Level 2: Derived geophysical variables at same resolution as L1 data
- Level 3: L2 projected onto a well defined spatial grid over a well-defined time period
- Level 4: model output or results from analyses of lower level data
 - e.g., Primary Productivity



Data Processing Levels

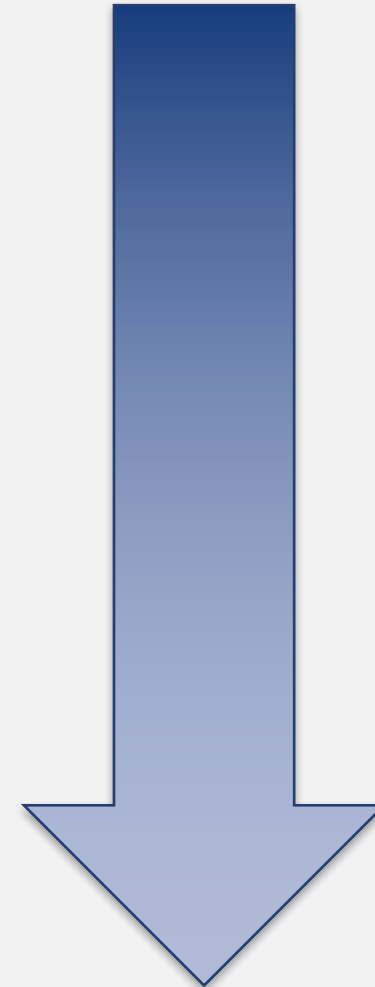
L0: Raw instrument data

L1: Geolocated and calibrated

L2: Products derived from L1B

L3: Gridded and quality controlled

L4: Model output: derived variables



Harder to Use

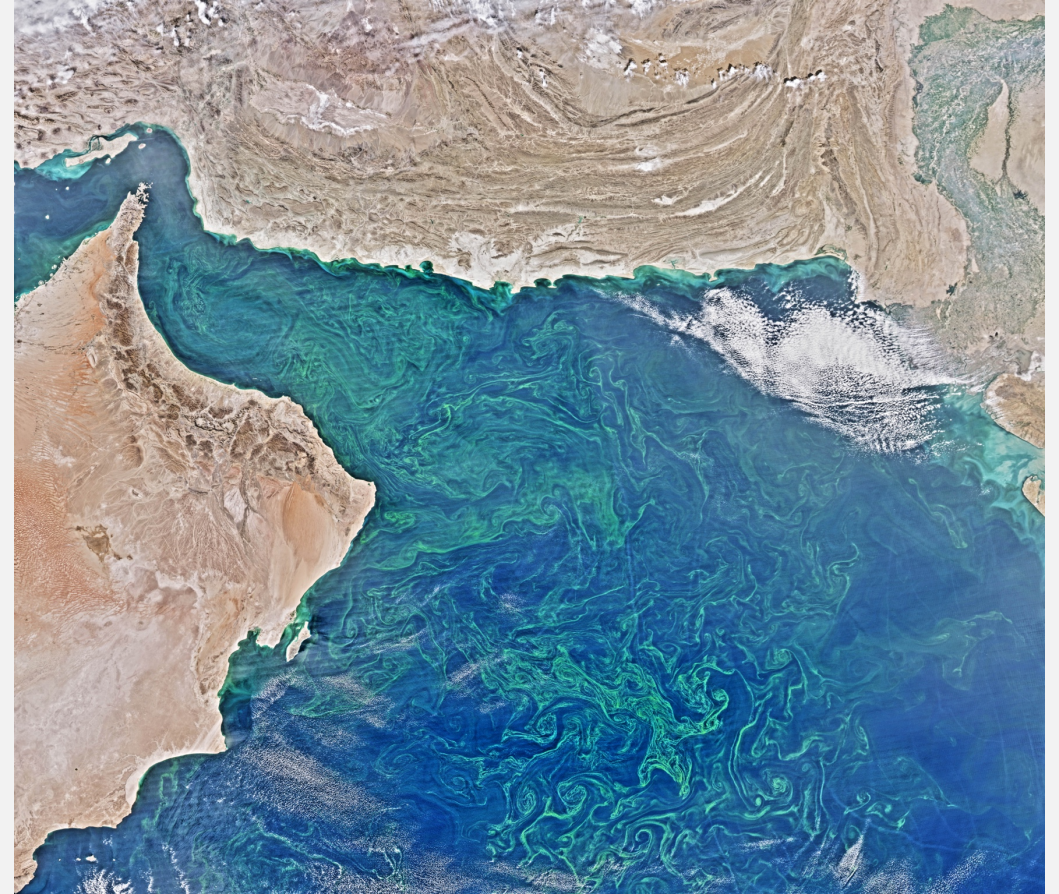
Easier to Use

An aerial photograph of a coastal region. On the left, a river with a light-colored, silty delta flows into the sea. The coastline is irregular with small inlets and peninsulas. The water near the shore is a vibrant turquoise, transitioning to a deep blue further out. A semi-transparent light grey rectangle is overlaid on the right side of the image, containing the title text.

Aquatic Remote Sensing Data Products and Their Uses

Agenda

- Light and Water
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
- NASA Satellite Data Processing Tools



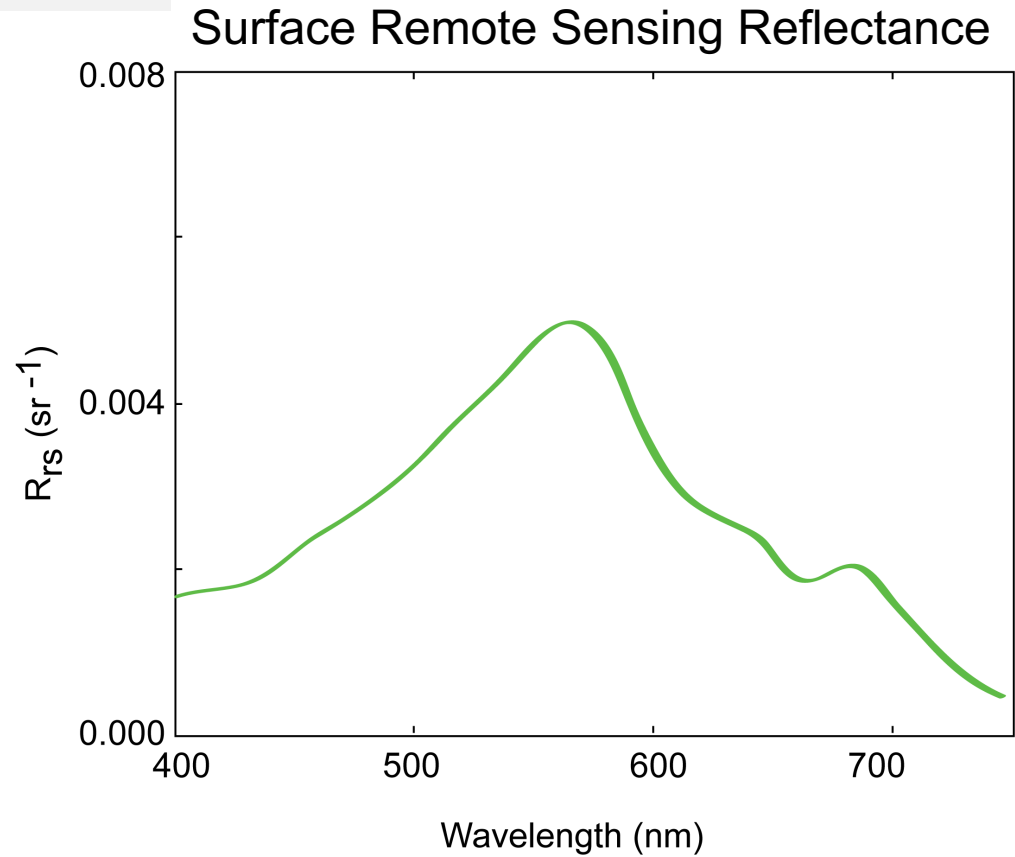
Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, <http://earthobservatory.nasa.gov/IOTD/view.php?id=85718>

What Can We Observe from Space?

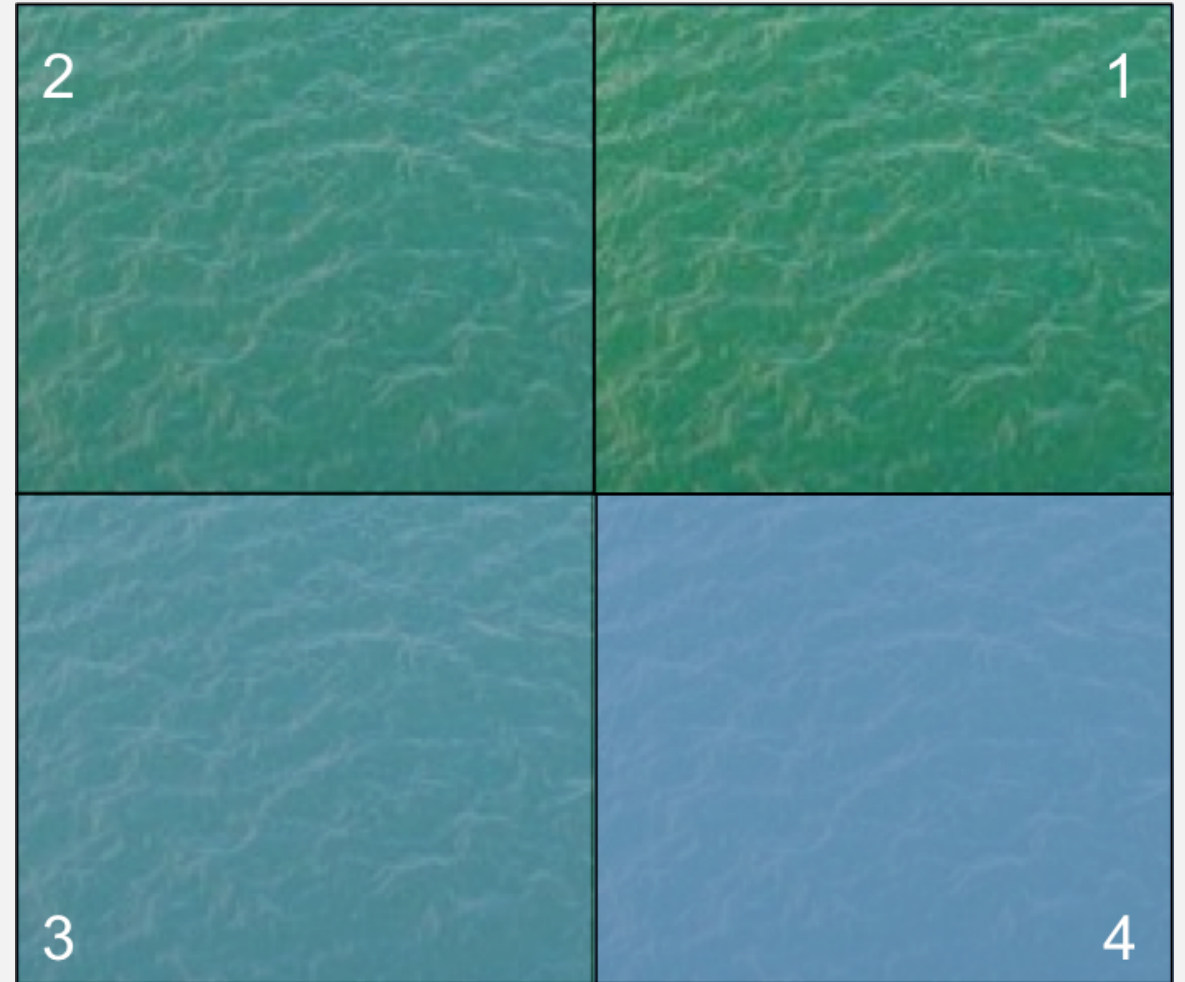
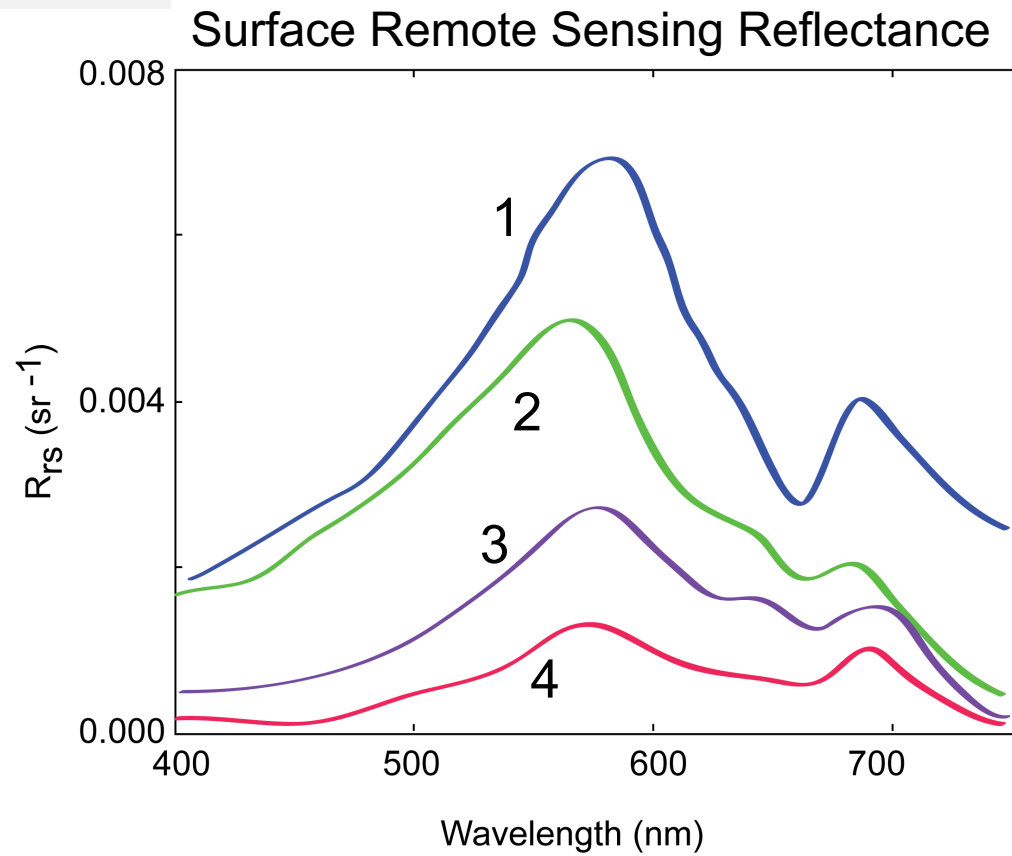
Ocean Properties Derived from Remote Sensing Imagery

Observation	Application
Chlorophyll-a	Phytoplankton biomass, primary productivity, biogeochemical cycling
Water Turbidity	Water quality, human and ecosystem health
Colored Dissolved Organic Matter (CDOM)	Water quality, biogeochemical cycling, human and ecosystem health
Sea Surface Temperature (SST)	Currents, primary productivity, climate studies, biogeochemistry, temperature flux
Surface winds	Currents, mixing, air-sea flux of gases
Salinity	Mixing, air-sea flux of gases, geostrophic currents, salt flux

Chlorophyll-a from Remote Sensing Reflectance (R_{rs})

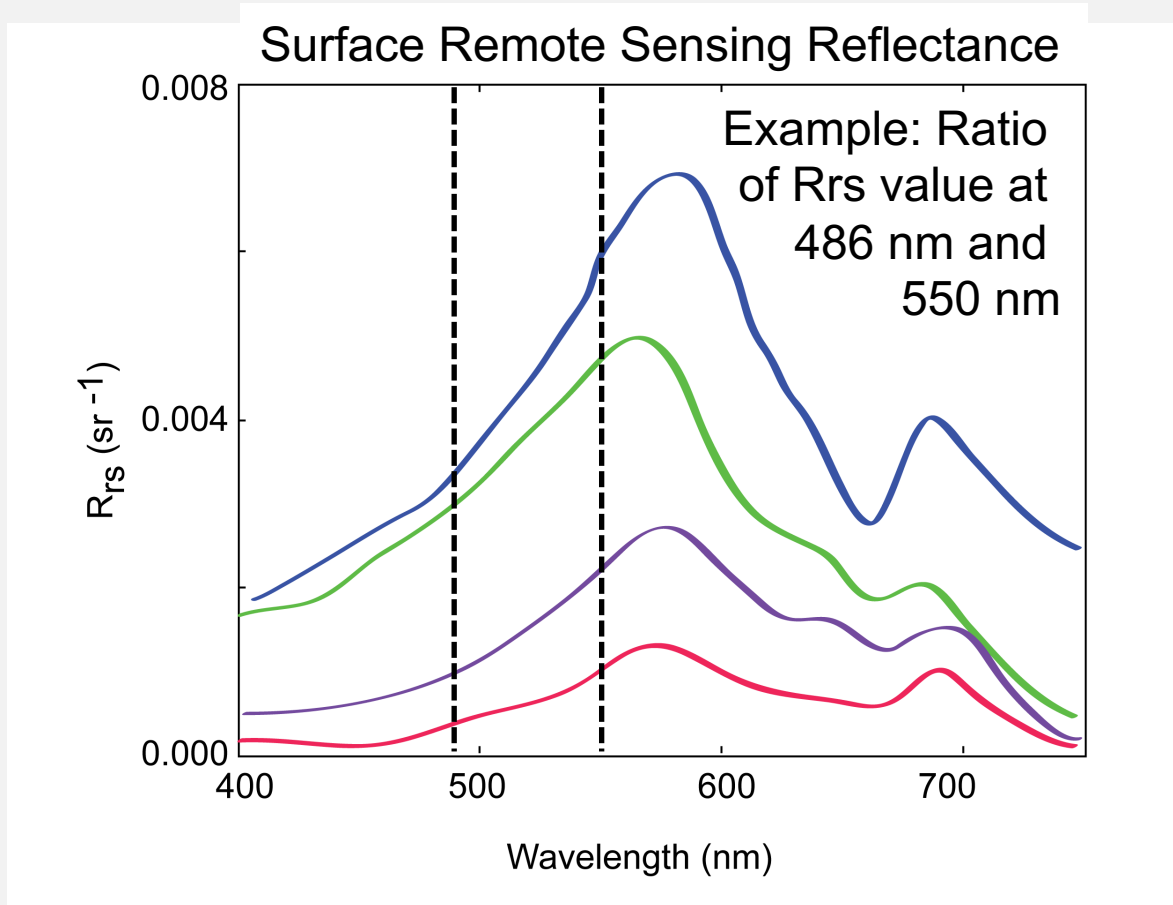


Rrs at Different Chlorophyll-a Concentrations

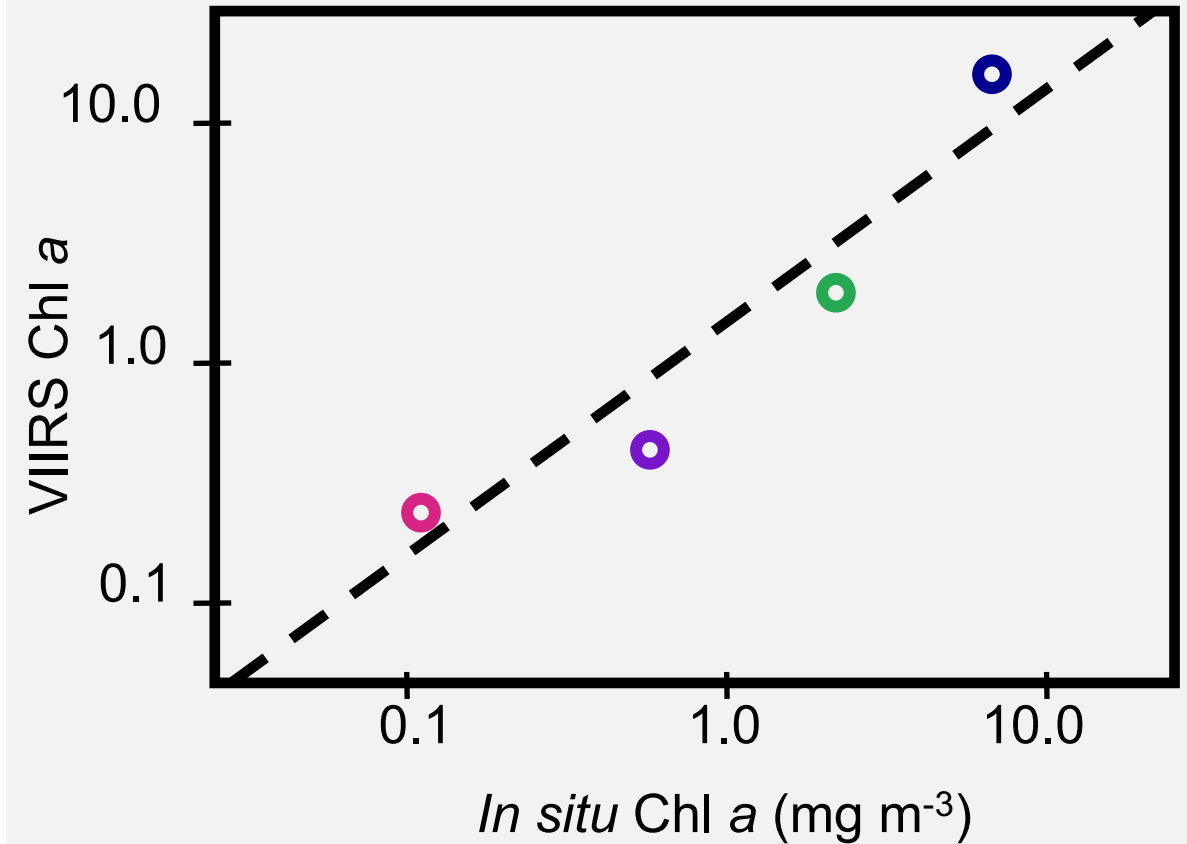


Chlorophyll-a Estimates

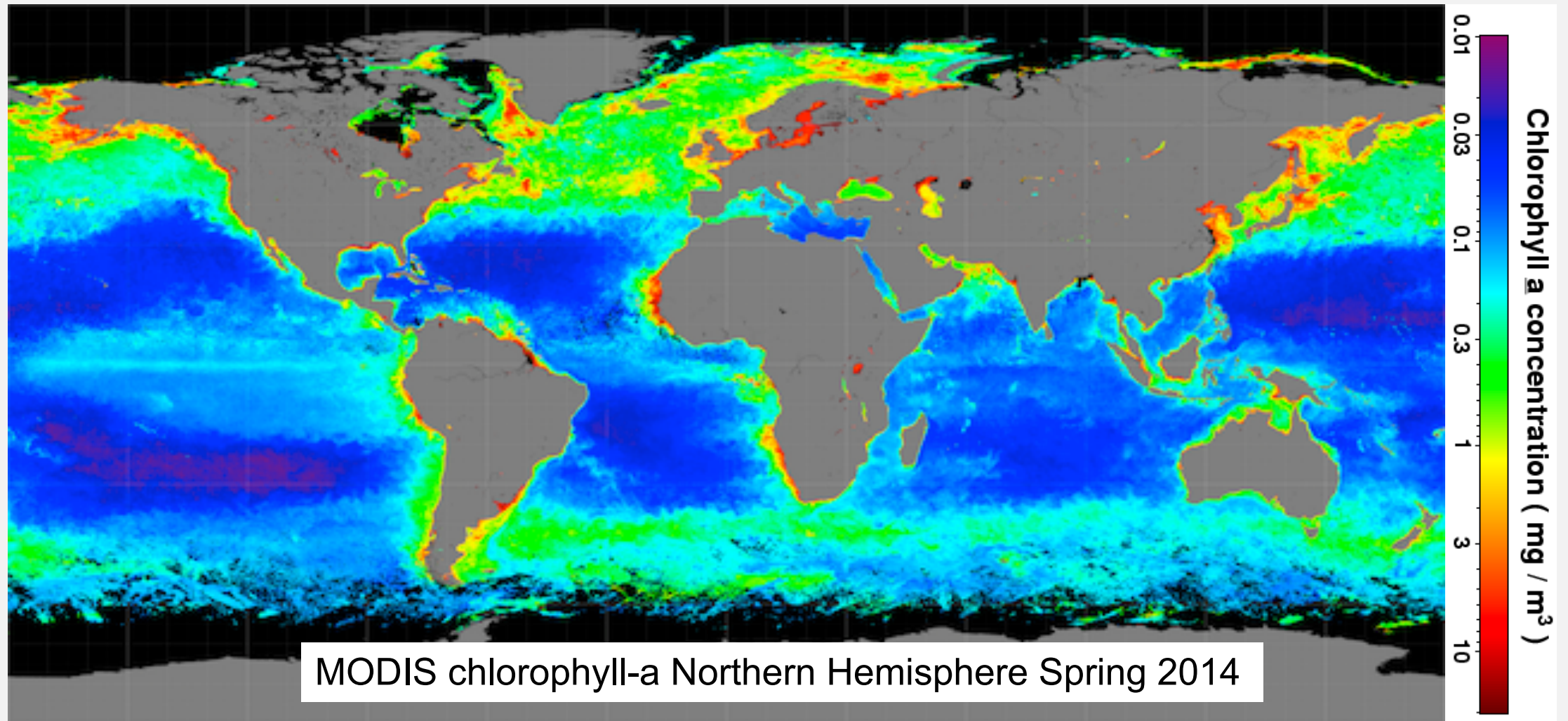
Estimations are a function of the ratios of R_{rs} values

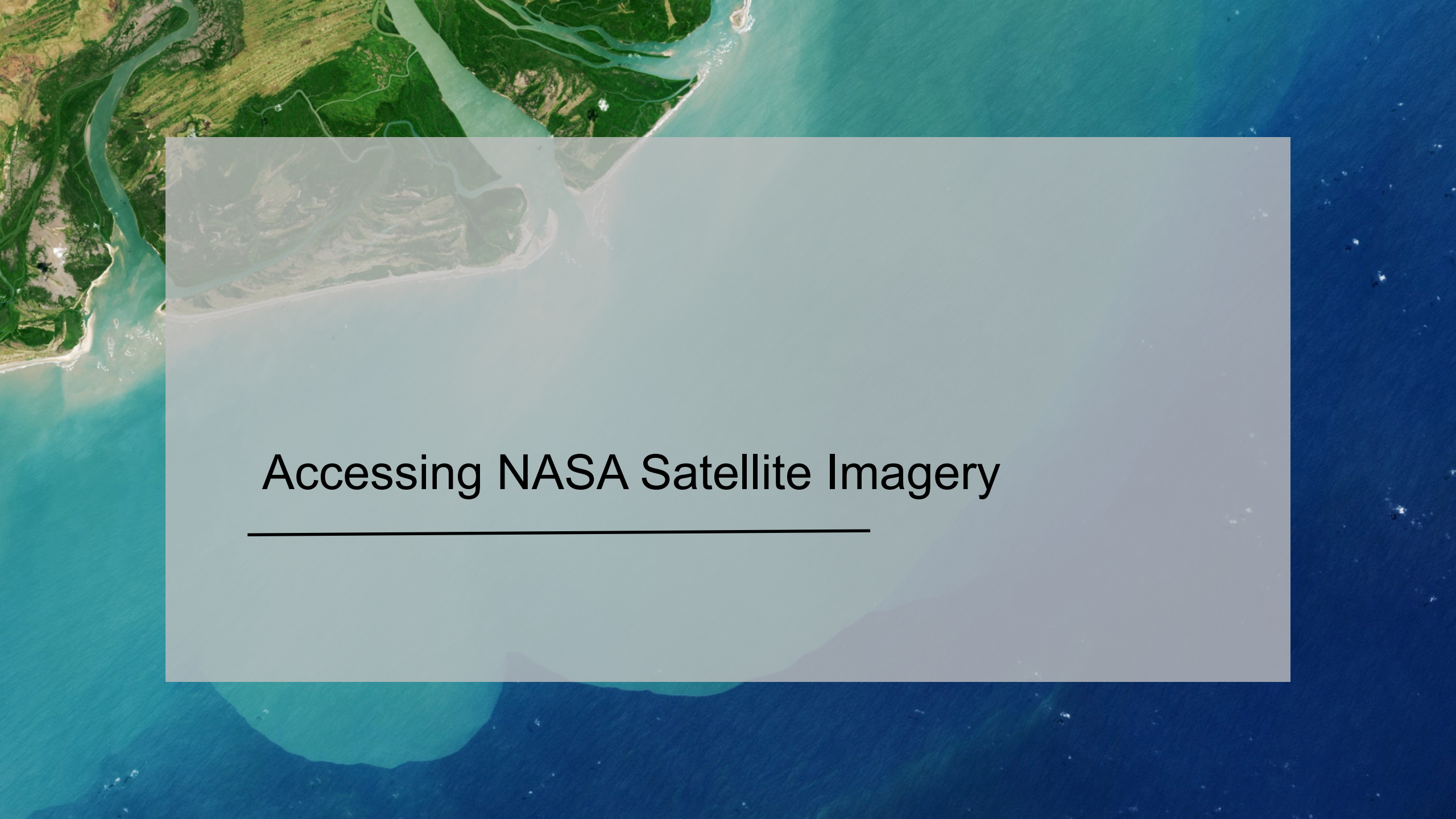


Algorithm description: http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a



Chlorophyll-a from Space

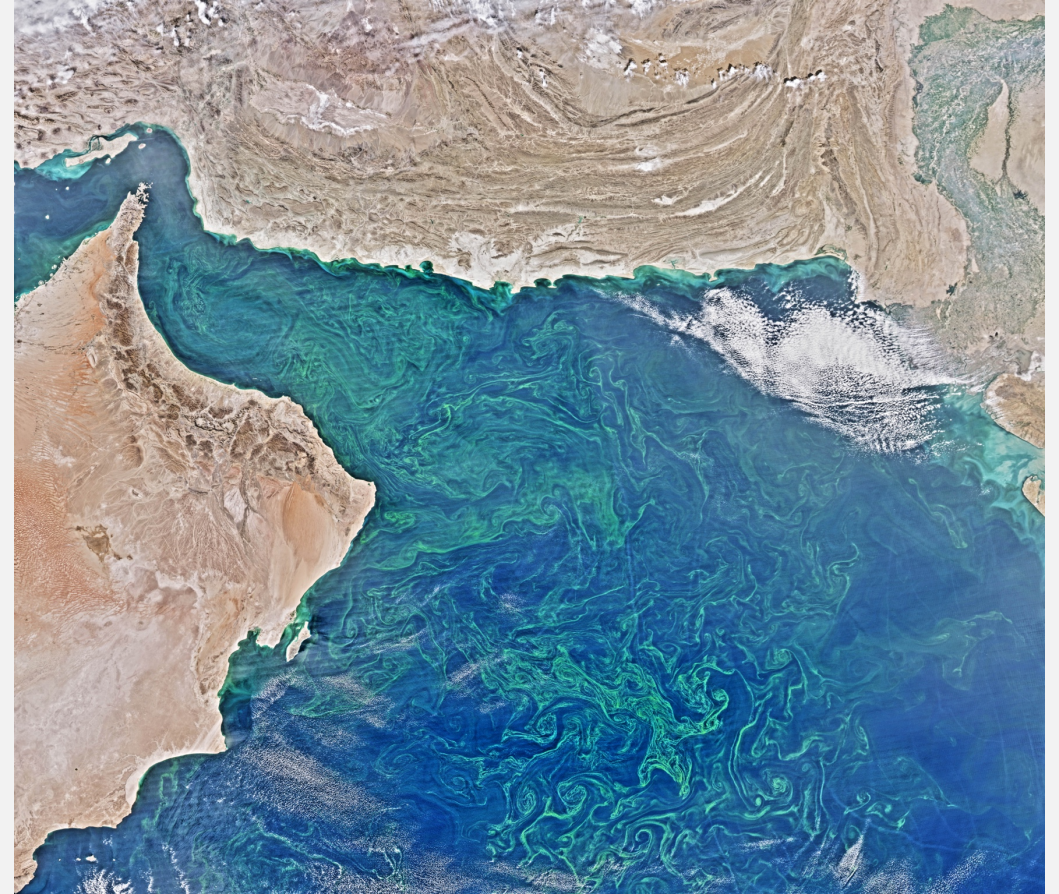


The background is a satellite image of a coastal region. On the left, a river with a light-colored, silty delta flows into a body of water. The land is green with some brown patches. The water transitions from a light turquoise near the shore to a deep blue further out. A large, semi-transparent light gray rectangle is centered over the image, containing the title text.

Accessing NASA Satellite Imagery

Agenda

- Light and Water
- Fundamentals of Remote Sensing
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
 - Worldview
 - OceanColor Web Data Browsers
 - Other Data Access Tools
- NASA Satellite Data Processing Tools

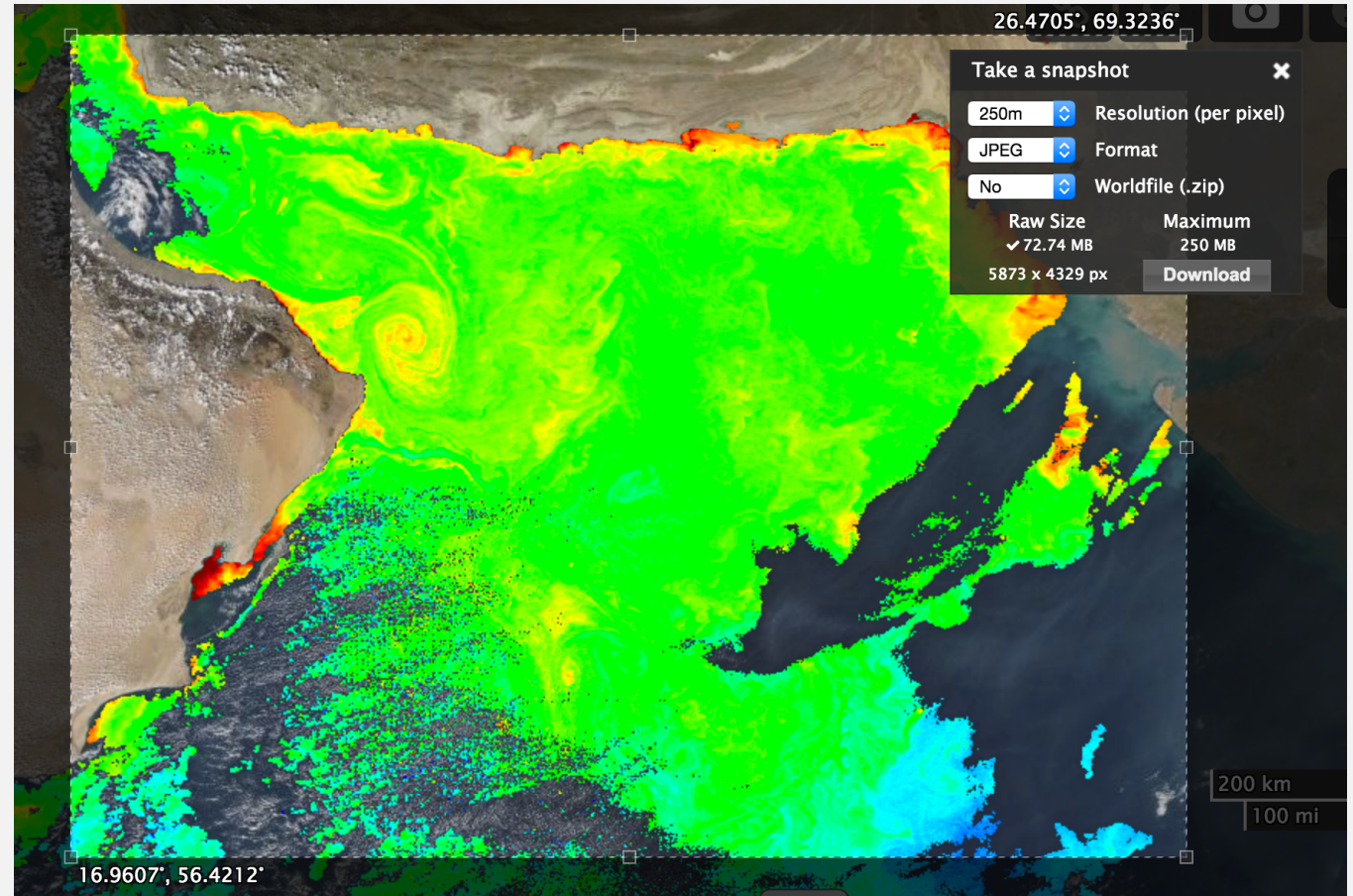


Phytoplankton Bloom in the Arabian Sea
Credit: N. Kuring, <http://earthobservatory.nasa.gov/IOTD/view.php?id=85718>

NASA Worldview

<https://worldview.earthdata.nasa.gov/>

- Interactive web-based tool for browsing satellite imagery
- Imagery is generally available within four hours of observation
- Daily imagery from May 2012 to present
- Data can be downloaded
- Image output in JPEG, PNG, GeoTIFF, and KML formats



NASA OceanColor Web – Data Access

<http://oceancolor.gsfc.nasa.gov/cms/dataaccess>

- Level 1 & 2 Browser
- Level 3 Browser
- Direct Data Access
- Data File Search
- SeaBASS Field Data

Data Access

The Ocean Biology Processing Group (OBPG) serves as the Distributed Active Archive Center (DAAC) for all Ocean Biology (OB) data produced or collected under NASA's Earth Observing System Data and Information System ([EOSDIS](#)). This website thus serves as the primary data access portal to the NASA OB.DAAC. The links below provide a variety of methods to access the holdings of the OB.DAAC, including visual browsers that enable point-and-click access by [data levels](#) and direct access for bulk download. In agreement with partner organizations, some data access requires [user registration](#) to enable better tracking of usage metrics.

Data Management

The data management plan describes the acquisition, generation, management, archive and distribution of science data products generated by the Ocean Data Processing System (ODPS). For a detailed description of science data products, data flows, supported sensors, and data availability, archiving and distribution, please refer to the [plan document](#).

Data Access Tools

[Level 1 & 2 Browser](#) - visual browse, download and data order access to all supported satellite data for Level-1 and Level-2 scenes at observed geographic scale and temporal granularity including cross satellite and *in situ* data search capabilities.

[Level 3 Browser](#) - visual access to global composites at various spatial and temporal scales.

[Direct Data Access](#) - direct access to all available data through http protocols suitable for [bulk download](#).

[Data File Search](#) - direct access via filename search, including support for wildcard search on partail filenames.

[SeaBASS Field Data](#) - community archive of field data relevant to ocean color research, algorithm development, and validation.

[Other Resources](#) - links to partners that also distribute OB.DAAC products or other products derived from OB.DAAC holdings.

<http://oceancolor.gsfc.nasa.gov/cgi/browse.pl>

SeaWiFS

☐ GAC

☐ MLAC

☐ VIIRS (Suomi-NPP)

MODIS

☒ Aqua

☐ Terra

☐ HICO (ISS)

MERIS

☐ RR

☐ FRS

☐ GOCI (COMS)

☐ CZCS (Nimbus-7)

Select

☒ Day

☐ Night

Radius (km) about map click or about typed-in location:

☒	72
☐	400
☐	800
☐	1200
☐	1500

Select swaths containing (at least):

☒	any part
☐	25 %
☐	50 %
☐	75 %
☐	all

Select only scenes having in situ matchups.

☐

Sunday, 23 June 2002 through Saturday, 9 July 2016

Chlorophyll

Select one or more regions:

- ☐ AdriaticSea
- ☐ AegeanSea
- ☐ Antarctica
- ☐ ArabianSea
- ☐ AralSea
- ☐ Arctic
- ☐ Australia
- ☐ AustraliaCoast
- ☐ Azores
- ☐ Bahamas
- ☐ BalticSea

or specify boundary coordinates or a single location:

N:

W: :E

S:

Display results at a time.

Mission

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2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

May 2016

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29	30	31				

June 2016

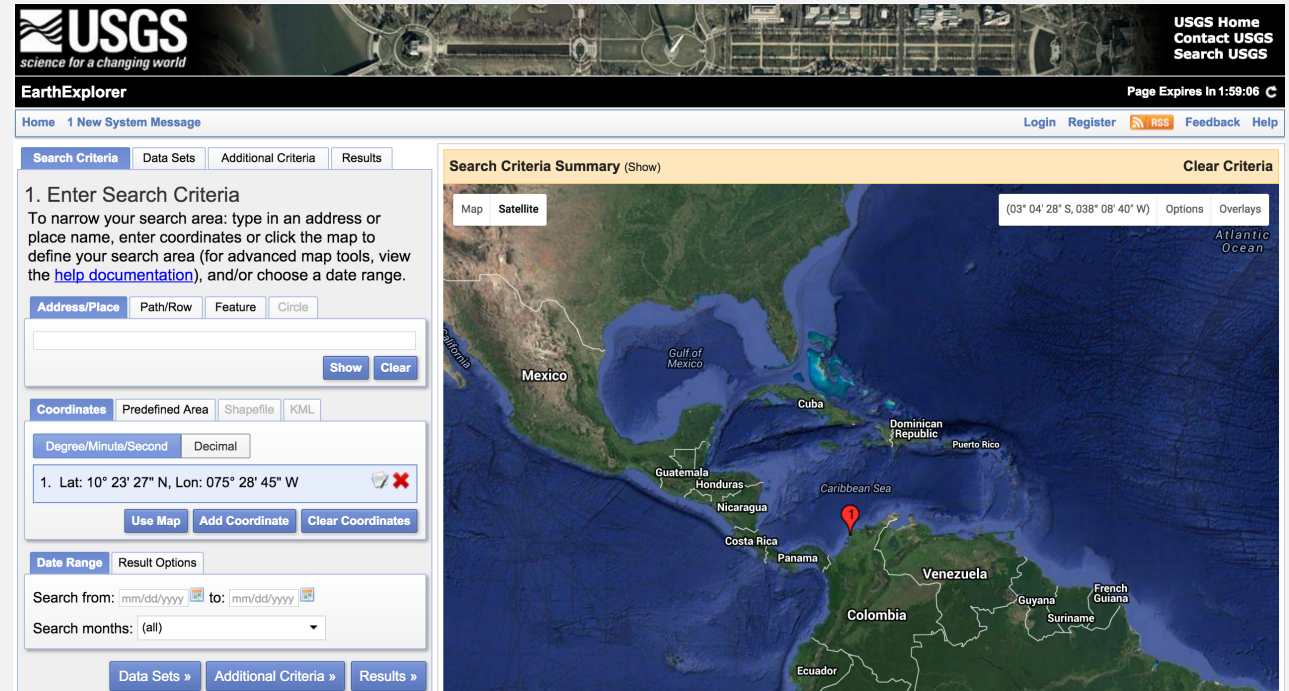
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July 2016

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31						

Some Other Data Access Tools

- NOAA CoastWatch
 - <http://coastwatch.noaa.gov/>
- NASA Giovanni
 - <http://giovanni.gsfc.nasa.gov/giovanni/>
- USGS Earth Explorer
 - <http://earthexplorer.usgs.gov/>



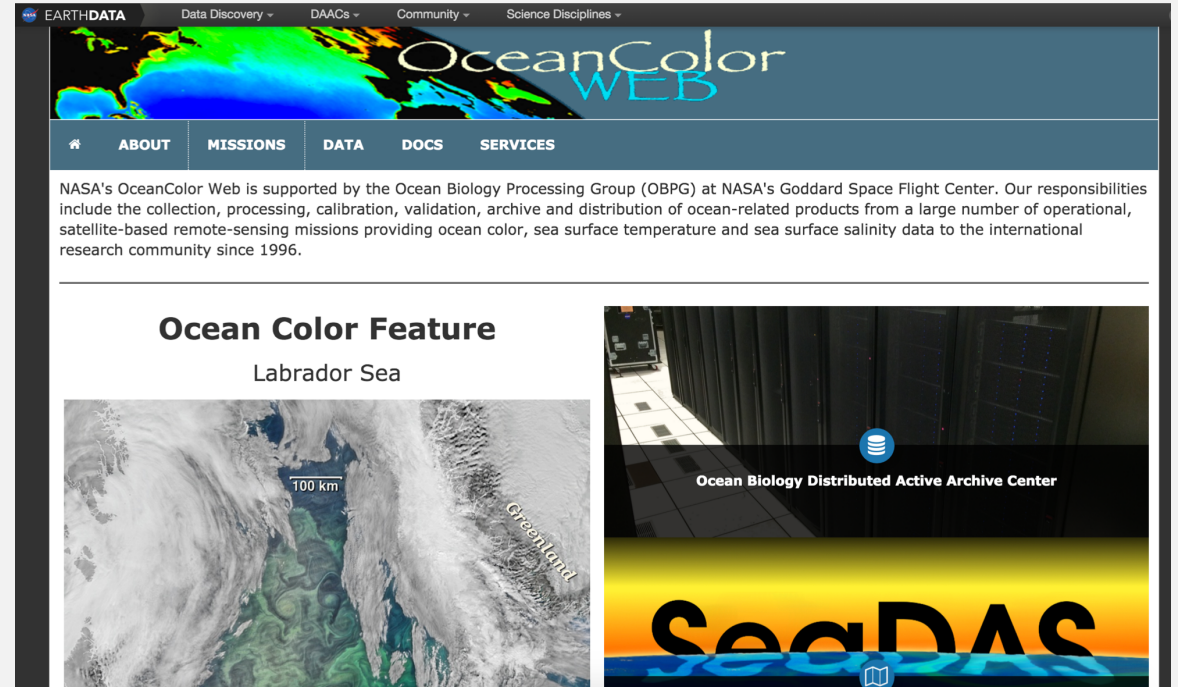
A satellite image of a coastal region, likely the Amazon River delta, showing a complex network of waterways and green land. A semi-transparent light blue rectangular box is overlaid on the image, containing the title text. The text is in a clean, black, sans-serif font. Below the title, a thin black horizontal line is positioned.

NASA Satellite Data Processing Tools

NASA OceanColor Web

<http://oceancolor.gsfc.nasa.gov/>

- OceanColor Web is supported by the Ocean Biology Processing Group (OBPG) at NASA Goddard
- OBPG's duties include collection, processing, calibration, validation, archive, and distribution of ocean-related data products from a large number of satellite missions



SeaWiFS Data Analysis System (SeaDAS)

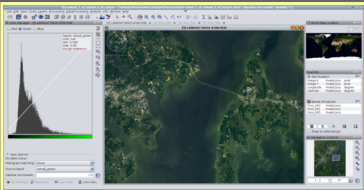
<http://seadas.gsfc.nasa.gov/>

- Image analysis package for the processing, display, analysis, & quality control of ocean color data
- Originally developed for SeaWiFS, but supports most U.S. and international ocean color missions
- Online tutorials, help pages, and an active user community in the Ocean Color Forum
- Attentive & friendly support team based at NASA Goddard

Missions ▾ **Data** ▾ **Documents** ▾ **Analyses** ▾ **People** **Forum** ▾ **Services** ▾ **Links**

SeaDAS

General Description



SeaDAS is a comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data. While originally developed to support the SeaWiFS mission, it now supports most US and international ocean color missions. The primary focus of SeaDAS is ocean color data, but it is applicable to many satellite-based earth science data analyses.

The latest version (SeaDAS 7.3.1) is the result of a collaboration with the developers of ESA's **BEAM** software package. The core visualization package for SeaDAS 7 is based on the BEAM framework, with extensions that provide the functionality provided by previous versions of SeaDAS..

Features
Requirements
License
Download

Supported Missions

- MODIS
- SeaWiFS
- CZCS
- VIIRS
- HICO
- Aquarius
- Landsat8/OLI
- MERIS
- OCTS
- OCM
- OCM-2
- OSMI
- MOS
- GOCI

User Support

- SeaDAS Video Tutorials and Demos
- SeaDAS FAQ
- SeaDAS Help Pages
- Other SeaDAS Tutorial Material
- Ocean Color Web
- Ocean Color Forum
- SeaDAS Mailing List

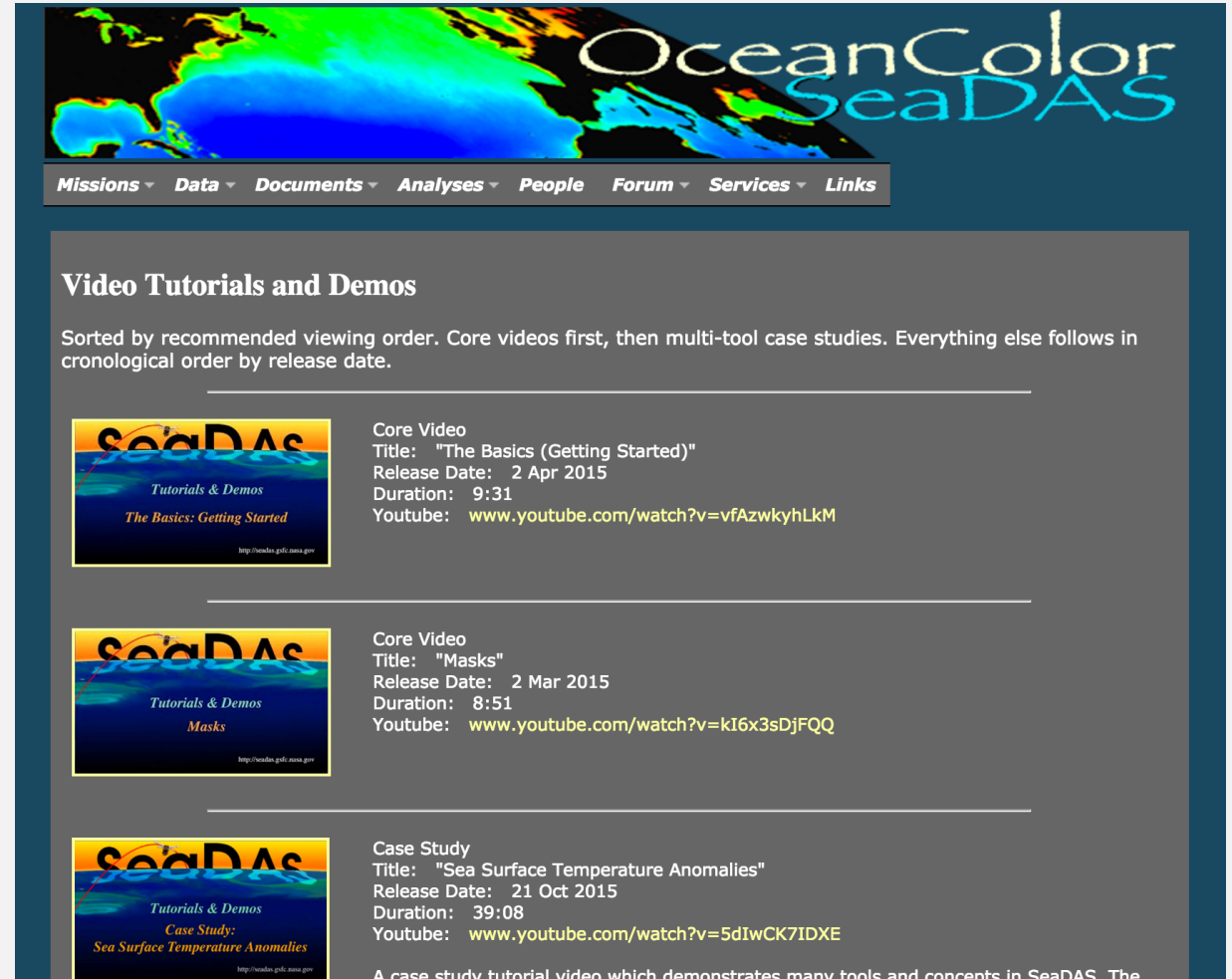
Other

- SeaDAS Visualization Source Code
- Processing Binaries and Source Code
- SeaDAS version 6.4
- MODISL1DB 1.8

Online Tutorials and Webinars for SeaDAS

<http://seadas.gsfc.nasa.gov/tutorial/>

- Strongly recommend completing all of the on-demand tutorials listed on this webpage
- SeaDAS supports a wide variety of satellite sensors so your investment in learning it will be time well spent
- Check out this SeaDAS webinar from June 15, 2016:
 - <https://earthdata.nasa.gov/user-resources/webinars-and-tutorials>



The screenshot displays the SeaDAS website interface. At the top, there is a header with a satellite image of the ocean and the text "OceanColor SeaDAS". Below the header is a navigation bar with links: Missions, Data, Documents, Analyses, People, Forum, Services, and Links. The main content area is titled "Video Tutorials and Demos" and includes a sorting instruction: "Sorted by recommended viewing order. Core videos first, then multi-tool case studies. Everything else follows in chronological order by release date." There are three video entries listed:

Thumbnail	Core Video
	Title: "The Basics (Getting Started)" Release Date: 2 Apr 2015 Duration: 9:31 Youtube: www.youtube.com/watch?v=vfAzwkyhLkM
	Title: "Masks" Release Date: 2 Mar 2015 Duration: 8:51 Youtube: www.youtube.com/watch?v=kI6x3sDjFQQ
	Case Study Title: "Sea Surface Temperature Anomalies" Release Date: 21 Oct 2015 Duration: 39:08 Youtube: www.youtube.com/watch?v=5dIwCK7IDXE

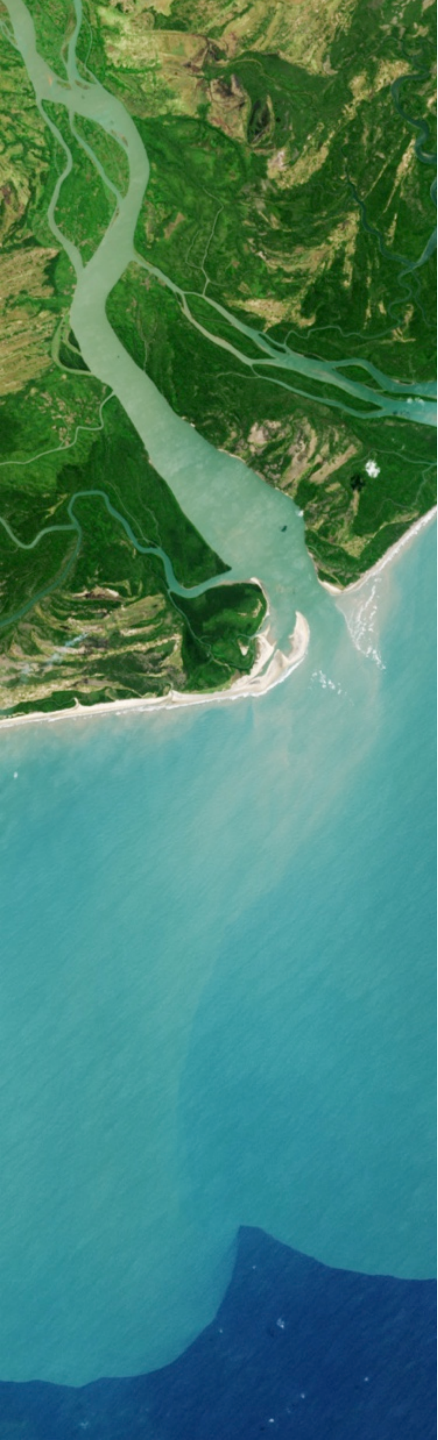
Below the third entry, there is a partial sentence: "A case study tutorial video which demonstrates many tools and concepts in SeaDAS. The

Interested in a More In-Depth Understanding of Aquatic Optics and Remote Sensing Imagery?

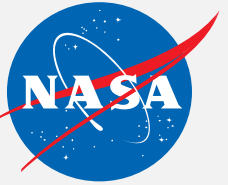
- For a more solid foundation in aquatic optics:
 - Ocean Optics Web Book: <http://www.oceanopticsbook.info/>
 - IOCCG Summer Lecture Series, 2016: <http://ioccg.org/what-we-do/training-and-education/ioccg-summer-lecture-series-2016/#lectures>
- For remote sensing imagery information, data access, and processing tools:
 - NASA's OceanColor Web: <http://oceancolor.gsfc.nasa.gov/cms>

Summary

- Light and Water
 - How light propagates through the atmosphere and water column, and back to sensor
 - Constituents of the water column and their inherent optical properties
- Fundamentals of Remote Sensing
 - Spatial, Temporal, Spectral Resolution
 - NASA Satellites and Sensors for Aquatic Applications
 - Image “Correction”
 - Satellite Data Processing Levels
- Aquatic Remote Sensing Data Products and Their Uses
- Accessing NASA Satellite Imagery
 - Worldview
 - OceanColor Web
 - Other Data Access Tools
- NASA Satellite Data Processing Tools
 - SeaDAS



National Aeronautics and
Space Administration



ARSET

Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

 @NASAARSET

Thank you!

<http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing>

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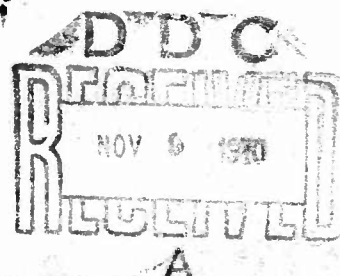
8973-26-F

AD 714001

THE MEASUREMENT OF WATER DEPTH BY REMOTE SENSING TECHNIQUES

F. C. POLCYN
W. L. BROWN
I. J. SATTINGER

October 1970



INFRARED AND OPTICS LABORATORY

Willow Run Laboratories
INSTITUTE OF SCIENCE AND TECHNOLOGY

Prepared for the Spacecraft Oceanography Project,
U. S. Naval Oceanographic Office, Washington, D. C.

Contract N62306-67-C-0243

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8973-26-F

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Infrared and Optics Laboratory
Willow Run Laboratories
THE INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

WILLOW RUN LABORATORIES

FOREWORD

The work reported herein has been sponsored by the Spacecraft Oceanography Project, NAVOCEANO, Washington, D. C. and carried out by the Willow Run Laboratories, a unit of the The University of Michigan's Institute of Science and Technology in Ann Arbor, under the direction of Marvin R. Holter, Head, Infrared and Optics Laboratory. Mr. John Sherman III is manager of the SPOC Project and provided technical monitoring of the investigation.

This document is the second annual report prepared under contract No. N62306-67-C-0243. These studies are to be continued under NASA sponsorship under contract NAS-9-9784. The Willow Run Laboratories' number for this report is 8973-26-F.

This report is one of a series in a program of remote sensing research initiated by M. R. Holter. A list of related reports in this program follows on succeeding pages.

WILLOW RUN LABORATORIES

RELATED REPORTS

- TARGET SIGNATURE STUDY, INTERIM REPORT, VOLUME V: CATALOG OF SPECTRAL REFLECTANCE DATA**, R. R. Legault, R. S. Gould, and T. Limperis, Report No. 5698-22-T(V), Institute of Science and Technology, The University of Michigan, Ann Arbor, October 1964 (Published as part of Data Compilation, AD 489 968, see p. vi).
- THE INVESTIGATION OF A METHOD FOR REMOTE DETECTION AND ANALYSIS OF LIFE ON A PLANET**, M. R. Holter, D. S. Lowe, and J. R. Shay, Report No. 6590-1-P, Institute of Science and Technology, The University of Michigan, Ann Arbor, November 1964.
- THE INVESTIGATION OF A METHOD FOR REMOTE DETECTION OF LIFE ON A PLANET**, L. D. Miller, Report No. 6590-4-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, Michigan, November 1965.
- UNUSUAL RECONNAISSANCE CONCEPTS INTERIM REPORT, VOLUME II: SOURCES OF EXPERIMENTAL ERRORS IN SPECTROPHOTOMETRIC MEASUREMENTS**, Dianne Goerge and T. Limperis, Report No. 5698-33-(II), AFAL-TR-65-331, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, January 1966, AD 481 796.
- UNUSUAL RECONNAISSANCE CONCEPTS INTERIM REPORT, VOLUME III: A BIBLIOGRAPHY OF RECENT CONTRIBUTIONS ON ELECTROMAGNETIC AND ACOUSTIC SCATTERING**, J. Ulrich, Report No. 5698-33-P-(III), AFAL-TR-65-331, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, January 1966, AD 481 817.
- TARGET SIGNATURE ANALYSIS CENTER: DATA COMPILATION**, D. G. Earing and J. A. Smith, Report No. 7850-2-B, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, July 1966, AD 489 968.
- DISPERSIVE MULTISPECTRAL SCANNING: A FEASIBILITY STUDY, FINAL REPORT**, J. Braithwaite, Report No. 7610-5-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, September 1966.
- AN INVESTIGATIVE STUDY OF A SPECTRUM-MATCHING IMAGING SYSTEM, FINAL REPORT**, D. S. Lowe, J. Braithwaite, and V. L. Larrowe, Report No. 8201-1-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, October 1966.
- DATA SIGNATURE ANALYSIS CENTER: DATA COMPILATION (SUPPLEMENT)**, D. Earing, Report No. 7850-9-B, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, January 1967, AD 379 650.
- OPTICAL SENSING OF MOISTURE CONTENT IN FINE FOREST FUELS, FINAL REPORT**, C. E. Olson, Jr., Report No. 8036-1-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, May 1967.
- TARGET SIGNATURE ANALYSIS CENTER: DATA COMPILATION (SECOND SUPPLEMENT)**, D. Earing, Report No. 8492-5-B, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, July 1967, AD 819 712.

WILLOW RUN LABORATORIES

TARGET SIGNATURE ANALYSIS CENTER: DATA COMPILATION (FIFTH SUPPLEMENT), D. Earing, Report No. 8492-15-B, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, August 1968.

CALIBRATION OF AN AIRBORNE MULTISPECTRAL OPTICAL SENSOR, L. M. Larsen and P. G. Hasell, Jr., Report No. 6400-137-T, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, September 1968.

TARGET SIGNATURE ANALYSIS CENTER: DATA COMPILATION (SIXTH SUPPLEMENT), D. Earing, Report No. 8492-26-B, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, October 1968.

INVESTIGATIONS OF SPECTRUM-MATCHING TECHNIQUES FOR REMOTE SENSING IN AGRICULTURE, Final Report, Report No. 1674-10-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, December 1968.

EFFECTS OF ATMOSPHERIC PATH ON AIRBORNE MULTISPECTRAL SENSORS, R. Horvath, J. G. Braithwaite, F. C. Polcyn, Report No. 1674-5-T, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, December 1968.

APPLICATIONS OF MULTISPECTRAL REMOTE SENSING TECHNIQUES TO HYDROBIOLOGICAL INVESTIGATIONS IN EVERGLADES NATIONAL PARK, A. L. Higher, N. S. Thomson, F. J. Thomson, M. C. Kolipinski, Technical Report 2528-5-T, January 1970, (Joint Report of The University of Michigan and the U. S. Department of the Interior).

TARGET TEMPERATURE MODELING, D. Bornemeier, R. Bennett, R. Horvath, Final Technical Report RADC-TR-69-404, Willow Run Laboratories, Institute of Science and Technology, The University of Michigan, Ann Arbor, December 1969.

HOW MULTISPECTRAL SENSING CAN HELP THE ECOLOGIST, F. C. Polcyn, N. A. Spansail, W. A. Malila, Remote Sensing in Ecology, University of Georgia Press, 1969.

INVESTIGATION OF MULTISPECTRAL DISCRIMINATION TECHNIQUES, R. F. Nalepka, Final Technical Report 2264-12-F, Willow Run Laboratories, Institute of Science and Technology, The University of Michigan, Ann Arbor, January 1970.

USE OF MULTISPECTRAL RECOGNITION TECHNIQUES FOR CONDUCTING RAPID, WIDE AREA WHEAT SURVEYS, R. E. Marshall and N. S. Thomson, Proceedings of the Sixth Symposium on Remote Sensing of the Environment, The University of Michigan, Ann Arbor, October 1969.

A SPECTRAL DISCRIMINATION TECHNIQUE FOR AGRICULTURAL APPLICATIONS, D. G. Earing and I. W. Ginsberg, Proceedings of the Sixth Symposium on Remote Sensing of the Environment, The University of Michigan, Ann Arbor, October 1969.

APPLICATION OF MULTISPECTRAL DATA AND PROCESSING TECHNIQUES TO THE DISCRIMINATION OF SINKHOLE ACTIVITY IN FLORIDA, A. E. Coker, U. S. Geological Survey, Tampa, Florida, and R. E. Marshall and N. S. Thomson, The University of Michigan, Ann Arbor, Proceedings of the Sixth Symposium on Remote Sensing of the Environment, The University of Michigan, Ann Arbor, October 1969.

WILLOW RUN LABORATORIES

- WATER DEPTH DETERMINATIONS USING REMOTE SENSING TECHNIQUES**, F. C. Polcyn and I. J. Sattinger, Proceedings of the Sixth Symposium on Remote Sensing of the Environment, The University of Michigan, Ann Arbor, October 1969.
- REFLECTANCE AND EMITTANCE FROM BROADLEAVED TREES DURING PERIOD OF PHYSIOLOGIC STRESS**, C. E. Olson, Jr., W. G. Rohde, and J. M. Ward, Proceedings of the Sixth Symposium on Remote Sensing of the Environment, The University of Michigan, Ann Arbor, October 1969.
- PREPROCESSING TRANSFORMATIONS AND THEIR EFFECTS ON MULTISPECTRAL RECOGNITION**, F. Kriegler, W. Malila, R. Nalepka and W. Richardson, Proceedings of the Sixth Symposium on Remote Sensing of the Environment, The University of Michigan, Ann Arbor, October 1969.
- MEASUREMENTS PROGRAM FOR OIL SLICK CHARACTERISTICS, FINAL REPORT**, R. Horvath, W. L. Morgan, R. Spellicy, Report No. 2766-7-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, February 1970.
- ATMOSPHERIC EFFECTS ON MULTISPECTRAL SENSING OF SEA SURFACE TEMPERATURE FROM SPACE FOR CLEAR ATMOSPHERES, QUARTERLY REPORT**, D. Anding, R. Kauth, Report No. 2676-2-P, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, June 1970.
- MULTISPECTRAL REMOTE SENSING OF URBAN FEATURES**, J. E. Colwell, Report No. 2772-6-F, Willow Run Laboratories, Institute of Science and Technology, The University of Michigan, Ann Arbor, March, 1970.
- AN INVESTIGATION OF GRASSLAND RESOURCES USING MULTISPECTRAL PROCESSING AND ANALYSIS TECHNIQUES**, T. W. Wagner and J. E. Colwell, Report No. 34795-1-F, Willow Run Laboratories, Institute of Science and Technology, The University of Michigan, Ann Arbor, in preparation.

WILLOW RUN LABORATORIES

ABSTRACT

✓e This study demonstrates successful remote determination of shallow water depth by measuring wave refraction changes and using the Fourier transform plane for wavelength measurements with data obtained at a Lake Michigan test site. The study shows that the technique is suitable for use from spacecraft altitudes, provided that water waves of suitable length occur in the region of interest. () R

A second demonstration of remote measurement of water depth was performed using data collected at Caesar Creek in the Florida Keys. For the first time, a newly developed multispectral technique, based on a ratio of reflected radiation in at least two spectral bands in the visible region of the spectrum, was used to determine water depth. Data were collected with The University of Michigan's multispectral scanner and recorded on magnetic tape. By digitizing the data and correcting for surface reflections, a depth chart can be generated from computer output.

An analysis of laser systems suitable for water depth determinations is also provided. It is anticipated that the use of laser depth measurements with the multispectral computer printout will provide best accuracy.

WILLOW RUN LABORATORIES

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THE MEASUREMENT OF WATER DEPTH BY REMOTE SENSING TECHNIQUES

¹ INTRODUCTION

In a previous study (Ref.1), four variables were identified on which a remote sensor might operate in order to measure depth or deduce the location of shallower water. The four variables included temperature changes, color changes, wave refraction, and time differences for laser pulse reflections. As in all detection problems, a classification of a particular depth is more reliable if it depends on a convergence of evidence from several sensors.

Since it was found that temperature changes were useful for locating shallow water out not for measuring depth, this report concentrates on the use of the latter three variables for depth measurements performed in three ways.

(1) By measuring wave refraction effects in the Fourier transform domain produced by an optical processor, with an aerial photograph used as the input transparency. This technique, discussed in Section 2, lends itself to use from any altitude, including those of earth satellites, and is independent of the light transmission characteristics of water.

(2) By measuring at different spectral intervals the relative intensities of light reflected by the ocean or lake bottom and correcting for surface reflection and scattering, using a multi-spectral scanner such as that developed by The University of Michigan. The first depth measurements made by these techniques are reported in Section 3.

(3) By measuring the time difference of laser pulses reflected from the water surface and from the bottom. This technique (see Section 4) provides an independent measure of the water depth at sample locations.

It is the ultimate goal of this project to combine the latter two techniques: laser depth measurement taken along transects, with two-dimensional depth contours produced with the multi-spectral digital-processing technique described in this report. The result will be a system of making rapid surveys of near-shore environments or other regions about which knowledge of water depth is needed to reduce hazards to ship navigation, to aid marine engineering projects, to study shore erosion, to permit quick assessment of storm-induced changes, and to aid in investigation of lake level and estuarine problems.

Although this is the second annual report to be prepared under Contract N62306-67-C-0243, the study is not yet complete; it will be continued under NASA sponsorship (Contract NAS-9-9784).

WAVE ANALYSIS TECHNIQUES

Optical data-processing techniques can be adapted to measure water depth by analyzing the characteristics of water waves as recorded by aerial or space photography. It is known that shoal areas and beaches influence both the wavelength and the direction of waves passing over them. The forward velocity of a wave train decreases appreciably when the waves pass over an area in which the water depth is less than about half the wavelength. In addition to noting the change in typical wavelength directly on the original photograph, the change could be observed in other ways. An indirect effect of shoal areas and beaches is to increase the wave height, producing breakers; thus, breakers are another indication of shallow water. Another effect is to cause refraction of the wave, resulting in a change in azimuth of the wavefront and a corresponding change in the direction of wave advance.

The change in wavelength and in wavefront orientation can be observed by subjecting the original images to certain optical data-processing methods (Ref. 2). When a portion of the original image is illuminated by coherent light, such as that produced by a laser, and the transmitted light is focused by the use of a spherical lens, the resulting presentation on a screen at the focal point of the lens shows, in a polar coordinate frame, the distribution of both wavelength and wavefront orientation contained in the illuminated portion of the original image. It should, therefore, be possible to analyze aerial photography of sea surfaces both to detect shoal areas initially and to measure water depth in these areas.

2.1. METHODS OF DEPTH MEASUREMENT USING WAVE ANALYSIS

Several computational procedures can be used in estimating water depth from measurements of aerial photography. The analytical basis for these various procedures is discussed in this section, and experimental studies of individual procedures are presented in Section 2.3.

First order theory of wave swells describes a train of waves advancing through deep water as having a velocity related to its wavelength and wave period as in the following equations:

$$L_o = 5.12 T^2 \quad (1)$$

$$C_o = \frac{L_o}{T} = 5.12 T \quad (2)$$

where L_o = deep-water wavelength (ft)

C_o = deep-water wave velocity (fps)

T = wave period (sec)

As waves approach shallow water of depth, d , the velocity of wave advance, C , and the wavelength, L , decrease appreciably for values of d/L_o less than about 0.5.

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This change in wave velocity is related to the fact that in shallow water the motion of individual particles of water is modified. In deep water, the orbit of each particle of water is circular in shape, with the radius of the circle decreasing rapidly with depth. In shallow water, the closeness of the bottom modifies the orbit to elliptical form, which has an effect on the forward velocity.

Since the period of a given wave train remains constant at all points along its path, a changing forward velocity changes the wavelength. It is therefore possible to measure depth from aerial photography by first measuring wave separation and directions of waves both in the shoal areas and in deep areas (deep is defined relative to the wavelength of the incoming waves). The wavelength in deep water (L_0) and the wavelength in shallow water (L) can be measured in a single aerial photograph. The measured ratio of wavelengths, L/L_0 , is functionally related to the ratio d/L_0 , so that depth, d , can be determined (Ref. 3). The optical data-processing methods discussed in the following sections provide an effective means of measuring L and L_0 .

When waves approach a beach at an angle, changes in the velocity of wave advance lead to changes in the wave orientation caused by refractive effects. The change in direction from deep to shallow water can also be accurately measured by optical data-processing methods. This approach is applicable, for example, for straight beaches with parallel contours. The direction of the incoming wave and the direction of the wave at the point of depth measurement are observed. These two measurements determine the ratio of depth, d , to deep water wavelength, L_0 . If L_0 is also measured, the depth can be determined. However, the measurement of changes in wave direction to determine depth presents complications. Where the bottom contour cannot be assumed as straight, the method must be modified by preparing a refraction diagram of the area of interest, extending into the ocean to points where the depth is equal to at least half the observed wavelength. As a means of detecting shoal areas, as distinguished from measuring them, the measurement of wave direction changes can be effective, provided the orientation of incoming waves is sufficiently regular to avoid masking the effect of the shoals.

Other approaches to depth measurement can be used if successive photographs at short intervals can be provided. Under these conditions, it becomes possible to measure not only wavelength and wave direction, but also wave velocity and wave period. If two pictures are taken at a known interval of time, the wave velocity in deep water, C_0 , and in the test area, C , can be determined. (To make accurate measurement of wave advance over a short time interval, a fixed reference point must be apparent in each photograph.) The wave velocity can be computed, by noting the change in wave position, as the ratio of distance traveled by the wave to the time interval between observations. The ratio C/C_0 derived from these pictures is equal to the ratio L/L_0 and can thus be used to determine d/L_0 . Wavelength can be measured directly from the photograph.

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Another alternative would be to measure L and C in the shoal area only. Wave period, T , can be computed as the ratio of wavelength to wave velocity, L/C . The wave period remains constant as the wave travels from deep to shallow water; hence, the measurement of T provides a means of computing L_0 or C_0 by the use of Eqs. (1) or (2). This method thus requires measurements only in the test area and eliminates the need for measurements in deep water. Its accuracy depends on the regularity of the wave patterns present at the time of measurement and on the resolution of the photography.

2.2. APPLICATION OF FOURIER TRANSFORM PROCESSING

Optical data processing has been performed on a number of aerial photographs covering both open sea and shoal areas, such as beaches and reefs. A generally valid relationship has been found between the wave characteristics as measured from the aerial photograph and the wavelength and orientation characteristics recorded by the optical processor. If a swell or local wave pattern with a clearly defined orientation and predominant wavelength content is apparent on the aerial photograph, the Fourier transform pattern produced by the optical processor will tend to show this dominant wave pattern as a circular dot of finite size at the appropriate wavelength and angle. Distance of the dot from the center of the pattern is inversely proportional to wavelength. The finite size of the dot indicates a scatter, in both wavelength and direction in the original imagery, to be expected in wave patterns, even under favorable conditions. The irregularity of the fundamental pattern and the existence of local chop will tend to introduce both lower and higher frequency components into the Fourier transform. In many cases, therefore, the idealized dot pattern expected for a single sinusoidal wave component becomes elongated to include a considerable variation of wavelength components. The angular spread is less affected, so that, in many examples, wave direction may be determined more accurately than the wavelength itself.

The interrelation of sun elevation, view angle, and wave spectrum appears to have some effect on the transform representation of a particular area. The wave pattern is most visible at the edges of the sun-glitter pattern, and may be nearly invisible at the center of the pattern or far outside the pattern. Sun glitter seems to emphasize those wave crests which are tangent to the sun-glitter circle. If further study confirms this effect, it may be used to advantage in eliminating the confusion resulting from the existence of several wave patterns.

The conclusions reached so far are that the two-dimensional Fourier transform gives a useful indication of dominant wavelength and direction. To obtain accurate measurements, (1) the wave pattern must be a fairly regular one and not a confused combination of several different wave trains; and (2) the proper exposure and sun-glitter pattern must be used. It is believed that additional investigation will improve the definition of the best conditions of use and develop refinements in technique which would further increase the accuracy of determining wavelength and wave direction.

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2.3. EXAMPLES OF OPTICAL DATA-PROCESSING TECHNIQUES FOR MEASURING DEPTH

As a quantitative example of the use of several wave analysis techniques for measuring water depth, an aerial photograph taken near the exit of the Grand River into Lake Michigan near Grand Haven was used. (See Figs. 1 and 2.) The objective of the task was to determine the depth of water in two areas, A and B. Area A is a rectangular area, 500×1300 ft, parallel to the shoreline, with its near edge about 270 ft offshore. Area B is a rectangular area of the same dimensions and orientation but with its near edge about 1600 ft offshore. To determine deep-water wavelength, L_0 , wave measurements were also made over Area C. The depth of water in Area C, approximately 40-45 ft, did not have an appreciable effect on the length or direction of the waves passing over it at the time the photograph was taken.

Two methods of calculation were used, one based on the difference in wavelength in Area A and Area C, and the other based on the change in direction of the waves in these two areas. Measurements of wavelength and wave direction were each made in more than one way to compare various techniques available.

We will consider first the determination of water depth by wavelength measurement. Measurements of wavelength were scaled directly from the aerial photograph and were also obtained from a Fourier transform made by optical processing (Fig. 3). The results of these measurements are shown in Table 1. Using the data taken from the Fourier transform measure-



FIGURE 1. LAKE MICHIGAN SHORELINE AT GRAND HAVEN

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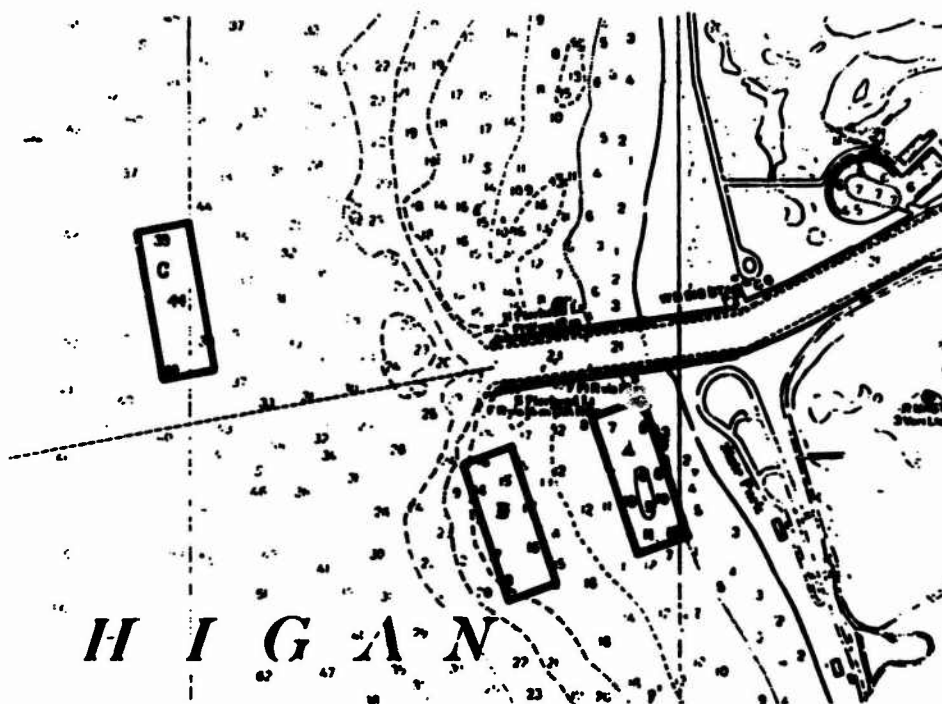


FIGURE 2. LAKE SURVEY CHART —GRAND HAVEN, MICHIGAN

TABLE 1. WAVELENGTHS DETERMINED BY
TWO METHODS

Method	Area A	Area B	Area C
Direct measurement of aerial photograph	53	82	92
Fourier transform	56.5	70	80

ments, the depth of Area A was found to be 7.9 ft. Inspection of Lake Survey Chart Number 765 of the Michigan coastline at Grand Haven indicates that the depth of Area A ranges from 6 to 10 ft. Fourier transform measurements were also used to compute the depth of Area B. The computed depth was 15 ft; depths determined from the chart ranged from 14 to 18 ft.

Water depth in Area A was also computed by comparing the angle of the incoming wave in Area A with that of Area C, where the wave orientation was presumably still outside the influence of the shore. Angle measurements were made by reference to both the original photograph and the Fourier transform.

Both methods gave values of 60° for Area C and 35° for Area A, measured with respect to the shoreline. Using these values, the value of d/L_0 for Area A can be obtained by using data

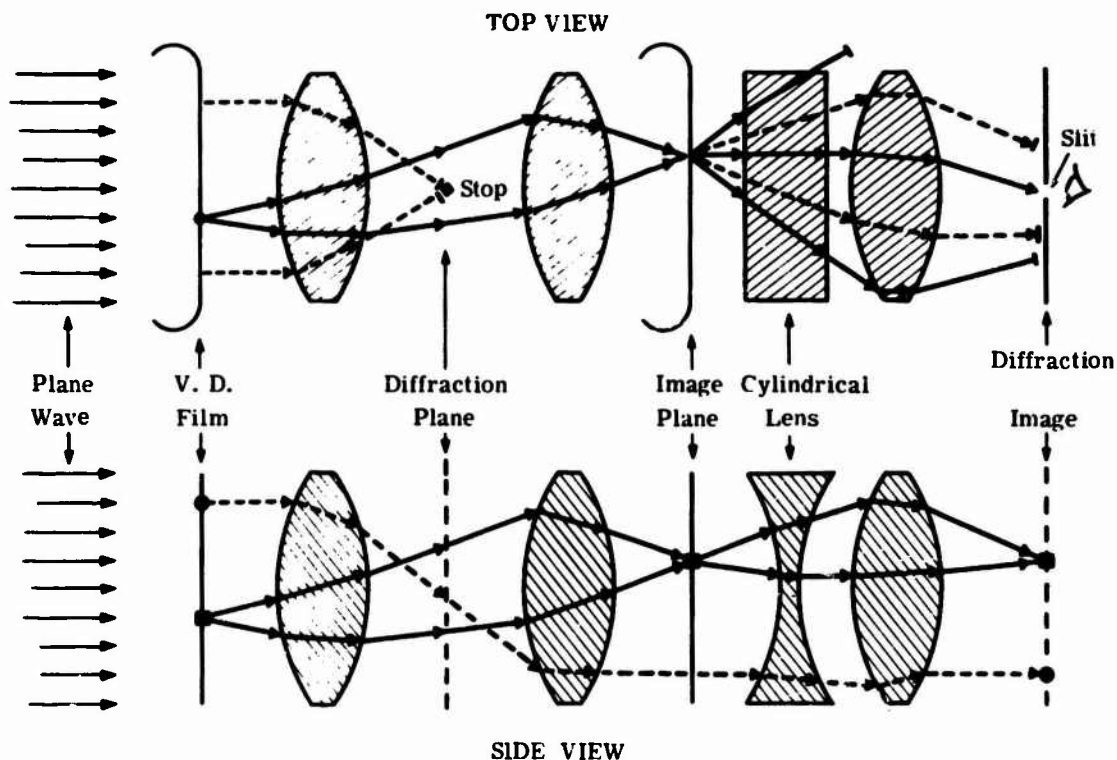


FIGURE 3. DIFFRACTIVE OPTICAL SYSTEM

such as that published in Ref. [4]. The value obtained for d/L_0 was found to be 0.086, and using the wavelength of 80 ft from Table 1, the water depth in Area A is computed as 6.9 ft, which checks closely with the value determined by wavelength measurements. For Area B, the angle of approach was 45° , giving an estimated depth of 12.0 ft. This is appreciably less than the chart value of 14-18 ft.

2.4. EFFECT OF ALTITUDE AND CLOUD COVER

The data from Mission 72, Lake Michigan, together with data from Mission 79, Gulf of Mexico, and samples of satellite photography provided an initial data base to study the effect of increasing altitude and cloud cover on the generation of interpretable optical transforms and on the measurement of wavelength. One of the advantages in using the optical transform is that at smaller photographic scales, the dot separation from the center in the transform increases and less confusion results in the bright central portion of the transform pattern. Figure 4, taken from an area near Cayo Arenas in the Gulf of Mexico, illustrates this effect. The area is in open deep water away from the diffraction effects caused by the island or refraction effects due to submerged shoals. The photography was taken at an altitude of 22,000 ft with a 6-in. focal length lens. Note the clean separation of the dot pattern for the fundamental wave component



FIGURE 4. CAYO ARENAS—(GULF OF MEXICO)

of the sea surface (see Figure 5). Figure 6 shows the transforms taken nearer the island at three different locations; the azimuthal changes in wave direction due to the diffraction of waves around the island are shown clearly in the transform domain when compared to the transform in Fig. 5.

The wavelengths measured in the sun-glitter region in Fig. 6 were in the 100-ft range but no depth measurements were made in the area since depths of 50 ft or less were not present. The required ratio of depth to wavelength of less than one-half implies that a determination of depth in a given area will depend on the existence of a particular set of conditions at the time the data is taken. Since these conditions may not always exist, a technique is needed to analyze rapidly many photographs in which routine data has been taken for a variety of other purposes. It is expected that scanning the transform plane for the dot separation will be a quicker and simpler method than scanning the original photograph.

Additional tests were also made of the effects of cloud patterns in portions of the photograph. Figure 7 shows a comparison of two transforms taken from sections of the photograph with and without cloud obscuration. The fundamental wavelength component was observed in both cases. The large cloud pattern generally transforms into the lower spatial frequencies located near the center. The presence of scattered clouds does effect the overall exposure

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(a) Aerial Photograph



(b) Fourier Transform

FIGURE 5. WAVES IN OPEN WATER

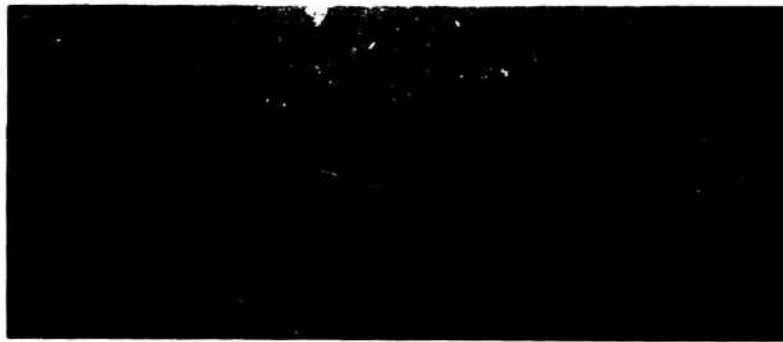
during the construction of the optical transform, indicating that an increase in exposure time may be necessary in some cases.

2.5. SPACE PHOTOGRAPHY

Frame AS7-4-1607 taken during the Apollo 7 flight distinctly shows a widespread, long wavelength swell moving in the direction of the Schouten Islands near New Guinea. The swell has an extremely regular pattern, consisting of wave crests many miles in length, essentially straight, with little or no apparent variation in wavelength. This type of wave pattern would have been caused by a recent storm at a considerable distance; the dispersive characteristic of water waves has separated the wavelength components in the storm area, so that only a single wavelength is present in the picture.

Optical data processing was applied to one section of this picture in which the wave pattern was most distinct (Fig. 8a). The resulting transform shows a very definite wave component ranging from 1040 to 1220 ft and an orientation angle ranging from 40 to 50°. Corresponding to the figures derived from the transform, measurements made from the original image indicated a typical wavelength of 1100-1200 ft and an orientation angle of 45°. An analysis of this frame has also been performed by Noble (Ref. 5).

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(a) Aerial Photograph (West of Cayo Arenas)



(b) Fourier Transform

FIGURE 6. DIFFRACTION OF WATER WAVES

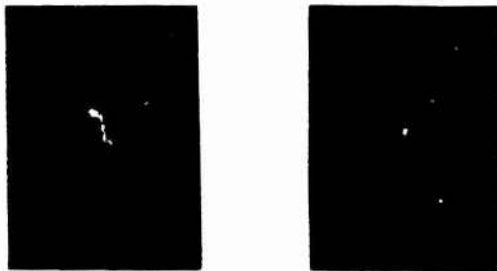
The swell can be seen reaching the large island shown in the picture, but because the sun-glitter pattern in the vicinity of the island provides only a low contrast in the wave image, it is difficult to obtain a transform pattern in this region. Measurements taken from the original image indicate that the wavelength becomes shorter in the vicinity of the island, but the wave direction does not appear to change appreciably. The long wavelengths composing the swell would be sensitive to relatively great bottom depths and are thus most likely to provide useful information concerning shallow water. It would be highly desirable to obtain imagery of long swells approaching land at shorter intervals between frames so that every part of the water surface of interest is in the favorable part of the sun-glitter pattern on at least one exposure.

Frame AS6-2-918 of Apollo 6 imagery shows an extensive wave system covering large areas of open ocean. The transform taken over a part of the frame (see Fig. 8b) representing a rectangle many miles on a side shows a wave system consisting predominantly of wavelengths ranging from 850 to 1050 ft over an angular range of 20° . Typical measurements from the original image show a wavelength of 1020 ft at an angle in the exact center of the angular range. If wave patterns with the easily identifiable limits shown in this example were available in the

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(a) Aerial Photograph



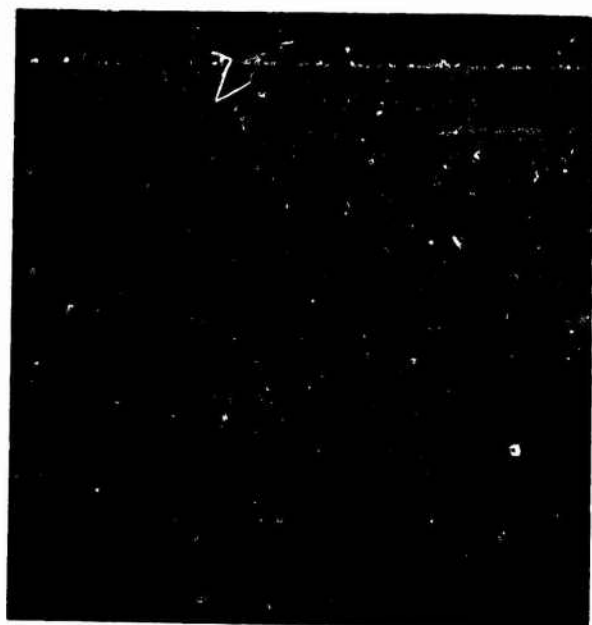
(b) Fourier Transform

FIGURE 7. CLOUDS AND CLOUD SHADOWS

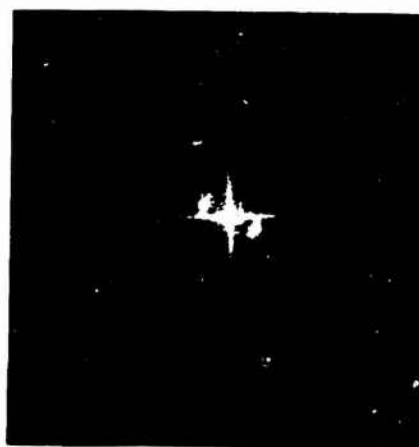
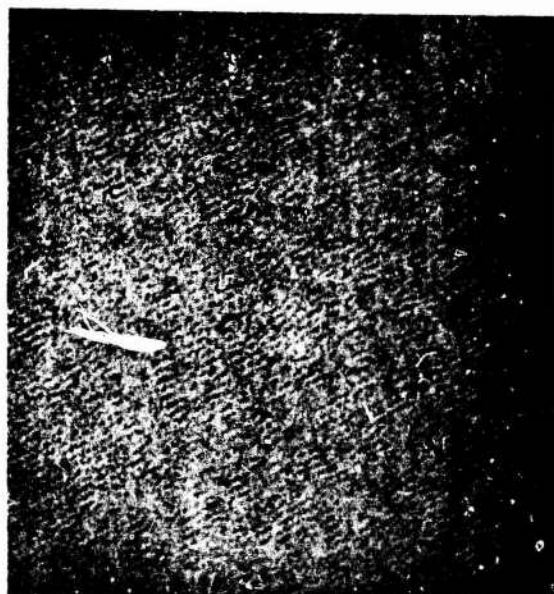
neighborhood of islands of shallow areas, it should be possible to detect and measure shallow water with fair accuracy.

Measurements were made from Fourier transforms taken of Apollo frame AS7-4-1607 and AS6-2-918 in order to determine the precision of wavelength and angle measurements produced by optical data-processing techniques, using manual data reduction by scale and protractor. Frame AS7-4-1607 is distinguished by the fact that the wave system is very regular as to both wavelength and wave orientation. The results of optical data processing on this frame indicate that wavelength measurements can be obtained with a precision of 2 or 3% and angle measurements with a precision of 2 or 3°. Assuming that this precision could be obtained in measuring both L and L_0 , it is possible to estimate the accuracy of computing depth for a known value of d/L_0 . If d/L_0 is equal to 0.100, for example, the depth could be estimated within about $\pm 10\%$. (In the Lake Michigan example previously presented, Area A had a d/L_0 of about 0.100.)

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(a) Apollo 7 Frame AS7-4-1607



(b) Apollo 6 Frame AS6-2-918

FIGURE 8. OPTICAL DATA PROCESSING

2.6. ALTERNATIVE METHODS OF OPTICAL DATA PROCESSING

2.6.1. TWO-DIMENSIONAL CROSS-CORRELATION PROCESSING

Other optical data-processing approaches to the problem of detecting and measuring shoal areas were investigated during this project to determine their potential advantages compared to the use of two-dimensional Fourier transform approach. For example, a two-dimensional cross correlation of the sea-surface image would contain information similar to that contained in the Fourier transform, but would have the advantage that the scale of output presentation is not tied as rigidly to the scale of the original image transparency placed in the optical data-processing system. It is possible, therefore, that relatively small sea-surface areas at relatively large scales could be used for processing. This would improve the spatial resolution with which wave data could be processed, although it would not reduce the scatter in the wave data.

As a typical example of results obtainable by this method, a cross-correlation display was made of a portion of Frame 8402 taken of Lake Michigan beach which contains a linear wave pattern approaching the beach. (See Fig. 9 for the input transparency made from the photograph.) This wave pattern is oriented at an angle of approximately 20° . The output produced by taking the cross-correlation of Fig. 9 is a broad band, oriented at approximately the same angle, representing the high correlation of the light-reflectance pattern along the wave crest. This broad band is bound on either side by two parallel dark bands representing the difference in reflectance between the wave crest and the adjacent wave troughs. The separation between the centers of the dark bands, produced at a scale of 7.4 times the scale of the original image, corresponds to the dominant wavelength in the image. Thus, the cross-correlation diagram can show the orientation and wavelength of a well defined wave pattern. The diagram can be adjusted for use with a broad range of photographic scale factors and can be restricted to coverage of small sea-surface areas. However, it seems to be more difficult to set up and work with, and more difficult to interpret than the Fourier transform, particularly if several wave trains are present at the same time. Although its use should not be ruled out on the basis of the brief investigation made so far, the present study has been concentrated on other methods.

2.6.2. SECTIONAL AUTOCORRELATION DIAGRAMS

Figure 10 is an example of a sectional autocorrelation diagram of a small area taken from Frame 1037 of the Lake Michigan shoreline. In this type of data analysis, the variable density pattern of a linear strip of the original photograph orthogonal to the wave crests is transformed into a corresponding linear strip on the autocorrelation diagram, the brightness of which corresponds to the autocorrelation of the signal on the original linear strip. (See Ref. 4.) The autocorrelation diagram along a vertical strip at any given value of x thus corresponds to the wave pattern along a vertical strip of the original image at a proportional distance along its x axis;

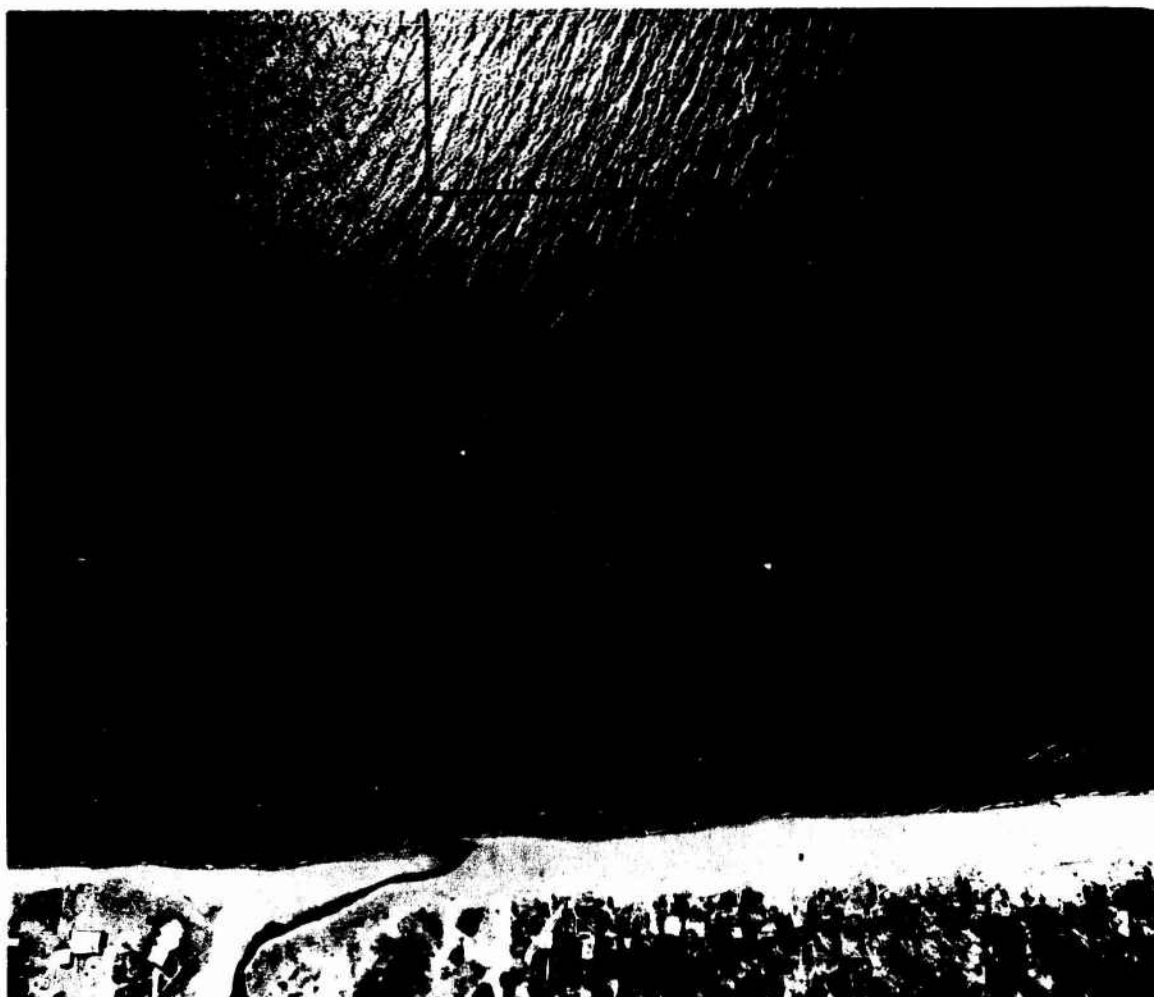


FIGURE 9. INPUT TRANSPARENCY FOR CROSS-CORRELATION OPERATION ON FRAME 8402—LAKE MICHIGAN BEACH

however, the scales are not necessarily equal on the two diagrams. The bright band near the center of the diagram corresponds to the peak value of the autocorrelation function for $\tau = 0$. In both directions from this bright band, the brightness varies with distance from the center, i.e., increasing magnitudes of τ , both positive and negative as distance from the center increases. The periodic character of the autocorrelation pattern indicates the presence of periodic variations in the original image, and the predominant wavelength in the original can be measured from the autocorrelation diagram, using a fixed scale factor determined by the optical setup. It should be noted that the sectional autocorrelation detects wavelength components only in one direction; components at right angles to this direction are not recorded.

The sectional autocorrelogram is useful in bringing out the predominant wavelength present in the original image. Where the original image has a regular pattern of waves, the perio-

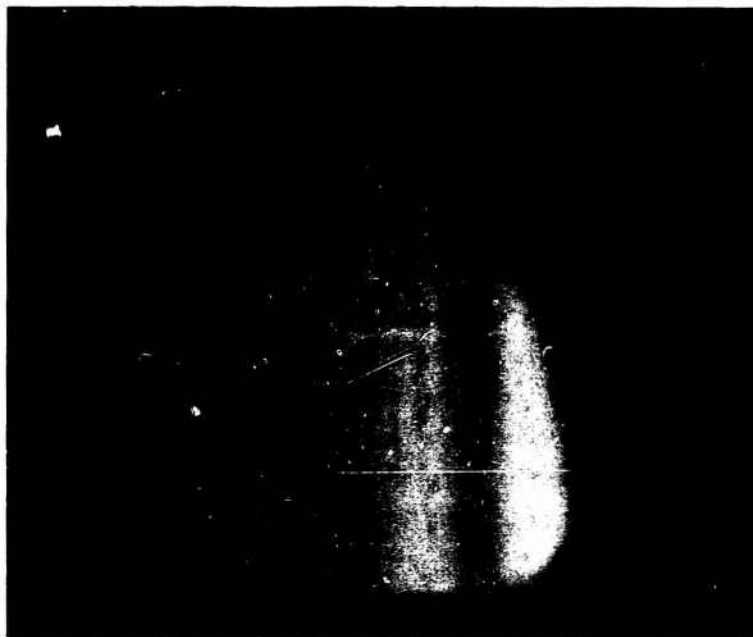


FIGURE 10. SECTIONAL AUTOCORRELATION OF FRAME 1037

dicity present in the autocorrelation diagram is apparent for 5 or 6 cycles and the wavelength on this diagram is easy to measure. However, the extent of the periodicity and its wavelength vary substantially depending on the position of the strip along the x axis of the diagram, indicating the variability inherent in the original image. Nevertheless, this form of presentation makes it possible to detect the predominant wavelength more easily than with the two-dimensional transform. Measurement of wavelength could be adapted to automatic processing without great difficulty.

2.6.3. SYSTEM-OPERATING CONCEPT USING OPTICAL DATA PROCESSING

Assuming that the use of the Fourier transform procedure proves to be adequate for our purposes, the resulting system might operate in the following manner. We will consider first the problem of detecting a shoal area in open water, where the shoal area and depth have sufficient effect to produce an appreciable refraction of the waves, causing a change in direction of at least 10° . Assuming the use of a satellite, imagery would be collected by means of a television system having sufficient resolution to see waves as short as 50 or 100 ft in wavelength. The television system would be continuously aimed toward the edge of the sun-glitter pattern, and imagery would be collected in such a manner as to observe the same portion of the sun-glitter pattern while the satellite traverses distances of many miles. This method of observation would assure uniformity in treatment of the wave patterns in the recording and processing operations. (The best angle of sun elevation for observing waves still remains to be determined.)

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The resulting image would be placed in an optical processing system designed to scan the image using an aperture as small as practicable. It is assumed that this aperture would project an area through the system which at any instant contained perhaps ten or twenty wave crests. In addition to a recording camera, the optical processing system would include a photoelectric device capable of producing a direct measurement of the total spread and mean value of angular orientation of the primary pattern in the transform. By restricting the data collection to sea conditions which consist of regular wave patterns (straight-line, long-crested swells) with no major interfering wave trains crossing the main pattern at small intersecting angles, it would be possible to restrict the normal transform to easily predictable patterns. Any anomalous variations from the normal range of orientations would then be easy to detect and could be checked further to assure that it was produced by shoals.

We will next consider the problem of measuring the spatial extent and depth of a shoal area, the existence of which has already been detected by other means. Here again it is important to restrict the coverage to conditions in which the sun-glitter pattern is uniform over the entire area of interest and in which the incoming wave pattern is as uniform as possible. This latter requirement would be realized under conditions of calm local seas in which an incoming swell arrives from a direction that minimizes interfering patterns caused by reflection or diffraction. Ocean forecasts could be used to select periods of conditions favorable for data acquisition. If the minimum usable aperture were small enough to resolve changes in wavefront alignment over short distances, and if the automatic photoelectric recording system mentioned previously were used, it would be possible to compute and plot the orthogonal to the wavefront as a function of location on the image. If a series of continuous orthogonals could be produced in this manner, and the incoming wave velocity were known, the orthogonals could conceivably be used to compute the depth of the bottom as a function of location. The accuracy with which this can be done cannot be predicted in advance, but would have to be determined by experiment. It would be possible to carry out such an experiment by hand calculation for one or two cases to determine the feasibility of the method.

In these data-processing operations, some human monitoring would be required to pre-select usable photographs and pinpoint areas of interest, but automatic processing equipment would perform the detailed analysis of the photographs.

Using a method of wavelength measurement, the data-processing operation would consist of scanning those parts of the picture which are of interest. Deep-water areas designated by the operator would be processed to provide measurements of L_0 . Large areas of deep water could be scanned to provide a large sample for determining mean wavelength. Scanning of shallow areas, on the other hand, must be limited to small apertures in order to maintain fine resolution in measurement of these areas. Readout of the processor would give a mean wavelength directly. Using analog or digital processing, the wavelength at each point over shoal areas could be computed as a fraction of deep-water wavelength, and water depth of the particular point computed.

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2.6.4. WAVE VELOCITY MEASUREMENTS

2.6.4.1. Moving Picture Techniques

Preliminary exploratory studies were conducted to determine the usefulness of moving pictures (or long sequences of still pictures) for measuring wave velocities, as a means of determining water depth. It appears that this technique can be used successfully, provided the pictures are taken under appropriate conditions.

It is desirable to obtain a picture sequence covering an interval of time sufficient to observe a single wave or short train of waves moving from deep water to shallow water. Obviously, the total period of time during which a small area could be kept under surveillance would be greatest if a helicopter were used as an aerial platform. If a fixed-wing aircraft is used, however, there is a definite limit for surveillance time determined by the aircraft speed and altitude, and the camera characteristics.

Assume an aircraft flying at an altitude of 20,000 ft and a speed of 250 knots (420 fps). Although the use of a moving picture camera is suggested here, even better results might be obtained with a camera designed to obtain wide-angle, high-resolution pictures at intervals of $1/2$ to 1 sec. If the camera has a field of view of 74° , a single frame would cover a distance of 30,000 ft on the earth's surface. A small area would thus remain in view of the camera for a period of 72 sec, although it is not likely that the illumination conditions for observing waves would be suitable over the entire range of viewing angles. In 72 sec, a wave train of 100-ft wavelength, travelling at a speed of about 23 fps, would move a distance of 1600 ft in deep water or 1100 ft in 10-ft-deep water. These distances are sufficient in many locations to track the wave from deep to shallow water. If longer wavelengths are present, they can be tracked over even greater distances.

With a resolution of 30 lines/mm and a 70-mm frame size, the ground resolution would be about 10 ft. Image motion would not appreciably degrade this resolution, provided the exposure could be kept to $1/125$ sec.

If 10-ft-deep water is to be measured by observing 100-ft waves, it would be desirable to measure wave velocity with no more than a 10% error. Even with 10-ft ground resolution, it should be possible to estimate the center of a wave crest to 10 ft. Thus, a 100-ft wave advance is needed to obtain the necessary measurement accuracy. In 10-ft-deep water, measurement accuracy requires a time interval of about 6 sec between the frames used for measurement of wave advance.

A representative system adapted to satellite application might be a television camera with a 2-in. screen having a total resolution of 5000 lines/frame and an optical system with a 12-in focal length. From an altitude of 300 nautical miles, this camera would produce a ground resolution of 60 ft and a viewing time of 13 sec. Obviously, this system would be less accurate

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than the aircraft system previously described, but could be used to observe longer wavelengths. For example, this system would allow observation of a wavelength of 500 ft corresponding to a wave velocity of 50 fps travelling 650 ft, in the available viewing time.

2.6.4.2. Experiments with Motion Pictures of Waves

Wave motions were observed by means of 16-mm moving pictures taken in a flight over the eastern shoreline of Lake Michigan and from a bridge over Ford Lake. The purpose of this exploratory study was to determine the usefulness of moving pictures for measuring wave velocities and directions as a basis for determining water depth. Although the aircraft flight characteristics were not optimum for the purpose, interesting and useful results were obtained.

The pictures of the Lake Michigan shoreline show incoming waves approaching the beaches. The height and speed of the airplane were such that single waves remained in the field of view of the camera for only 3 or 4 sec. With the limited observation period available, it was not possible to follow the progress of a single wave long enough to determine its velocity with adequate accuracy. An aerial platform with a lower velocity-height ratio would therefore be advantageous for extending the period of time for observing individual waves. Individual waves could then be identified and followed for the entire period of time they were in view, indicating that it would be possible to obtain accurate measurements of wave velocity over extended distances. In many instances, an individual wave crest appears to change shape and may disappear. However, wave trains of as few as two or three wave crests will maintain their identity and can be followed by the eye.

In order to obtain usable velocity measurements, a fixed object or landmark must be present in the scene, as a reference for distance measurements, and the photographic scale must be known either from measurements of known objects in the scene itself or from a knowledge of the aircraft altitude and camera characteristics.

The pictures taken from a bridge at Ford Lake were oblique views. They were not suitable for making velocity measurements, but covered longer intervals of time than were possible with aerial photography. The movies tended to confirm the conclusions previously stated about the ability to track individual waves and wave trains for substantial periods of time.

2.7. RECOMMENDATIONS FOR FUTURE RESEARCH AND DEVELOPMENT

The work performed under the present program indicates that methods of wave analysis using aerial and space photography and optical data-processing techniques for detection and measurement of doubtful shoals are technically feasible and offer the possibility of improved performance over existing methods. Much additional theoretical and experimental research remains to be done to develop these techniques to operational status. This section outlines some directions for future research to achieve an operational capability.

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2.7.1. ACQUISITION OF ADDITIONAL PHOTOGRAPHIC COVERAGE

Analysis of aerial and space photography obtained during the present project suggests some of the requirements for obtaining useful data from such coverage. By obtaining photographic coverage meeting these specifications, it should be possible to demonstrate experimentally the capabilities indicated by analysis of imagery taken under unfavorable conditions.

Pictures should be taken with both 9-in. × 9-in. aerial camera and 16- or 35-mm movie camera. Pictures of selected areas should be taken simultaneously with both types of cameras to provide comparison of results. It is preferable to take a large number of pictures of a small number of selected areas (including both beaches and open ocean) rather than single pictures at evenly spaced intervals of 10-20 sec. Pictures of beach areas should be taken from a position that produces sun glitter all the way to the shore line. (In the Lake Michigan pictures, the sun glitter was concentrated at some distance offshore, so that breakers and surf did not show up very well.)

One or more sets of pictures should be taken of areas covered by ground-truth teams. Ground truth should be collected simultaneously with the flyover. Features to observe include dominant period of breakers and character of chop, swell, and other wave components (e.g., size, orientation, and wavelength). If convenient, still pictures or movies of the offshore area should be taken. Depth measurements at points offshore should be obtained in as much detail as possible, with distances recorded offshore and alongshore from identifiable landmarks.

2.7.1.1. Aerial Camera

For each sequence of pictures, intervals between shots should be 1 to 3 sec, depending on how rapidly film can be advanced. The interval should be known to 0.1 sec or better to allow computation of speed of wave advance. An intervalometer should be used, if available. A stop watch placed at the edge of the camera frame would provide necessary accuracy.

If a 6-in. focal length camera is used (74° field of view), the frame covers a square area on the ground of 30,000 ft on a side (for 20,000-ft flight altitude). This area would stay within view for about 70 sec (at 250-knot speed), but variations in the sun-glitter pattern might limit the usable time to much less.

2.7.1.2. Moving Pictures

Color film should be used throughout the tests, since it increases the ability to discriminate detail. Pictures should be taken with the camera mounted in the aircraft for vertical photography. Camera speeds of 16 frames/sec are adequate to follow wave trains. For aircraft applications, film speed and lens opening should be chosen to permit the use of exposure as short as $1/125$ sec, in order to avoid appreciable loss of resolution because of image motion. Neglecting image motion, ground resolution for a 16-mm camera at 30 1/mm from 20,000 ft would be about 25 ft.

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2.7.1.3. Choice of Subject Matter

For experimental studies, ocean areas used as subjects for data collection should preferably be in the neighborhood of islands or other land masses which should appear in the imagery as convenient reference points. Areas for which there is extensive hydrographic data are desirable, although ground-truth data may be needed in addition to check some of the results. Some areas in which doubtful hydrographic data exist should also be included to provide checks on the effectiveness of the methods being developed.

Timing of coverage is as important as selection of subject areas. Past experience indicates the importance of making measurements on regular wave trains, on which there is as little interference as possible from other wave trains. Minimum interference from cloud cover is also desirable. Scheduling flights during weather conditions conducive to obtaining useful coverage should be aided by information obtained from weather- and ocean-forecasting services.

2.7.2. PROPOSED SPACE EXPERIMENT IN OCEANOGRAPHY

Experiments conducted with satellite-based, remote sensing equipment would permit further evaluation of the techniques under realistic operational conditions. In these experiments, imagery should be obtained of ocean areas known to contain shallow bottoms, e.g., areas in the Bahamas. Repeated coverage should be obtained during succeeding passes over the same test area. Preferably, coverage should be obtained under various conditions of sun elevation. It is particularly desirable to obtain coverage at times when extensive wave systems are present. Long wavelength swells arising from distant storms provide the best conditions for detecting and measuring shallow water.

Usefulness of the data would be enhanced if overlapping coverage could be obtained during a single pass. Since waves are most visible in the sun-glitter pattern, the overlapping coverage would increase the ocean area observed under conditions of best visibility. Also, if enough overlapping frames could be repeated at intervals as short as 1 sec, it might be possible to estimate wave velocities by observing the advance of individual waves.

3

MULTISPECTRAL PROCESSING TECHNIQUES FOR DEPTH MEASUREMENTS

3.1. INTRODUCTION

The shallow water features in the Caesar Creek and Pacific Reef regions off the coast of Miami, Florida, provide an ideal situation for verifying depth-measurement techniques. Caesar Creek is a ship channel which is easily recognizable in aerial imagery because of its shape and depth. The Pacific Reef has sufficient spatial variation to offer easy recognition as well as a

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large variety of depths, making it useful for calibrating depth-measurement schemes. These areas are shown on the chart depicted in Fig. 11.

The availability of multispectral data for doing water-depth measurements suggests at least two techniques. One straightforward technique would be to compute spectral signatures for water of known depths in order to recognize areas of comparable depths elsewhere in the scene. Although this approach has been used successfully in recognizing surface features, the introduction of an intervening water layer—with its variable absorptance—over bottom types with variable reflectance would tend to make this approach ineffective.

The other technique, adopted for this study, overcomes this limitation; this approach utilizes a comparison of the intensities of light reflected from the ocean floor as determined by signal levels in different channels of a multispectral optical-mechanical scanner. The details of this approach are given in the following section. Because of the nature of the technique,

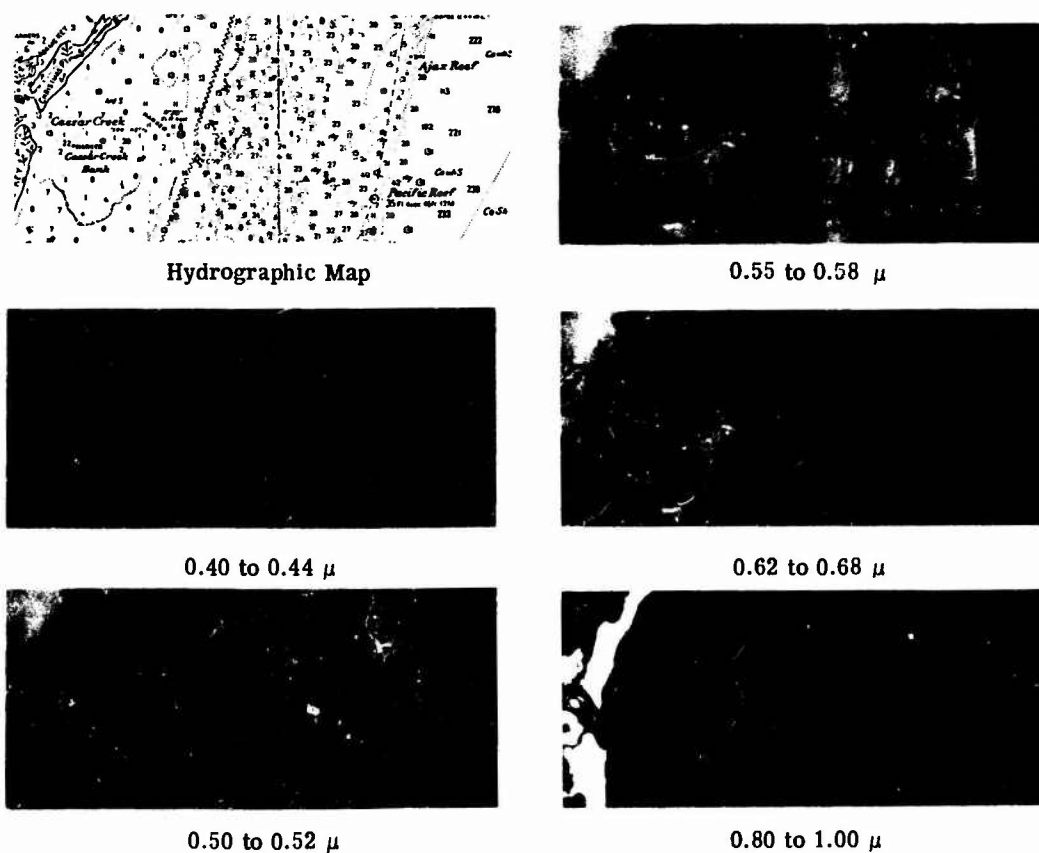


FIGURE 11. MULTISPECTRAL MAPPING OF CAESAR CREEK AND PACIFIC REEF.

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variations in water absorptance and in the reflectance of the ocean floor tend to be damped out, allowing a fairly accurate depth determination over a wide area.

Because the water must be quite transparent in order to measure reflections from the ocean floor, it is only practical to use wavelengths close to $0.54 \mu\text{m}$. The fact that the configuration of existing multispectral scanners produces only three or four usable wavelength channels imposes a slight limitation on the approach. It will be shown, however, that depths can be determined accurately in spite of this limitation. Development of a scanner with high spectral resolution from about 0.5 to $0.64 \mu\text{m}$ would serve to improve the measurements and increase the reliability of detecting shoals.

3.2. APPROACH

The electromagnetic power received by an optical system oriented toward the water consists of components of scattered sunlight (from the water and the atmosphere) and reflected sunlight (from the ocean floor and the water surface). Because the power reflected by the ocean floor must pass through an absorbing water layer, the amount reaching the system will be dependent upon the amount of absorptance which, in turn, is a function of the thickness of the water layer.

Quantitatively, this situation can be described by the following simplified equation:

$$P = \rho H e^{-(\sec \theta + \sec \phi) \alpha z} + \rho_{a/w} H + P_{\text{scattered}} \quad (3)$$

where

- P = total power received
- $P_{\text{scattered}}$ = power scattered (all sources)
- H = solar irradiance at water surface
- ρ = reflectance of ocean floor
- $\rho_{a/w}$ = reflectance of air/water interface
- α = absorptance of the water
- z = depth of the water
- θ = viewing angle (from vertical)
- ϕ = solar illumination angle (from vertical)

Admittedly, this equation does not account for atmospheric absorption, differences in absorption and scattering in the light incident upon and reflected from the ocean floor, and other relatively minor effects. The inclusion of these effects, however, would greatly complicate matters without appreciably improving the accuracy of the measurements.

The equation, even in its present simple form, does not lend itself well to depth calculations because of the two terms listed last above. The elimination of these terms is accomplished by measuring P over deep water:

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$$P_{\infty} = \lim_{z \rightarrow \infty} P = \rho_{a/w} H + P_{\text{scattered}} \quad (4)$$

It is not quite true that these terms are the same as those in Eq. (3), since the amount of light scattered by deep water is greater than that scattered by shallow water. The difference, however, will be small, and thus it should be possible to reduce the equation to a manageable form as follows:

$$P - P_{\infty} = \rho H e^{-(\sec \theta + \sec \phi) \alpha z} \quad (5)$$

In practice, this is accomplished by scanning over deep water and averaging together many scan lines for each spectral channel to obtain P_{∞} as a function of scan angle and wavelength. This function is then subtracted from each scan line obtained over shallow water, leaving, to first order, only the desired quantity represented by Eq. (5).

In actual applications, there are very few known quantities in Eq. (5). The power (P) is represented by a voltage (V_i) on magnetic tape, recorded from a sensor output:

$$V_i = K_i P_i \quad (6)$$

The constant, K_i , can be obtained from system calibration. In the Caesar Creek and Pacific Reef application, signals from the sensors were measured as the scanner passed over a piece of opal glass, through which sunlight was passing, at the end of each scan line. The voltage thus obtained from a given spectral channel can be represented by the following:

$$(V_s)_i = K_i (\rho_s)_i H_{\lambda i} \quad (7)$$

where s refers to the sun sensor, i refers to the channel of interest, and $(\rho_s)_i$ is the throughput of the sun sensor, determined by using standard reflectance panels on the ground. Thus, for example, if the reflectance of the scene were equal to ρ_s , the signal from the scene would have the same amplitude as the signal from the sun sensor. Since V_s and ρ_s are known, Eq. (7) can be inverted and substituted into (6) to obtain

$$V_i = \frac{(V_s)_i}{(\rho_s)_i} \frac{P_i}{H_{\lambda i}} \quad (8)$$

In turn, substitution of (8) into (5) yields

$$V_i = \frac{(V_s)_i}{(\rho_s)_i} \rho_i e^{-(\sec \theta + \sec \phi) \alpha_i z} \quad (9)$$

The expression thus obtained is in a form which can be used for depth measurements, since everything except z is either known or can be determined well enough in advance to provide reasonably accurate results.

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The most troublesome quantities in Eq. (9) are ρ and α . Further manipulation of the equation can ameliorate the situation. Using two channels of data, and taking the ratio of the voltages, we obtain

$$\frac{V_i}{V_j} = \frac{(V_s)_i (\rho_s)_j \rho_i}{(\rho_s)_i (V_s)_j \rho_j} e^{-(\sec \theta + \sec \phi)(\alpha_i - \alpha_j)z} \quad (10)$$

Rearranging and solving for z , (10) becomes

$$z = \frac{1}{(\sec \theta + \sec \phi)(\alpha_i - \alpha_j)} \ln \frac{(V_i/\rho_i) (V_s/\rho_s)_i}{(V_j/\rho_j) (V_s/\rho_s)_j} \quad (11)$$

Note that we are now concerned with differences in α and ratios of ρ .

To assess the improvement thus obtained, consider Fig. 12 which shows α for several different water conditions. Note that there are two distinct regions where $\alpha_i - \alpha_j$ is independent of water conditions:

- (1) 0.55 μm to 0.64 μm
- (2) wavelengths above and below (1)

Region (1) encompasses three spectral channels of The University of Michigan scanner: 0.52-0.55 μm , 0.55-0.58 μm and 0.58-0.62 μm . Because these channels have high signal-to-noise ratios and are in the region of highest water transparency, they were used in the trial runs of the depth-measuring program.

A similar consideration applies in the case of the reflectance of the ocean floor. Curves of the reflectance (see Fig. 13) of some representative wet sands show that the ratio of the reflectances of two bottom types at a given wavelength is relatively insensitive to variations in the kind of materials present.

In order to eliminate areas which were not underwater, use was made of the 0.8- to 1.0- μm channel of the multispectral scanner. For all practical purposes, water is opaque in this near infrared channel. Therefore, any signal detected in this channel (after subtracting scattered sunlight and surface reflections) would indicate an above-water feature, making depth measurement impossible. Such points were assigned a depth of zero and calculations were begun on the next point in the scene.

Computer programs were devised to (1) measure the deep-water signal, (2) subtract this measurement from the data, and (3) compute the depth according to Eq. (11). This program can be used on weighting factors applied to the combinations of spectral channels with outputs of (1) the best combination, (2) a weighted mean, and (3) a weighted deviation. The format of the out-

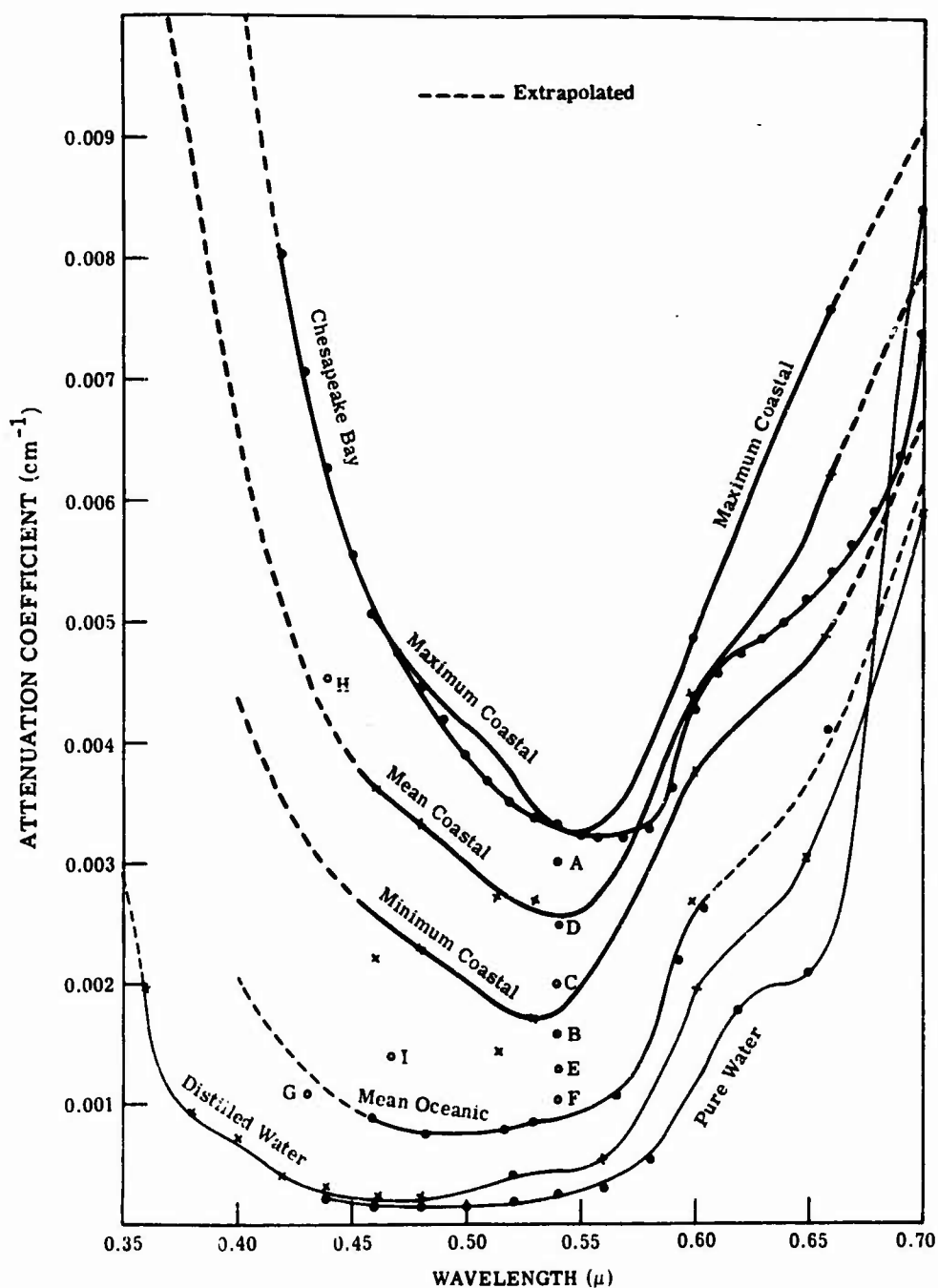
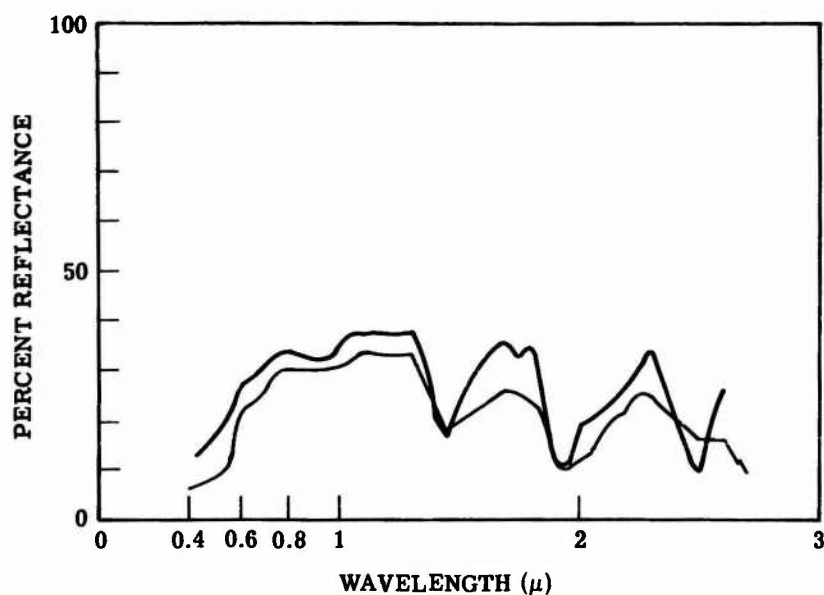
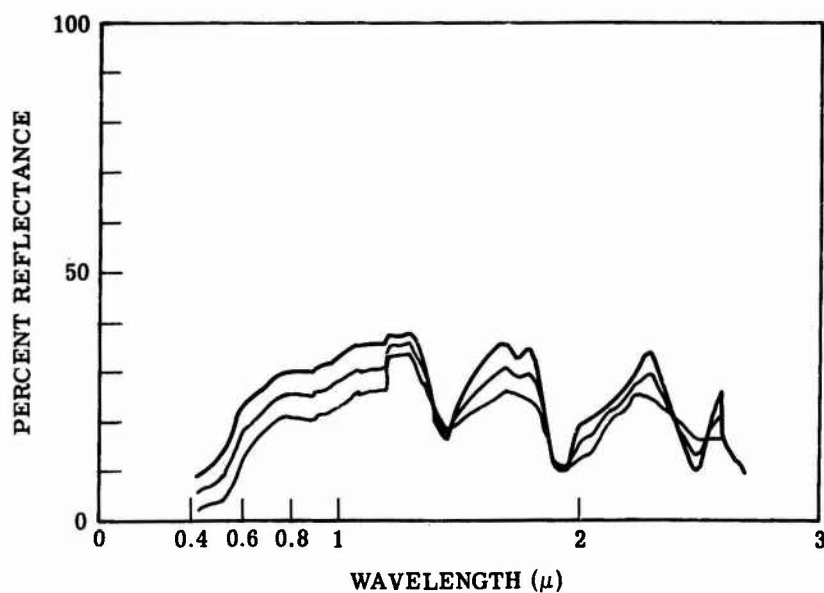


FIGURE 12. ATTENUATION COEFFICIENT VERSUS WAVELENGTH FOR PURE WATER AND SEA WATER

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(a) Composite Plot of Reflectance from Wet, Sandy Soils (Sand, Loamy Sand)



(b) Mean and Mean $\pm$ One Standard Deviation of the Reflectance from Wet, Sandy Soils (Sand, Loamy Sand)

FIGURE 13. SPECTRAL REFLECTANCE OF SANDY SOIL

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puts is such that a computer map can be printed directly from them, as shown in Fig. 14.

[Note: This figure was obtained from data which had been smoothed in order to diminish the effects of system noise. In effect, the spatial resolution was diminished to an effective 20 ft × 20 ft, although each point on the computer map still represents a 6.7-ft × 6.7-ft area.]

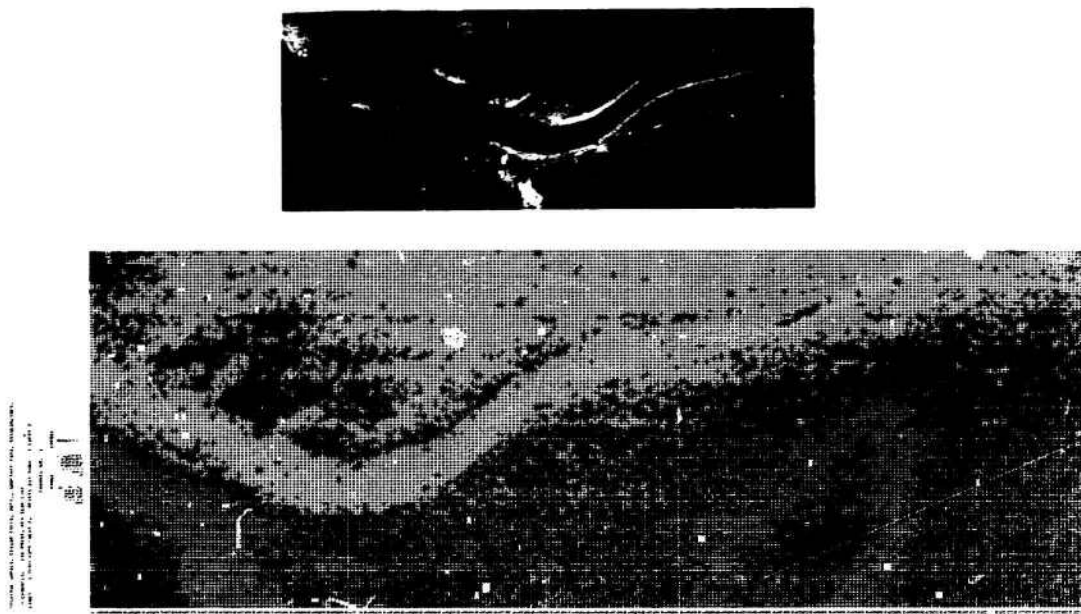


FIGURE 14. DEPTH CHART — CAESAR CREEK — OBTAINED BY DIGITAL PROCESSING OF MULTISPECTRAL SCANNING (See enlargement of Fig. 14 inserted at the end of the report.)

3.3. ANALYSIS OF RESULTS

The depth map for the Caesar Creek area was compared with the U. S. Coast and Geodetic chart of the area in Fig. 10. The deepest portion of the ship channel, according to the computer output, is 1.25 m (i.e., about 4 ft). According to the chart, the actual depth goes up to 20 ft. In the absence of onsite verification of the true depth, the following explanations are offered:

- (1) The true depth is about 4 ft, because the channel has been filled in with silt.
- (2) The true depth is greater than 4 ft, but the water has become clouded (e.g., by tidal action).
- (3) The calculations are not as accurate as they should be.

Some hand calculations indicate that (3) is not a good explanation of this effect. Thus, we tend toward (1) or (2).

The calculations proceeded as follows. The data for spectral channel 4 (i.e., 0.52-0.55 μm) are, at the deepest point of the ship channel,

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$$\begin{aligned}
 V_4 &= 0.371 \\
 \rho_4 &= \text{unknown} \\
 (V_s)_4 &= 1.60 \\
 (\rho_s)_4 &= 0.14 \\
 \alpha_4 &= 0.25 \text{ (mean coastal water)} m^{-1} \\
 \theta_4 &= 0.15 \text{ rad} \\
 \phi_4 &= 0.60 \text{ rad}
 \end{aligned}$$

Using an inverted form of Eq. (9) and using $z = 6$ m, we obtain:

$$\rho_4 = V_4 \left(\frac{\rho_s}{V_s} \right)_4 e^{(\sec \theta + \sec \phi) \alpha_4 z} = 0.78 \quad (12)$$

This figure is too high. Calculations for channels 5 and 6, the other two used, yield reflectances of 1.15 and 4.57 respectively. Of course, these are physically impossible. These figures appear to be at least 8 times greater than the true values of ρ , implying that z is probably at least 3 times too large. Using $z = 2$ m (about 6 1/2 ft), the computed values of ρ become:

$$\begin{aligned}
 \rho_4 &= 0.10 \\
 \rho_5 &= 0.15 \\
 \rho_6 &= 0.59
 \end{aligned}$$

These values are certainly more realistic.

Similar values for ρ could have been obtained had we used the mean oceanic value for α (i.e., $\alpha_4 = 0.083$, $\alpha_5 = 0.115$, and $\alpha_6 = 0.25$) and the chart-obtained value of $z = 6$ m:

$$\begin{aligned}
 \rho_4 &= 0.09 \\
 \rho_5 &= 0.14 \\
 \rho_6 &= 0.41
 \end{aligned}$$

Subsequent onsite verification showed that the high signals in this area were probably the result of very turbid water occurring at the time of high tide.

3.4. VARIABILITY IN THE DATA

There are at least three sources of variability of the data put out by the depth-measurement analysis: (1) system noise, including the analog-to-digital quantization of signal levels; (2) uncertainties and/or variations in the turbidity of the water and in the reflectance of the ocean floor; and (3) uncertainties and/or variations in the deep-water signal levels, including sun glint and wave phenomena. In addition to these factors, the equations which have been programmed are greatly simplified.

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In the face of these observations, it is interesting to note that the measurements which have been obtained are in agreement with the charts of the area. Onsite inspections should remove uncertainties which still remain.

Aside from considerations of the accuracy of the results, there is the question of verification of the results when using different combinations of spectral channels. Several computer maps of the same area shown in Fig. 13 were made, comparing the results using different combinations of data channels 4, 5, and 6. Each combination was weighted by a normalized function proportional to the difference in absorptances of the pair of spectral channels being used. It was verified that the large difference in absorptances provides greater confidence in the calculations.

In future work on this problem, it is hoped that onsite depth measurements and/or the inclusion of a laser depth-measuring device will provide calibration of the technique.

4

LASER-RANGING TECHNIQUES FOR IDENTIFYING SHALLOW WATER FEATURES

An earlier study conducted under this program (see Ref. 1) concluded that water depth could be determined directly by use of an optical laser system which would measure the time difference between the laser-beam reflection from the water surface and the reflection from the bottom. Because of some ambiguities and errors in the discussion of this technique in Ref. [1], the discussion which follows is intended to supplement and update the previous annual report.

The performance of a laser-ranging system in depth measurements is dependent upon many variables, including spectral characteristics, geometric factors, and system design parameters. Further constraints are effected by size, weight, and power limitations imposed by the platform (i.e., the aircraft or satellite), as well as by the altitude and velocity of the platform.

Referring to the earlier study, the maximum depth of penetration of the laser beam in water can be expressed as follows:

$$r = \underbrace{\frac{1}{2\alpha}}_{\text{Term 1}} \ln \left\{ \underbrace{\rho_b \tau_a^2 (1 - \rho_w)^2}_{\text{Term 2}} \left[\frac{\cos \theta}{\pi(h+r)^2} \right] \underbrace{\left[\frac{P_t \tau_t \tau_r A_r}{(\text{SNR}) \left(\frac{2ek^2 \Delta f P_r}{S_c} \right)^{1/2}} \right]}_{\text{Term 3}} \right\} \quad (13)$$

Term 1 is the spectrally dependent term; term 2 represents the geometric factors such as altitude and angle of incidence; and term 3 encompasses the laser equipment parameters. The

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derivation of Eq. (13) is presented in the appendix to Ref. [1]. The definition of symbols for this and the following equations are given below:

- r = depth of water
- α = absorption coefficient of water
- P_t = transmitter power
- τ_t = transmittance of transmitter optics
- τ_r = transmittance of receiver optics
- τ_a = transmittance of air
- ρ_b = reflectance of ocean bottom
- $1 - \rho_w$ = air/water transmittance
- A_r = area of receiver collector
- S_c = photomultiplier cathode sensitivity (A/W)
- θ = angle between transmitter axis and water surface normal
- h = height of aircraft or spacecraft
- SNR = signal-to-noise ratio
- e = electronic charge
- k = secondary emission factor
- Δf = electrical bandwidth
- P_r = received signal power

The depth equation (13) is simplified in that all noise sources to the photomultiplier receiver are ignored except the shot noise caused by P_r , the signal power received at the detector. Since the other sources of noise are generally from 4 to 44 orders of magnitude less than P_r , their contribution is negligible. The signal power is given by

$$P_r = \underbrace{\rho_b \tau_a^2 (1 - \rho_w)^2 e^{-2\alpha r}}_{\text{Term 1}} \underbrace{\left[\frac{\cos \theta}{\pi(h+r)^2} \right]}_{\text{Term 2}} \underbrace{P_t \tau_t \tau_r A_r}_{\text{Term 3}} \quad (14)$$

As before, term 1 is the spectrally dependent term; term 2 is geometrically dependent; and term 3 covers system parameters.

Substituting P_r into the depth equation (13), it can be seen that the required magnitude of P_r is dependent upon the signal-to-noise ratio (SNR) and photomultiplier cathode radiant sensitivity (S_c) as follows:

$$P_r = (\text{SNR})^2 \left(\frac{2ek^2 \Delta f}{S_c} \right) \quad (15)$$

Using this result, P_r can be eliminated from the range equation, leaving

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$$r = \frac{1}{2\alpha} \ln \left\{ \rho_b \tau_a^2 (1 - \rho_w)^2 \left[\frac{\cos \theta}{\pi(h+r)^2} \left[\frac{P_t \tau_t \tau_r A_r}{(SNR)^2 \left(\frac{2ek^2 \Delta f}{S_c} \right)} \right] \right] \right\} \quad (16)$$

Inversion of the range equation (16) shows that the peak power required to penetrate to a given depth of water is proportional to $e^{2\alpha r}$, illustrating that the power required by the transmitter increases rapidly with small increases in α . For this reason, it is mandatory that the laser output fall in the 0.51- μ m to 0.56- μ m portion of the spectrum, where α is relatively small. From physical characteristics data (see Ref. 1, p. 52), it is seen that high-powered lasers ($P_t \geq 10^9$ W) exist for 5 wavelengths in the 0.3- μ m to 0.7- μ m spectrum, with 2 of these in the low α region. Table 2 lists these wavelengths, the corresponding attenuation coefficients for mean coastal waters, and the attenuation ($e^{2\alpha r}$) for depths of 10 m and 1 m.

TABLE 2. WAVELENGTHS AND CORRESPONDING COEFFICIENTS FOR MEAN COASTAL WATERS, AND THE ATTENUATION FOR DEPTHS OF 10 m AND 1 m

Wavelength	Attenuation Coefficient	Attenuation For 10-m Depth	Attenuation For 1-m Depth
0.3371	1.45	3.9×10^{12}	18.2
0.3472	1.24	5.9×10^{10}	11.9
0.5300	0.252	154	1.66
0.5510	0.264	196	1.70
0.6943	0.785	6.6×10^6	4.81

It is quite evident from the table that the attenuation outside the 0.51- μ m to 0.56- μ m region is excessive for most of the depths of interest. Table 3 presents other parameters of interest for the same 5 lasers.

The choice of a laser with a high peak power (P_t) at the wavelength of the minimum attenuation coefficient for coastal waters appears to afford the greatest potential for depth penetration to identify shallow water features. Table 4 gives characteristics for lasers operating in the

TABLE 3. ADDITIONAL PARAMETERS FOR SAME FIVE LASERS

Wavelength	Atmospheric Transmission		Coastal Seawater Reflectance	Ocean Floor Reflectance
	0.5 km	200 Nautical Miles		
0.3371	0.843	0.342		
0.3472	0.856	0.380		
0.5300	0.933	0.715	0.0612	0.04-0.24
0.5510	0.938	0.758	0.0545	0.03-0.36
0.6943	0.960	0.798		

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TABLE 4. CHARACTERISTICS FOR LASERS OPERATING IN THE 0.3- μ m TO 0.7- μ m REGION

Wavelength (μ m)	Type	Material	Output (j)	Peak Power (W)	Pulse Width (nsec)	PRF (Hz)	Efficiency (%)
0.3371	Gas	N ₂ in air	0.1	10 ⁶	4	100	1.0
0.3472*	Solid State	Cr ³⁺ :Al ₂ O ₃	75	100 $\times$ 10 ⁶	10	100	0.01
0.5300*	Solid State	Nd ³⁺ :Glass	300	560 $\times$ 10 ⁶	10		1.0
0.5300*	Solid State	Nd ³⁺ :YAG	30	56 $\times$ 10 ⁶	10	100	1.0
0.5510 } 0.5950 }	Liquid Dye	Rodamine 6G in CH ₃ HO	150	2 $\times$ 10 ⁶	5	1500	0.036
0.6943	Solid State	Cr ³⁺ :Al ₂ O ₃	1500		10	100	0.1

*Second Harmonic. Operating temperature = 300°K for all three wavelengths. Beamwidth = 1 mrad for all except: Nd³⁺:Glass (7.5 mrad)
Cr³⁺:Al₂O₃ (2 mrad at 0.6943 μ m)

0.3- μ m to 0.7- μ m region. This listing of Q-switched lasers has standardized the outputs to 10-nsec (or less) pulses at a pulse-rate-frequency (PRF) of 100 Hz. Since the output power is a constant percentage (70% and up) of the rated average output power, higher PRF's and narrower pulse widths must be traded off at the expense of lower peak powers and higher processing bandwidth requirements.

The most powerful laser listed in Table 4 is the second harmonic of the 1.06- μ m Nd³⁺:Glass laser. A large laser, its rod is 94-cm long with a 3.8-cm outside diameter and a 3-cm core diameter. A closed-cycle liquid cooling system is required. Optical pumping is provided by four 1-m flashtubes with a required total input power of 180 W.

Electronic processing of the laser data is complicated because of the narrow pulses involved. For example, a 5-nsec pulse width requires high signal-to-noise ratios and 200-mHz bandwidths in the video amplifiers and preamplifier. The range resolution R_n in water for such a system is given by

$$R_r = \frac{CT}{n_w}$$

where C = velocity of light in vacuo (2.99793×10^8 m/sec)

T = pulse width (sec)

n_w = index of water refraction (1.33338).

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Thus, the range resolution for a 5-nsec pulse-width is 1.12 m. Range resolution can be improved an order of magnitude by using a 2-gate system which tracks the received signals from the water surface and ocean floor, but it is difficult to implement with a single pulse (i.e., no integration). The fine resolution described above will be degraded somewhat because of the scattering of the beam in the water and (for the satellite case) the curvature of the earth, both of which cause stretching of the received signal pulses.

The peak power which will be used depends indirectly upon the desired data rate. If it is assumed that a data point is desired for every meter of flight line traversed, an aircraft flying at 120 knots will require a PRF of 60 Hz and a satellite orbiting at an altitude of 200 nautical miles will require a PRF of 7500 Hz. Using a pulse-width of 10 nsec, the peak power of the highest power Nd^{3+} :Glass laser will be 5×10^8 W for aircraft and 4×10^6 W for spacecraft.

The required power input to the Nd^{3+} :Glass laser is 180 W, which can be supplied in an aircraft but which might pose problems in a satellite. Since almost all (99.76%) of this input power has to be dissipated as heat with liquid coolant and heat exchangers, the satellite will be further burdened by the size and weight of the cooling system for the laser. It is probable that in a satellite laser output, peak power may have to be sacrificed in order to obtain acceptable weights for prime power and cooling systems.

4.1. OPERATIONAL CONSIDERATIONS

Data processing, whether by automatic equipment or human operators, requires that the signal be greater than the system noise. Human operators require less signal-to-noise ratio (SNR) than machine processors. Since the data rates are 60 points/sec for aircraft and 7500 points/sec for a satellite, human operators will be unable to handle the results. Thus, automatic data processing will be required and higher SNR will be necessary.

Digital communications and pulsed radar theory show that $\text{SNR} = 11.1$ is required for a probability of error equal to 0.1; further reduction of the probability of error to 0.01 (1%) requires $\text{SNR} = 20$. All calculations which follow are based on the higher SNR, yielding a detection probability of 99%.

The accuracy of the results will be affected by refraction of the laser beam by the water. If the beam strikes the water at an angle, it will be refracted toward the normal. The angle at which the beam strikes the water will in turn be affected by the presence of waves. The average slope angle of ocean waves usually varies from about 3° to 6° , although the shallow depths of coastal waters can increase this to 19° . With such high incidence angles, the laser beam will be refracted away from the normal and the measured depth will be too large, indicating deeper-than-actual water, the opposite indication from what is needed for identifying hazardous underwater features.

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Much of the problem caused by surface wave effects can be eliminated by scanning. To maintain the same spatial resolution, therefore, the data rate will have to be increased. The increased data rate will result in decreased peak power of the laser transmitter because of the required increase in the PRF.

4.2. PERFORMANCE CALCULATIONS

A computerized tradeoff study of laser depth-ranging systems was presented in Ref. [1]. Following publication of the study, it was discovered that errors in the computer outputs changed the results of the study. Rather than completely redoing the tradeoff studies, it was decided that some typical parameters would be used to make the calculations in order to give an idea of what is practical at present. Table 5 lists those typical parameters for a profiling system carried by an aircraft at a 0.5-km altitude and in a satellite orbiting at a 200-nautical-mile (370-km) altitude. In both cases, a $0.5330 \mu\text{m Nd}^{3+}$:Glass laser was used, with a data patch spacing of 1 m. An RCA 7029 photomultiplier (S-17 spectral surface) is used in both receivers. On the basis of the data listed in Table 6, the values of α and of r (for mean coastal waters) were calculated and are given in Table 6.

TABLE 5. LASER DEPTH-RANGING SYSTEM PARAMETERS AND OPERATIONAL CONDITIONS

Operational Conditions	Aircraft	Satellite
Altitude (km)	0.5	370
Ground Speed (m/sec)	62	7475
Illuminated Patch Diameter (m)	0.05	1.85
Physical Environment		
Atmospheric Transmittance (τ_a)		
Clear Day	0.933	0.715
Hazy Day (Sea Level $\alpha = 1 \text{ km}^{-1}$)	0.617	0.279
Air/Water Transmittance ($1 - \rho_w$)	0.945	0.945
Ocean Floor Reflectance (ρ_b)	0.10	0.10
Laser System Parameters		
Transmitter: Type	1-Stage Oscillator	1-Stage Oscillator
Peak Power (W)	5×10^8	8×10^6
Pulse Width (nsec)	10	10
Pulse-Repetition-Frequency (Hz)	60	7500
Power Input (W)	180	360
Aperture Diameter (cm)	20	1900
Beam (mrad)	2.1	0.005
Transmittance of Optics	0.97	0.97
Receiver: Type	Pseudo-Cassegrainian	Pseudo-Cassegrainian
Aperture Area (π^2)	1.0	1.0
Transmittance of Optics	0.450	0.450
Electronic Bandpass	100 mHz	100 mHz
SNR	20	20

WILLOW RUN LABORATORIES

As indicated by the figures in Table 6, significant depth penetration from satellite altitudes can be obtained only at the expense of reliability of detection. This would indicate that the data rate (PRF) must be reduced and/or the input power increased in order to regain reliability at satellite altitudes. The implications of such modifications have been discussed previously.

TABLE 6. VALUES OF αr AND OF r
(FOR MEAN COASTAL WATERS)

<u>Platform</u>	<u>αr</u>	<u>$r(m)$</u>	<u>Detection Probability</u>
Aircraft			
Clear Day	9.5	38	0.99
Hazy Day	9.1	36	0.99
Spacecraft			
Clear Day	0.37	1.5	0.99
	1.06	4.2	0.82*
Hazy Day	0.10	0.4	0.82*

*SNR = 10

WILLOW RUN LABORATORIES

REFERENCES

1. F. C. Polcyn and R. A. Rollin, Remote Sensing Techniques for the Location and Measurement of Shallow-Water Features, Report No. 8973-10-P, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, January 1969.
2. P. L. Jackson, "Diffractive Processing of Geophysical Data," Appl. Opt., Vol. 4, No. 4, April 1965, pp. 419-427.
3. Graphical Construction of Wave Refraction Diagrams, U. S. Naval Oceanographic Office, H. O. Pub. No. 605, 1964.
4. P. L. Jackson, "Sectional Correlograms and Convolutions by a Simple Optical Method," Geophysics, Vol. 33, No. 5, October 1968.
5. Vincent Noble, Ocean Swell Measurements from Satellite Photographs, Remote Sensing of Environment, Vol. 1, No. 3, Summer 1970, pp. 151-154.

WILLOW RUN LABORATORIES

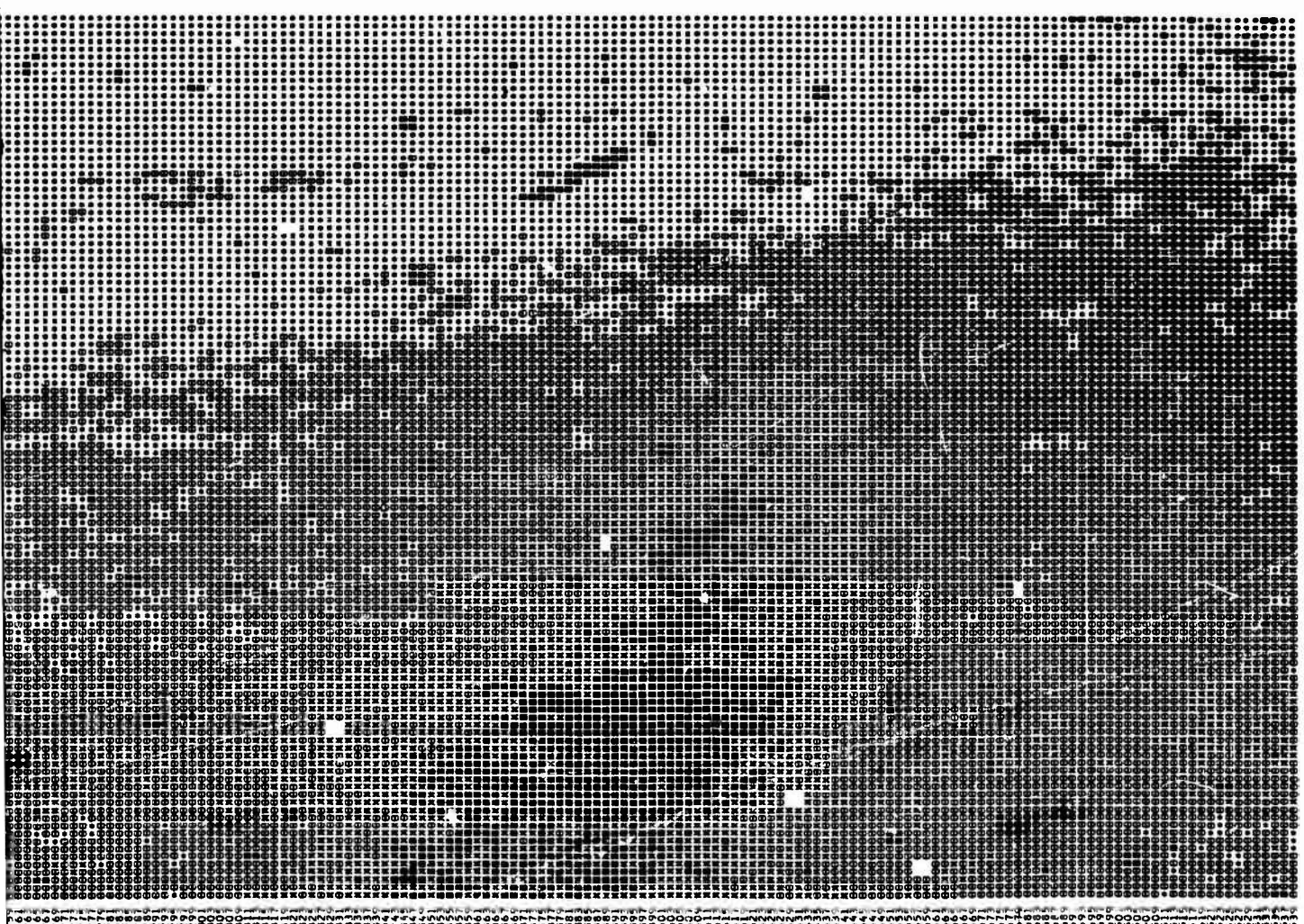


FIGURE 14. (Repeated) DEPTH CHART—CA
PROCESSING OF MULTISE

A

DEPTH IN METERS

RANGE	SYMBOL
0 0	■
0 .3140	※
.3140 .6260	θ
.6260 .9390	*
.9390 1.2520	=
1.2520 1.5440	-
1.5440 10.0000	



-CAESAR CREEK—OBTAINED BY DIGITAL
SPECTRAL SCANNING

B

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Remote Sensing of Agriculture

NASS' Cropland Data Layer Program

Claire Boryan

claire_boryan@nass.usda.gov

USDA/NASS



NASS Overview

Provider of timely, accurate, and useful statistics in service to U.S. agriculture

NASS - Data and Statistics - Microsoft Internet Explorer

Address: http://www.nass.usda.gov/Data_and_Statistics/index.asp

USDA United States Department of Agriculture
National Agricultural Statistics Service

The 2002 Census of Agriculture is the most comprehensive source of statistics portraying our nation's agriculture

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All NASS

Advanced Search
Search Tips

Browse NASS by Subject

- Crops and Plants
- Demographics
- Economics
- Environmental
- Livestock and Animals
- Charts and Maps
- Education and Outreach
- Statistics by State

Select a State

Data and Statistics

Quick Stats (Agricultural Statistics Data Base)

NASS publishes U.S., state, and county level agricultural statistics for many commodities and data series. Quick Stats offers the ability to query by commodity, state(s) and year(s), providing the most up-to-date statistics including all revisions. The query dataset can be downloaded for easy use in your database or spreadsheet.

Query our Quick Stats Data Base

Additional Crops County Resources

Maps of crops county estimates for acreage and yield are available from NASS as both CSV data files and maps.

County data from Quick Stats data is also available in pre-extracted data sets by year and by crop.

Census of Agriculture

To query Census of Agriculture data, choose from the Census years below. To view the Census publications, click here:

Data Queries for 2002, select below:

Select a Census Query

Data Queries for 1997, 1992, 1997

Interactive Data

NASS provides a variety of tools for interacting with our Census datasets.

Interactive Statistical Maps

Interactive Census Maps for 2002 Census Highlights

Table Lens

Table Lens Application for 1997 Census Data

Last modified: 12/30/05

NASS Home | USDA.gov | FEDSTATS | Economics Statistics System (ESS) | Site Map
FOIA | Accessibility Statement | Privacy Policy | Non-Discrimination Statement | Information Quality | FirstGov | White House

2001 Wildlife Damage Survey

7.7 Percent of Crop Value Lost to Deer and Geese

Maryland farmers lost \$17.2 million of corn, soybeans and wheat to deer or geese during 2001, translates to Maryland farmers losing 7.7 percent of the crop value to deer and geese. Soybean acres for the greatest economic loss, totaling \$9.1 million, 11 percent. Corn losses were \$6.6 million, 5.8 percent and wheat \$1.5 million, 5.6 percent. Deer damage resulted in losses of \$13.6 million, 6.1 percent, while geese losses were \$3.6 million, 1.6 percent.

Production losses totaled 6.0 million bushels. Corn losses were 3.2 million bushels, soybean losses are 2.2 million bushels and wheat accounted for 0.6 million bushels. Production losses to deer were 4.7 million bushels and geese 1.3 million bushels.

In terms of yield, losses to deer were most severe in Central and Western Maryland, while geese damage greater on the Eastern Shore. Corn yield losses of 9.6 bushels per acre and 7.4 bushels per acre were reported in Central and Western Maryland, respectively. The Lower Eastern Shore reported the highest soybean loss of 6.1 bushels per acre.

Sixty-two percent of farms reported deer or geese damage to one or more crops. Damage was reported on percent of farms raising corn, 58 percent of farms growing soybeans and 27 percent of farms with wheat.

Maryland 2001 Crop Loss from Deer

Region	Crop	Acres Harvested	Harvested Yield (bushels)	Average Yield Loss (bushels)	Production Loss (bu)	Economic Loss (\$)
Western Maryland	Corn	5,200	124,4	7.4	40,100	83
	Soybeans	300	34.7	9.9	1,301,250	2,843
	Wheat	200	45.7	2.0	440	1
Central Maryland	Corn	114,200	58.4	3.9	360,780	1,479
	Soybeans	94,200	34.0	3.0	126,290	319
	Wheat	38,200	63.0	3.0	146,200	299
Southern Maryland	Corn	25,800	112.7	4.9	146,200	299
	Soybeans	43,200	38.0	3.0	142,260	584
	Wheat	36,900	57.0	0.9	14,400	36
Upper Shore	Corn	197,800	159.2	5.1	800,700	1,241
	Soybeans	212,000	39.8	2.4	856,800	2,262
	Wheat	88,800	44.0	1.1	99,150	213

USDA **NEWS RELEASE**
NATIONAL AGRICULTURAL STATISTICS SERVICE
United States Department of Agriculture • Washington, DC 20250
Ag Statistics Hotline: (800) 727-9540 • www.nass.usda.gov

Contact: Ellen Dougherty, (202) 690-8122
Jeff Geuder, (202) 720-2127

USDA FORECASTS RECORD-SETTING CORN CROP FOR 2007

Washington, Aug. 10, 2007 – U.S. corn production is projected to reach a record-setting 13.1 billion bushels, 10.6 percent more than the 2006 crop.

Based on conditions as of August 1, 2007, the U.S. corn crop is projected to average 160.4 bushels per acre, up 3.7 bushels from last year's average of 156.7 bushels per acre. The average yield is based on 160.4 million acres of corn for grain, up from 156.7 million acres in 2006.

Yield forecasts are higher in the Corn Belt, particularly in the Delta. Meanwhile, hot, dry conditions in the Southeast and eastern Corn Belt, Ohio Valley and parts of the South are expected to reduce yields in those areas.

WISCONSIN AGRICULTURAL STATISTICS SERVICE
P.O. Box 8034 Madison, WI 53708-8034
In cooperation with WI Department of Agriculture, Trade and Consumer Protection

2002 Dairy Producer Opinion Survey

November 2002

Wisconsin Milk Production To Recover

Milk production is expected to increase in Wisconsin during the next five years according to a survey conducted by the Wisconsin Agricultural Statistics Service. This statewide survey of producers asked for their plans with the assumption that milk prices for the next five years will be at the same level as the past five years. The survey was conducted during May and June 2002.

Based on the survey, 60 percent of producers expect to keep the same herd size, 20 percent plan to increase herd size, and 20 percent intend to discontinue milking by 2007. Actual results will depend on future milk prices, input prices, financing availability, crop yields, and other factors.

The number of herds projected for 2007 shows that the diversity of small to large herds will continue. The most prevalent herd size will remain at 50 to 99 cows.

All Milk Price, Wisconsin Annual Average, 1985 - 2002

Wisconsin Dairy Herds by Herd Size

Milk cow herd size	May 2002 herds	May 2007 herds (projected) %	Change 2007/2002
1 - 29	2,800	1,440	-45
30 - 49	4,700	3,440	-27
50 - 99	7,400	5,600	-24
100 - 199	1,900	2,080	+9
200 - 499	700	600	-29
500+	200	440	+120
Total	17,500	19,900	+20

1/7The May 2007 projection is based on farmers' opinions May-June 2002, with the assumption that milk prices for the next five years will be at the same level as the past five years.

Small Dairy Farms Plans for May 2007

Herds	Keep same herd size	Increase herd size	Discontinue milking
Number	47	17	38
Percent	71	9	20
2,800	63	19	18
1,900	53	37	10
700	33	59	8
200	22	78	0
17,500	60	29	20

207 projection is based on farmers' opinions May-June 2002, with the assumption that milk prices for the next five years will be at the same level as the past five years.

Percent of Herds by Size Group 2007 Projection

Legend

- 1-29
- 30-49
- 50-99
- 100-199
- 200-499
- 500+

2002 Census of Agriculture - NASS Interactive Mapping - United S - Microsoft Internet Explorer

National Agricultural Statistics Service 2002 Census of Agriculture

United States All data items are from Chapter 2 - Table 1. Area Summary Highlights: 2002
Selected crops harvested - Land in orchards (acres)

State: United States - County Level

Data Item: Selected crops harvested - Land in orchards (acres)

United States Total: 5,330,439

State:

County:

County Total:

Download data as CSV | XML | PDF

Help Print Return to

Legend

Scale: National

Zero or Data Withheld

<= 20,000

20,001 to 40,000

40,001 to 60,000

60,001 to 80,000

80,001 to 100,000

100,001 >=

(Changes the data range based on National or State level)

Comparisons: 6

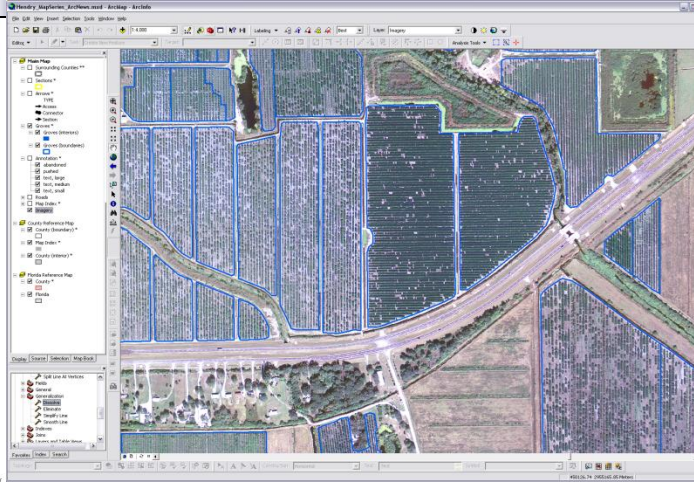
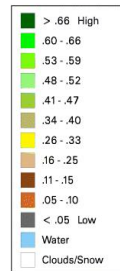
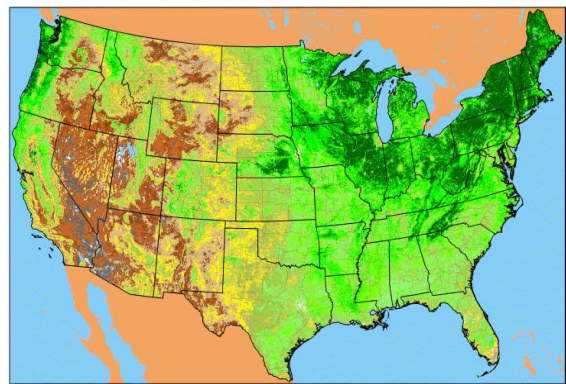
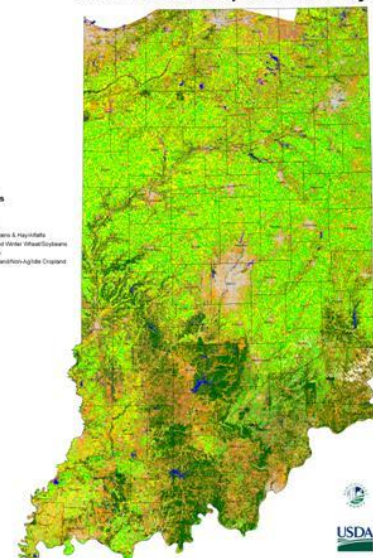
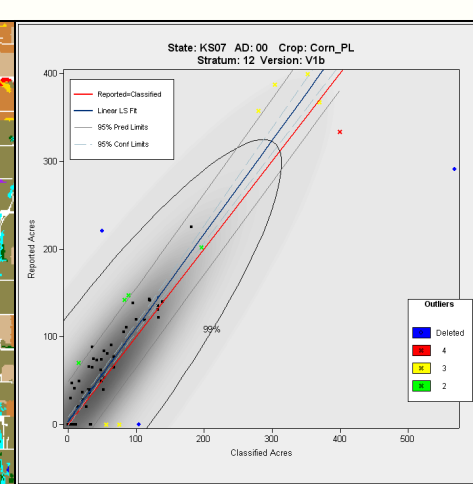
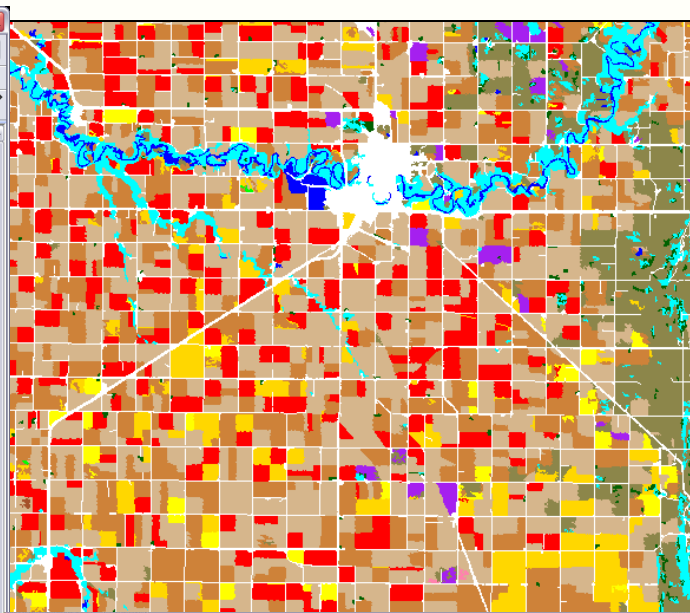
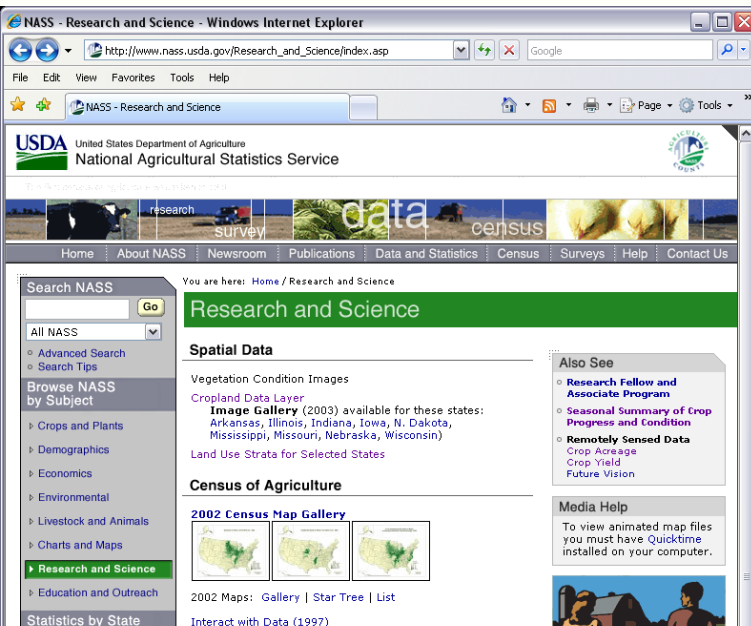
Color: Green

Source: USDA-NASS 2002 Census of Agriculture
© USDA-NASS 2005-2006

Navigate: Mouse-over a specific state/county to view the state/county level data. Right click to zoom (option-click for MAC users). Hold the Alt key and click+drag to pan. For additional assistance with this application, [click here to view the support page.](#)

Geospatial Information Branch

Spatial Analysis Research

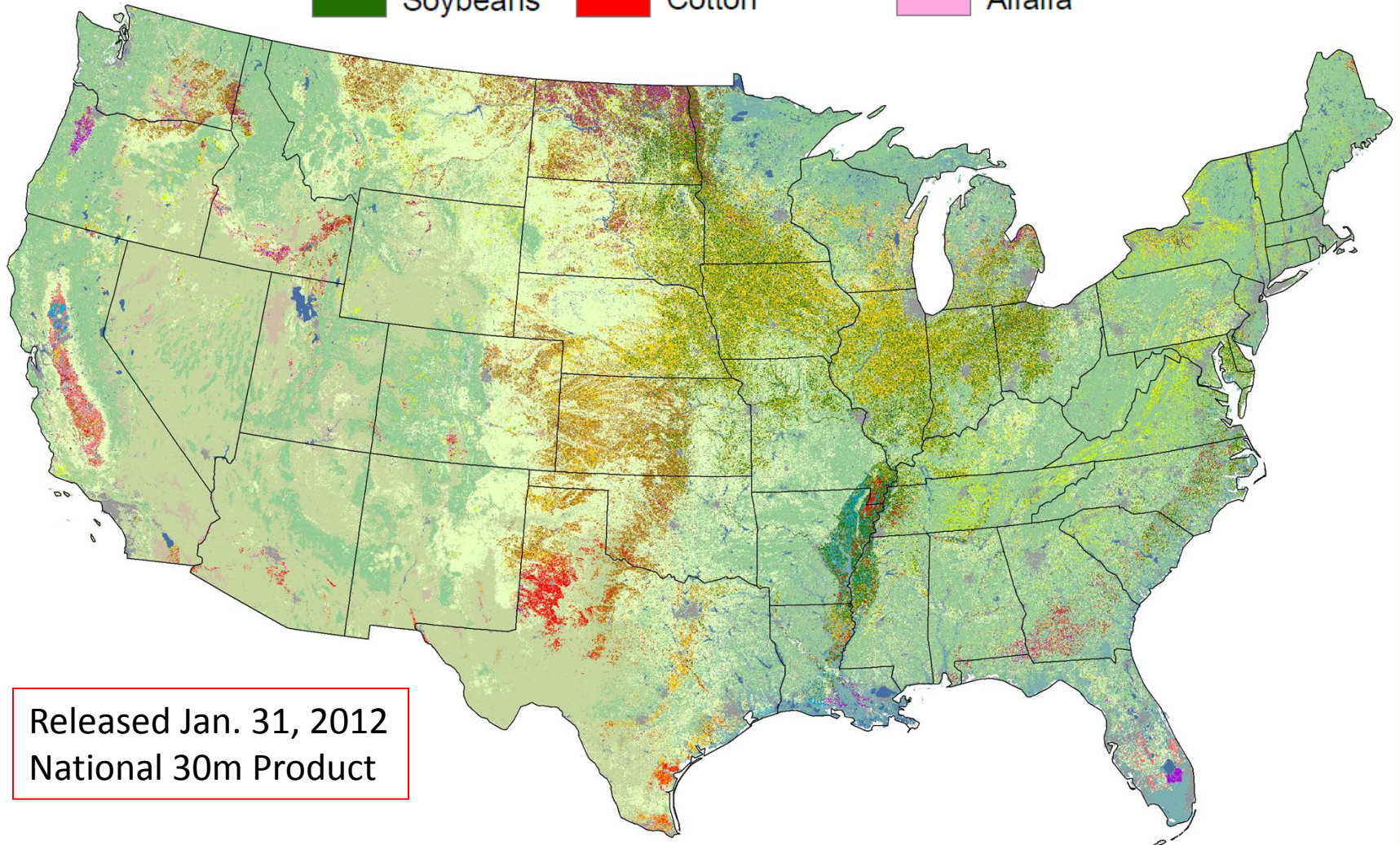


Remote Sensing Acreage Estimation Program Objectives

- “Census by Satellite”
 - Without area duplication
 - Major corn and soybean regions
- Provide timely, accurate, useful independent estimates
 - Measurable error
 - County and state level
- Public domain crop specific crop classification
 - <http://nassgeodata.gmu.edu/CropScape>
 - [NRCS Geospatial Data Gateway](#)
 - <http://www.nass.usda.gov/research/Cropland/SARS1a.htm>
 - Google CropScape!

What is the Cropland Data Layer (CDL)?

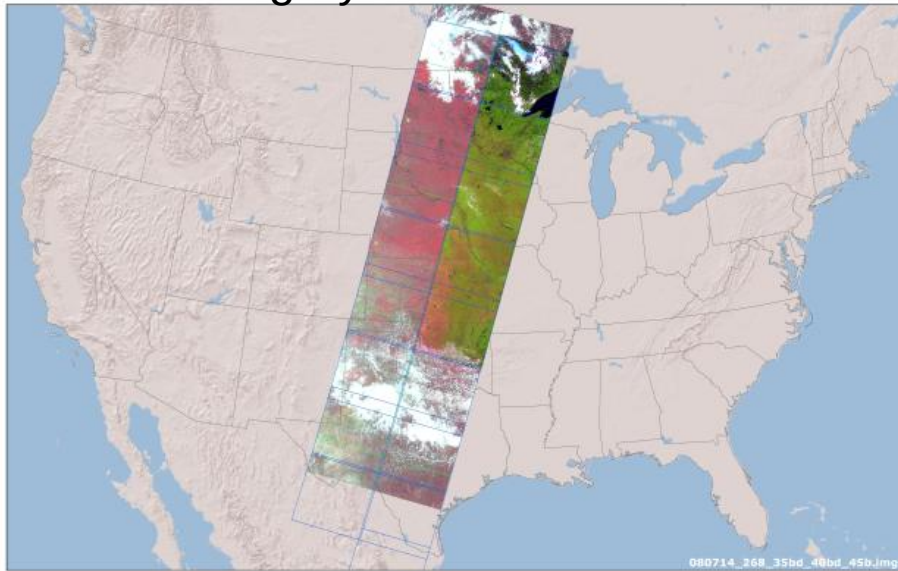
The Cropland Data Layer product is a raster-formatted, geo-referenced, crop specific, land cover map.



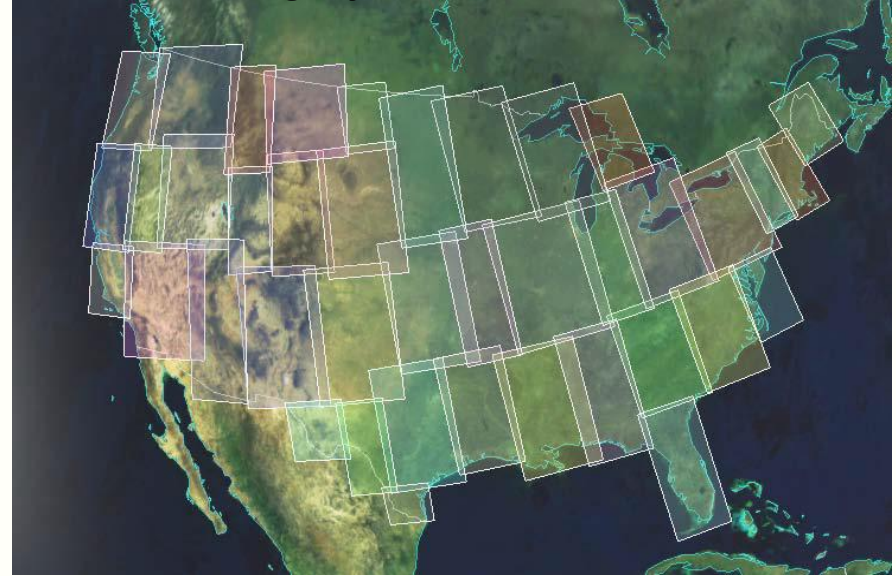
Released Jan. 31, 2012
National 30m Product

2011 Cropland Data Layer Inputs

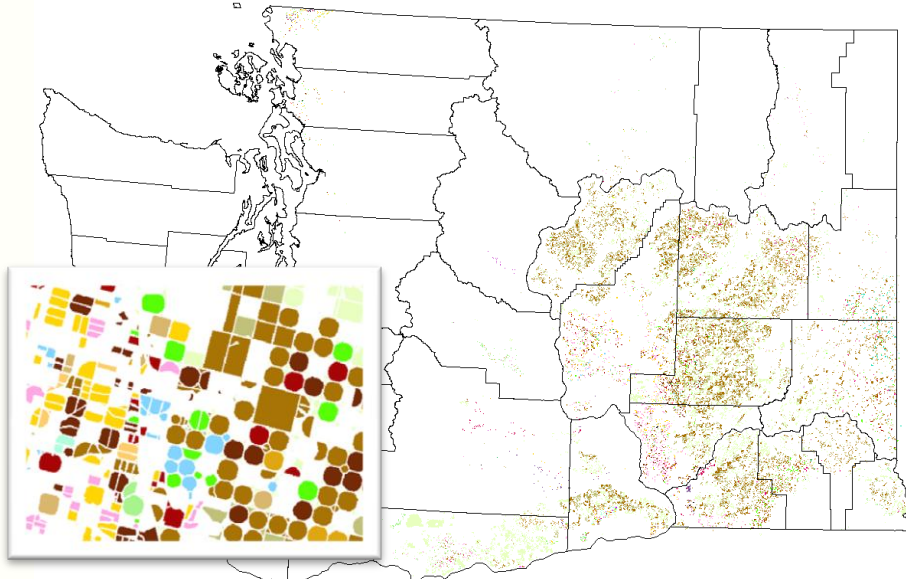
Satellite Imagery – Landsat



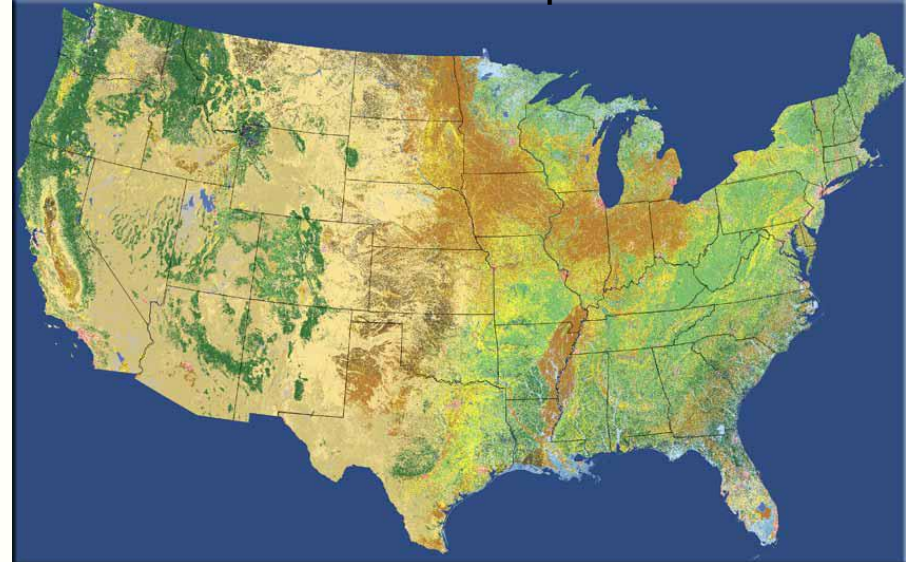
Satellite Imagery – Deimos & UK2



Farm Service Agency: Common Land Unit



2006 NLCD & Derivative products

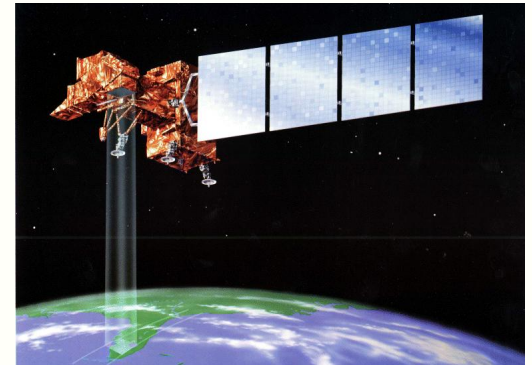


Landsat Imagery 1997-2012

Landsat 5 launched 1984 (3 yr design life!)

– Thematic Mapper (TM) Sensor

Landsat 7 launched 1999 Thematic Mapper (ETM+) Sensor



The Landsat Data Gap

Landsat 7 ETM+



Landsat 5 TM



News Release

November 30, 2005 Ron Beck

Landsat 5 Experiencing Technical Difficulties

On November 26, 2005, the back-up solar array drive on Landsat 5 began exhibiting unusual behavior. The solar array drive maintains the proper pointing angle between the solar array and the sun. The rotation of the solar array drive became sporadic and the solar array was not able to provide the power needed to charge the batteries. Maintaining power to the batteries is critical to sustain proper operation of the spacecraft. The primary solar array drive failed under similar circumstances last January. As a result of this current situation, imaging operations will be suspended for at least the next two weeks or until attempts to solve the problem have been resolved.

Source: USGS, Landsat Project:

http://landsat.usgs.gov/slc_enhancements/slc_off_level1_standard.php

Deimos and UK2 Micro Satellites

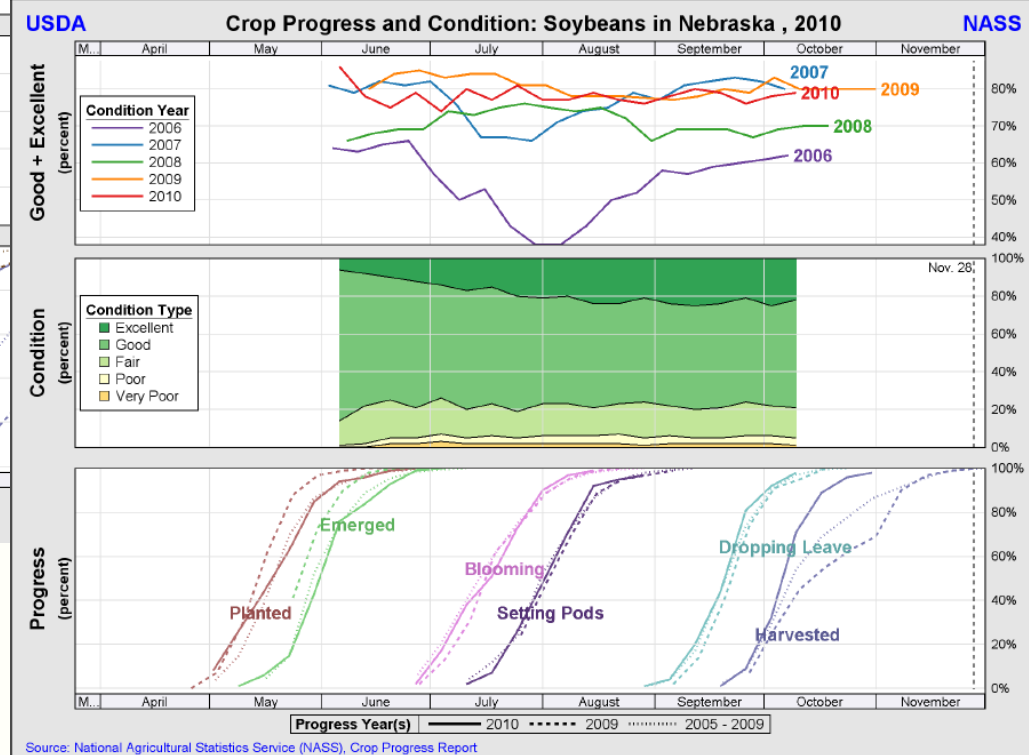
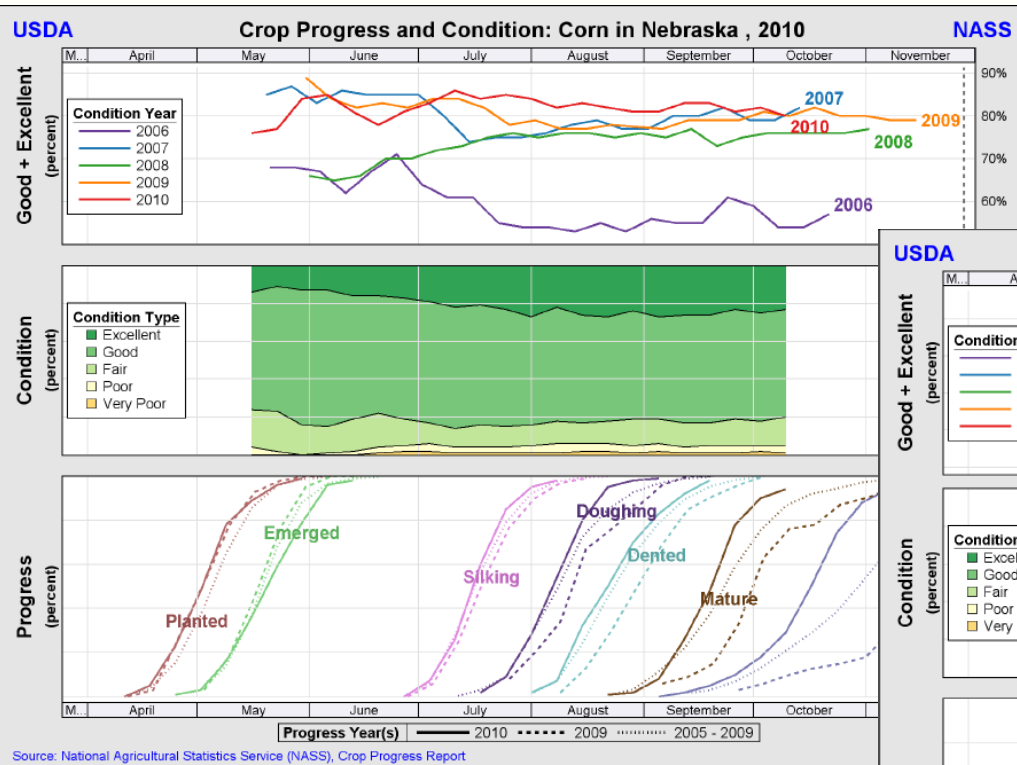
(22-metre, multi-spectral DMC imager
600km imaging swath)



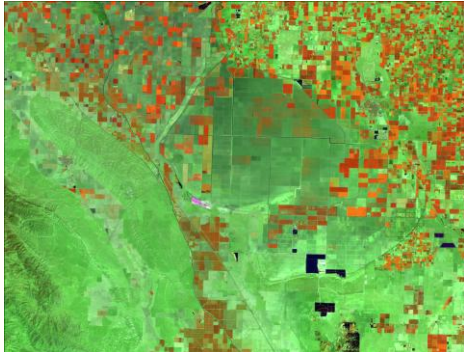
Sensor Specifications Compared

	<u>TM</u>	<u>Deimos/UK2</u>
Launch Date	1984	2009
Altitude	705 km	686 km
Temporal Resolution	16 days	4 days
Spatial Resolution	30 x 30 m (reflective) 120 x 120 m (thermal)	22 x 22 m (reflective)
Radiometric Resolution	8 bit (256)	10 bit (1024)
Spectral Resolution	6 (B, G, R, NIR, SWIR, MIR) + Thermal IR	3 (G, R, NIR)
Swath wide	185 km	600 km

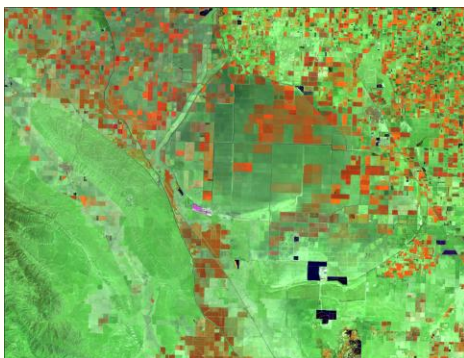
Image Timing



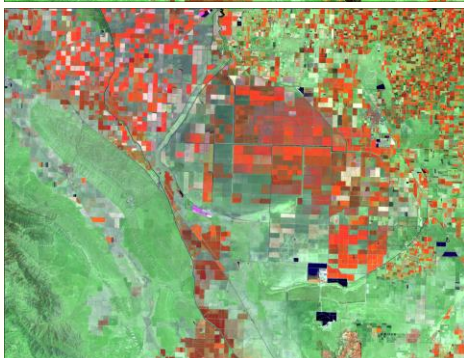
April



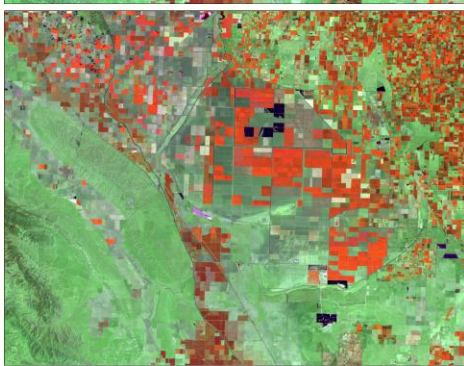
May



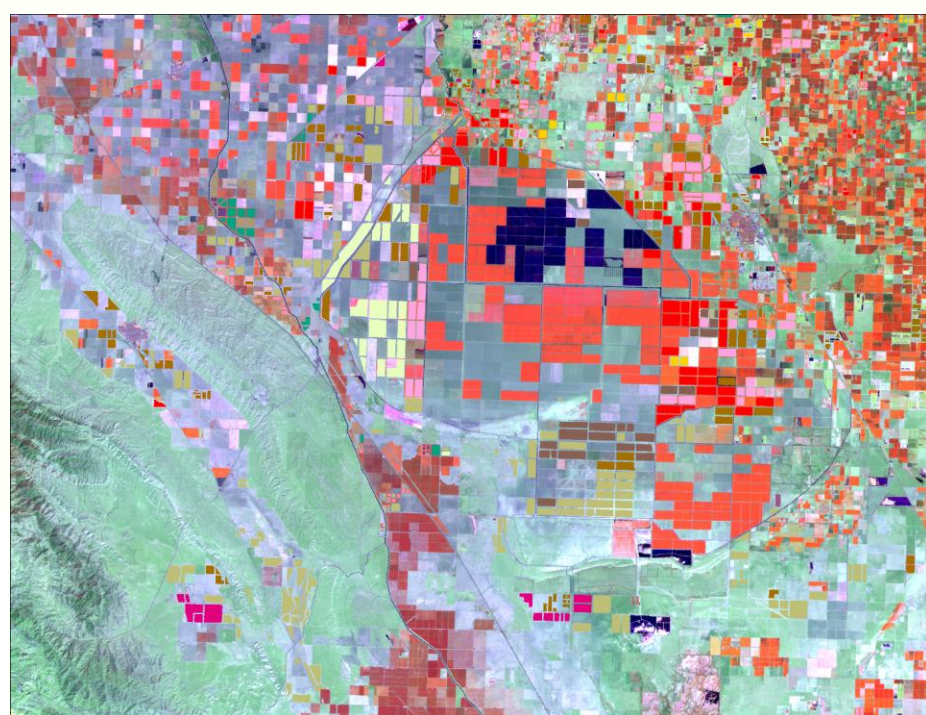
June



July



August
with farm
data

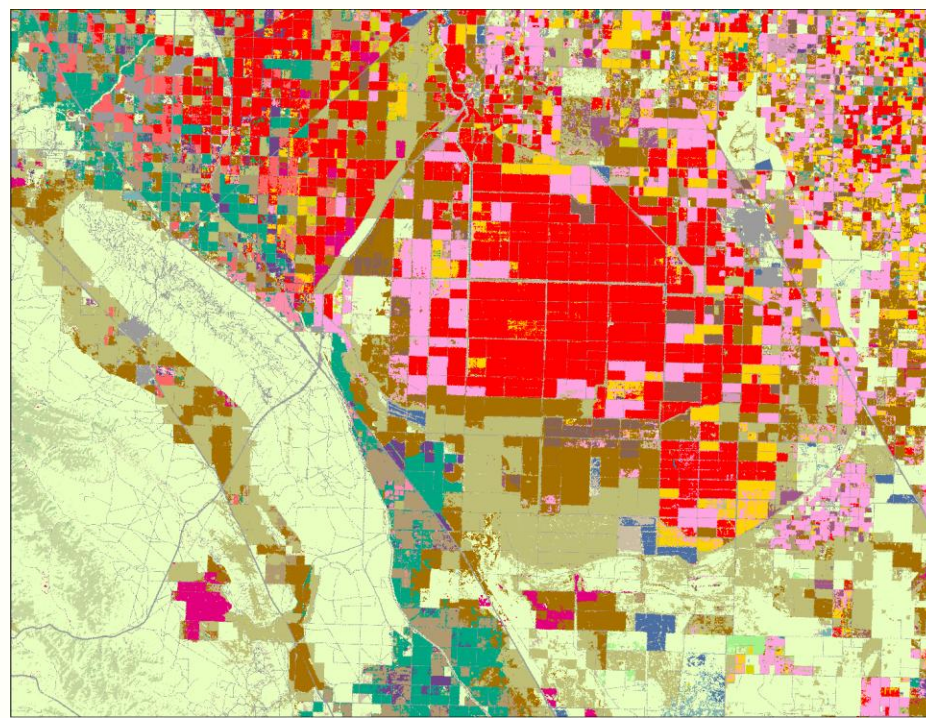


Land Cover Categories

Agriculture

- Pasture/Grass
- Alfalfa
- Fallow/Idle Cropland
- Winter Wheat
- Barley
- Cotton
- Almonds
- Corn
- Durum Wheat

Final
CDL



Cropland Data Layer Program Components



- Satellite Imagery : Landsat TM, Deimos and UK2 data
- Ground truth: FSA/CLU + 578 & NLCD
- Ancillary data sets
- Commercial Software Suite
- See5 Decision Tree Methodology
- Estimation
- CropScape

Ground Truth – Land Cover

Agriculture Ground Truth

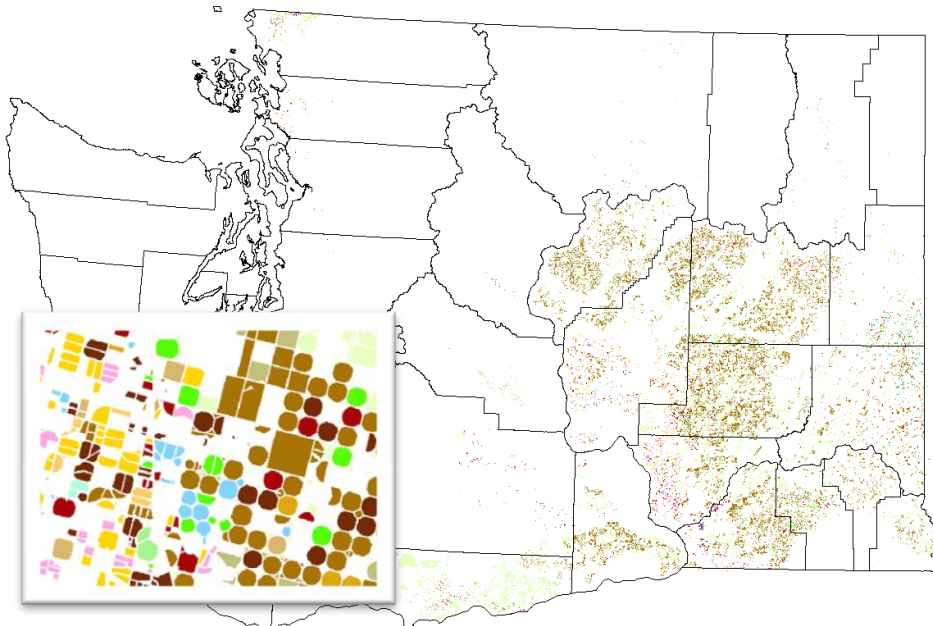
Provided by Farm Service Agency

Identifies known fields and crops

Divide known fields into 2 sets

70% used for training software

30% used for validating results



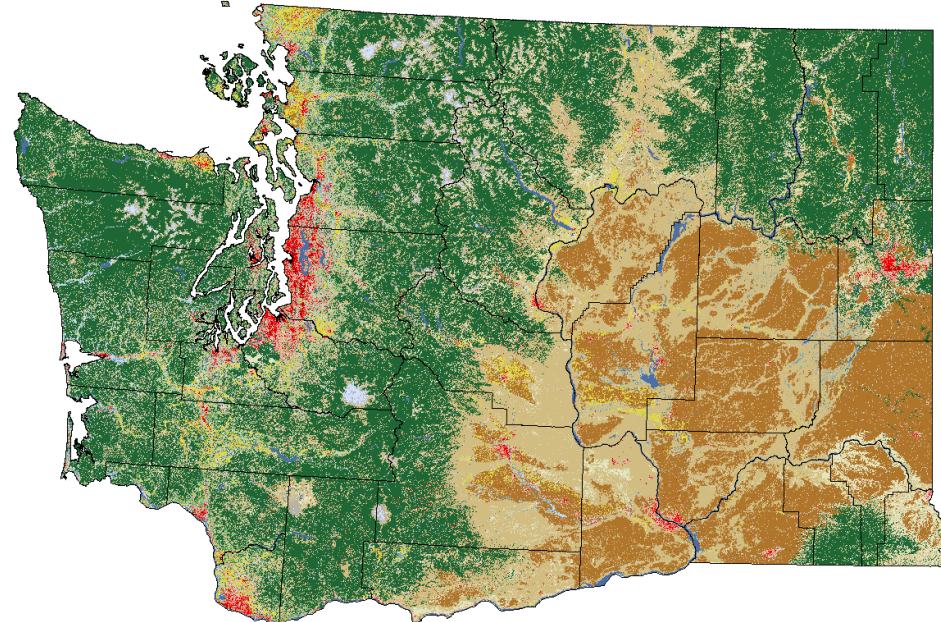
Non-Agriculture Ground Truth

USGS National Land Cover

Dataset

Identifies urban infrastructure and
non-agriculture land cover

Forest, grass, water, cities

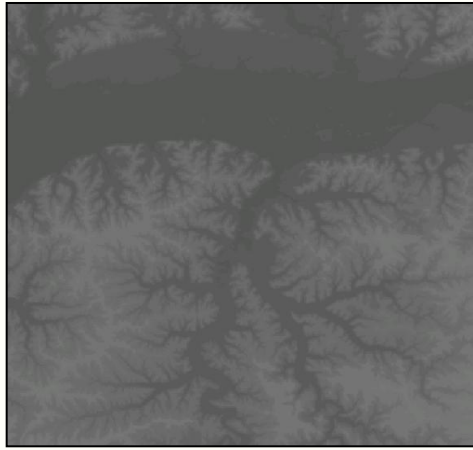


Cropland Data Layer Program Components

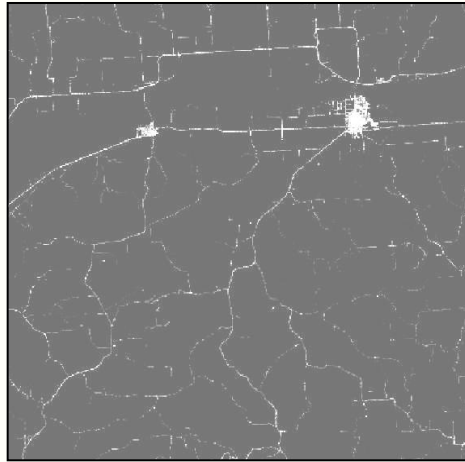


- Satellite Imagery: Landsat TM and Deimos and UK2 data
- Ground truth: FSA/CLU + 578 & NLCD
- Ancillary data
- Commercial Software Suite
- See5 Decision Tree Methodology
- Estimation
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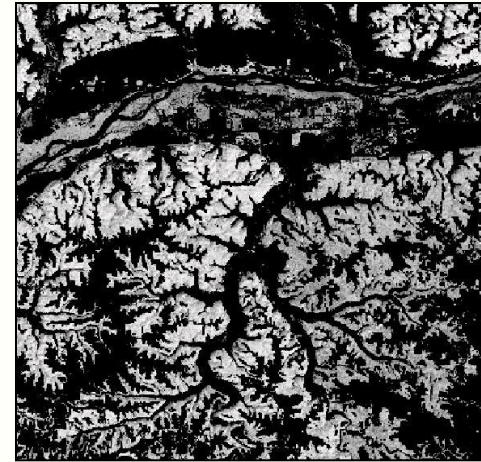
Ancillary Data – USGS/NASA Products



Elevation

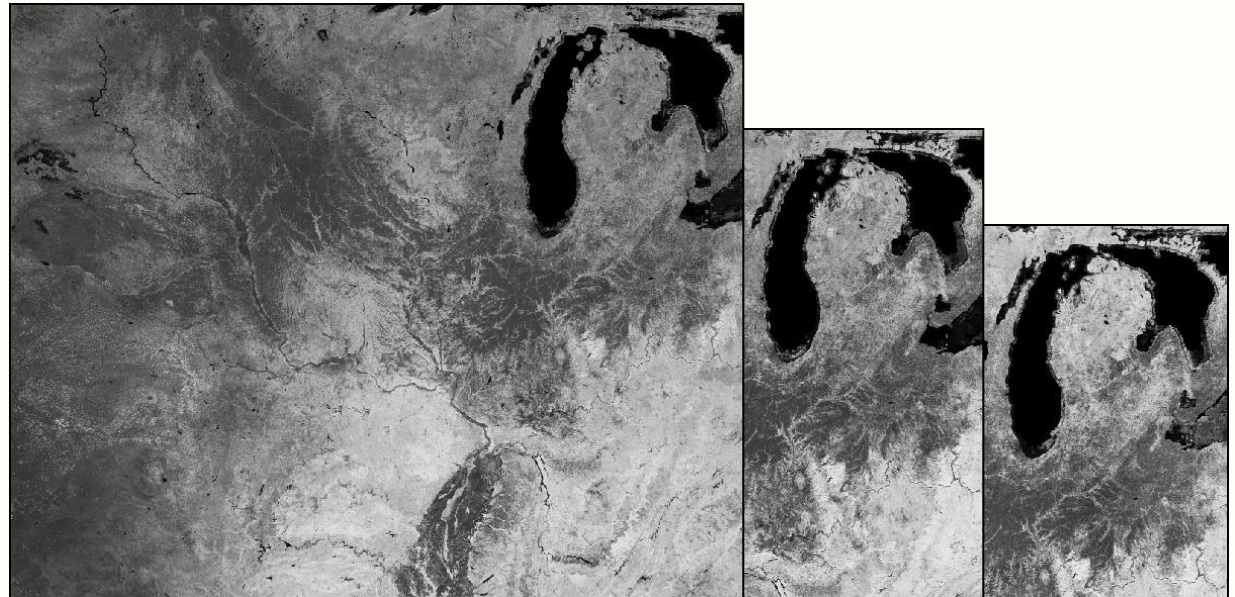


Imperviousness



Forest Canopy

NASA MODIS Terra
(16-day NDVI composite)



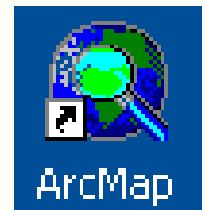
Cropland Data Layer Program Components

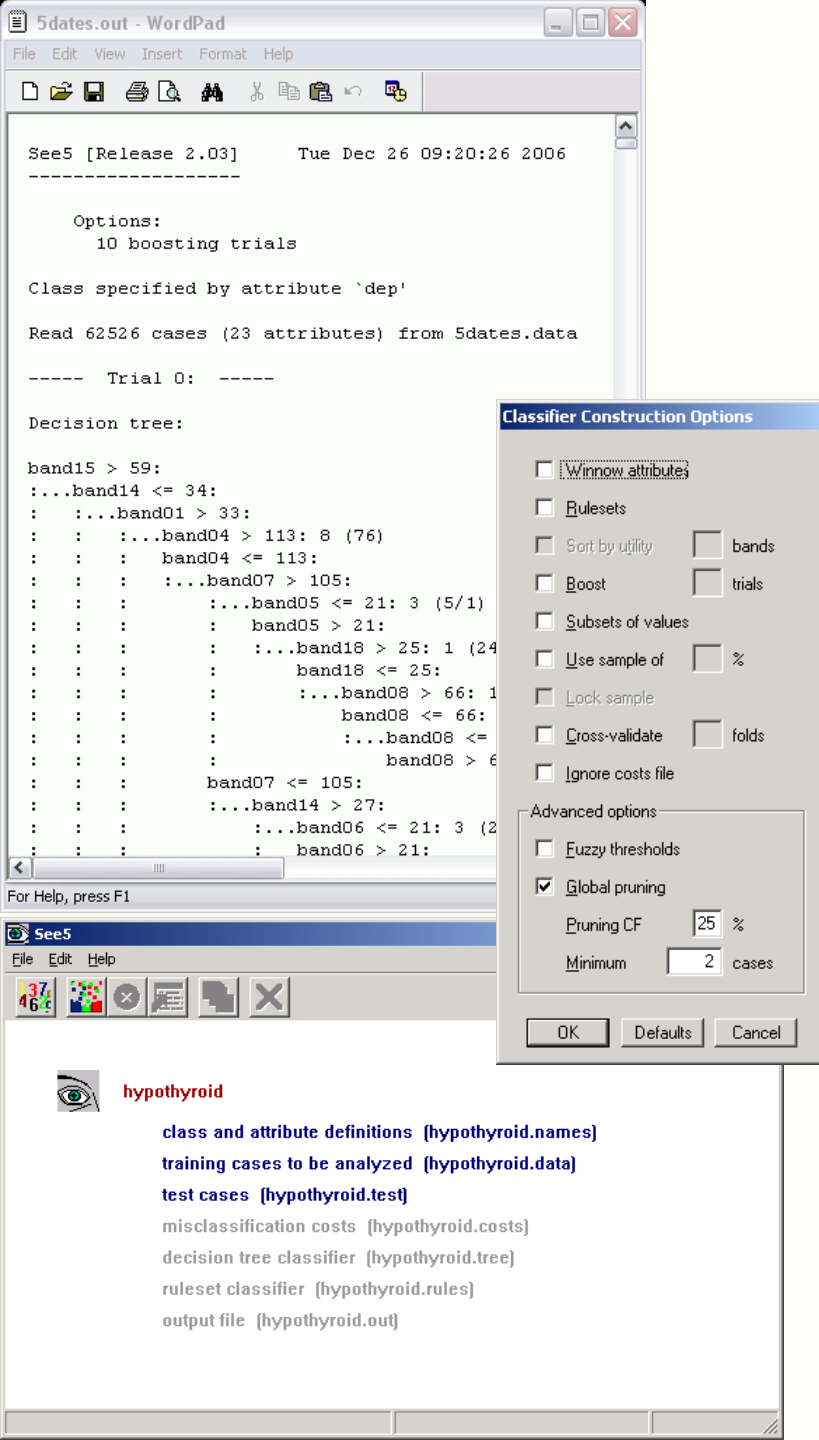


- Satellite Imagery: Landsat TM , Deimos and UK2 data
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Commercial Software Suite

- Imagery Preparation
 - Leica Geosystems ERDAS Imagine
- Image classification
 - Decision tree software
 - See5.0 www.rulequest.com
- Ground Truth Preparation
 - ESRI ArcGIS
- Acreage Estimation
 - SAS/IML workshop





See5 Decision Tree Classifier

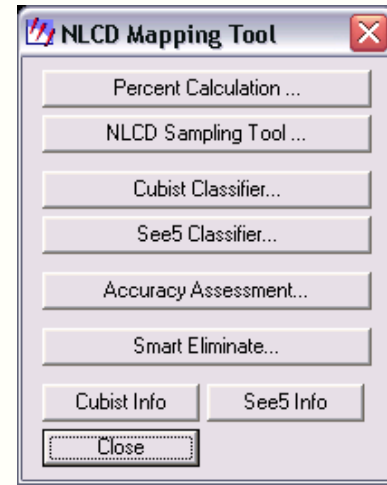
State-of-the-art technique for image classification

- Relatively cheap (\$750)

Incorporates a powerful ensemble method known as “boosting”

The “NLCD Mapping Tool” was integrated into ERDAS Imagine

- Provided gratis by USGS



**RULEQUEST
RESEARCH**
data mining tools

Accuracy Assessments

Crop-specific covers only	*Correct	Accuracy	Error	Kappa
OVERALL ACCURACY	740009	93.56%	6.44%	0.8488

Cover Type	Attribute Code	*Correct Pixels	Producer's Accuracy	Omission Error	Kappa	User's Accuracy	Commission Error	Cond'l Kappa
Corn	1	28358	95.36%	4.64%	0.9528	93.08%	6.92%	0.9297
Cotton	2	11757	95.08%	4.92%	0.9505	94.59%	5.41%	0.9456
Rice	3	2	28.57%	71.43%	0.2857	66.67%	33.33%	0.6667
Sorghum	4	21251	89.85%	10.15%	0.8972	92.46%	7.54%	0.9236
Soybeans	5	12885	86.15%	13.85%	0.8604	88.61%	11.39%	0.8851
Sunflowers	6	102	89.47%	10.53%	0.8947	99.03%	0.97%	0.9903
Peanuts	10	512	90.14%	9.86%	0.9014	92.09%	7.91%	0.9208
Barley	21	785	71.95%	28.05%	0.7194	97.39%	2.61%	0.9739
Durum Wheat	22	48	42.86%	57.14%	0.4286	100.00%	0.00%	1.0000
Spring Wheat	23	205	56.47%	43.53%	0.5647	99.03%	0.97%	0.9903
Winter Wheat	24	580437	97.54%	2.46%	0.9631	94.00%	6.00%	0.9117
Other Small Grains	25	1120	56.97%	43.03%	0.5694	93.57%	6.43%	0.9356
Win Wht /Soyb Dbl Crop	26	14758	79.51%	20.49%	0.7932	90.06%	9.94%	0.8996
Rye	27	13249	66.90%	33.10%	0.6664	91.39%	8.61%	0.9129
Oats	28	2941	64.85%	35.15%	0.6479	95.18%	4.82%	0.9517
Millet	29	439	77.02%	22.98%	0.7701	96.48%	3.52%	0.9648
Canola	31	337	75.90%	24.10%	0.7590	98.83%	1.17%	0.9883
Alfalfa	36	19653	88.21%	11.79%	0.8807	91.78%	8.22%	0.9168
Dry Beans	42	115	88.46%	11.54%	0.8846	93.50%	6.50%	0.9350
Potatoes	43	49	96.08%	3.92%	0.9608	100.00%	0.00%	1.0000
Other Crops	44	50	45.87%	54.13%	0.4587	80.65%	19.35%	0.8064
Misc Veggies & Fruits	47	33	54.10%	45.90%	0.5410	86.84%	13.16%	0.8684
Watermelon	48	24	77.42%	22.58%	0.7742	85.71%	14.29%	0.8571
Peas	53	188	72.59%	27.41%	0.7258	96.91%	3.09%	0.9691
Clover/Wildflowers	58	21	36.21%	63.79%	0.3621	75.00%	25.00%	0.7500
Fallow/Idle Cropland	61	30612	69.78%	30.22%	0.6922	90.48%	9.52%	0.9025
Peaches	67	9	36.00%	64.00%	0.3600	100.00%	0.00%	1.0000
Other Tree Nuts & Fruit	71	69	33.82%	66.18%	0.3382	83.13%	16.87%	0.8313

*Correct Pixels represents the total number of independent validation pixels correctly identified in the error matrix.

Accuracy Assessments

	Cover Type	Attribute Code	*Correct Pixels	Producer's Accuracy	Omission Error	Kappa	User's Accuracy	Commission Error	Cond'l Kappa
IA	Corn	1	2197719	96.58%	3.42%	0.9226	97.86%	2.14%	0.9509
	Soybeans	5	1471094	96.24%	3.76%	0.9392	95.78%	4.22%	0.9320
IL	Corn	1	2258219	98.06%	1.94%	0.9527	98.58%	1.42%	0.9650
	Soybeans	5	1339089	96.36%	3.64%	0.9438	97.96%	2.04%	0.9681
NE	Corn	1	1856422	97.29%	2.71%	0.9605	97.32%	2.68%	0.9608
	Soybeans	5	849249	95.83%	4.17%	0.9513	96.95%	3.05%	0.9643
SD	Corn	1	803251	94.29%	5.71%	0.9342	95.78%	4.22%	0.9513
	Soybeans	5	707383	95.03%	4.97%	0.9439	97.72%	2.28%	0.9741

	Crop-specific covers only	*Correct	Accuracy	Error	Kappa
IA	OVERALL ACCURACY	3688803	95.74%	4.26%	0.9145
IL	OVERALL ACCURACY	3730093	97.05%	2.95%	0.9426
NE	OVERALL ACCURACY	3071960	94.05%	5.95%	0.8981
SD	OVERALL ACCURACY	2306428	87.51%	12.49%	0.8416

State level accuracies
are very high

Producer's Accuracy: relates to the probability that a ground truth pixel will be correctly mapped and measures errors of omission.

Errors of Omission: occur when a pixel is excluded from the correct category.

User's Accuracy: indicates the probability that a pixel from the classification actually matches the ground truth data and measures errors of commission.

Errors of Commission: occur when a pixel is included in an incorrect category.

Kappa Coefficient: A statistics measure of agreement, beyond chance, between two maps.

Cropland Data Layer Program Components



- Satellite Imagery: Landsat TM, Deimos and UK2 data
- Ground truth: FSA/CLU + 578 & NLCD
- Ancillary data sets
- Commercial Software Suite
- See5 Decision Tree Methodology
- Estimation
- CropScape

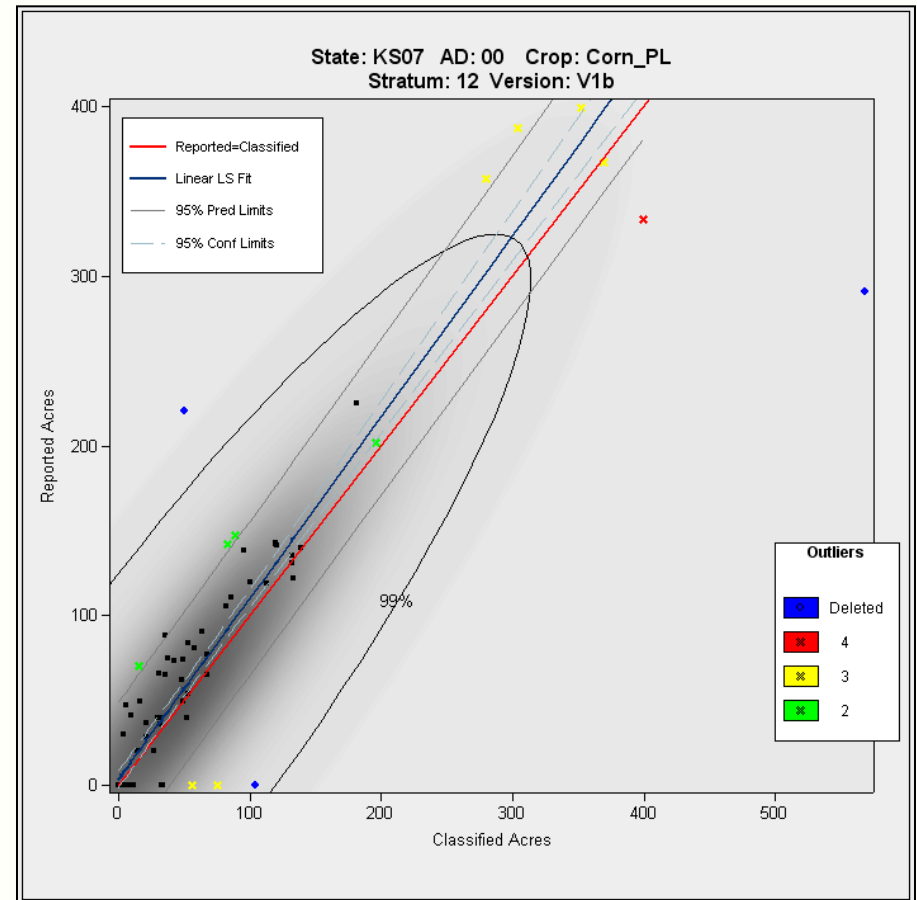
Regression-based Acreage Estimator

Regression used to relate categorized pixel counts to the ground reference data

- (X) – Cropland Data Layer (CDL) classified acres
- (Y) – June Agricultural Survey (JAS) reported acres

Using both CDL and JAS acreage results in estimates with reduced error rates over JAS alone

Outlier segment detection - removal from regression analysis



Acreage not just about counting pixels

January

Su Mo Tu We Th Fr Sa
1 2 3 4 5

February

Su Mo Tu We Th Fr Sa
1 2

March

Su Mo Tu We Th Fr Sa
1

CDL Production Schedule

8:● 15:○ 22:○ 30:○

6:● 13:○ 20:○ 28:○

7:● 14:○ 21:○ 29:○

April

Su Mo Tu We Th Fr Sa
1 2 3 4 5
6 7 8 9 10 11 12
13 14 15 16 17 18 19
20 21 22 23 24 25 26
27 28 29 30

5:● 12:○ 20:○ 28:○

May

Su Mo Tu We Th Fr Sa
1 2 3
4 5 6 7 8 9 10
11 12 13 14 15 16 17
18 19 20 21 22 23 24
25 26 27 28 29 30 31

5:● 11:○ 19:○ 27:○

June

Su Mo Tu We Th Fr Sa
1 2 3 4 5 6 7
8 9 10 11 12 13 14
15 16 17 18 19 20 21
22 23 24
29 30

3:● 10:○

Crop Acreage Report
CDL winter wheat

July

Su Mo Tu We Th Fr Sa
1 2 3 4 5

Crop Production Report
CDL all crops

2:● 10:○ 18:○ 25:○

August

Su Mo Tu We Th Fr Sa
1 2
3 4 5 6 7 8 9
10 11 12 13 14 15 16
17 18 19 20 21 22 23
24 25 26 27 28 29 30

1:● 8:○ 16:○ 23:○ 30:○

September

Su Mo Tu We Th Fr Sa
1 2 3 4 5 6
7 8 9 10 11 12 13
14 15 16 17 18 19 20
21 22 23 24 25 26 27
28 29 30

7:○

Small Grains Annual Summary
CDL small grains

October

Su Mo Tu We Th Fr Sa

Crop Production Repo:
CDL all crops

Historical:

Crop Production Annual Summary

CDL all crops/county estimates

November

Su Mo Tu We Th Fr Sa

Su Mo Tu We Th Fr Sa

3 4 5 6

0 11 12 13

7 18 19 20

4 25 26 27

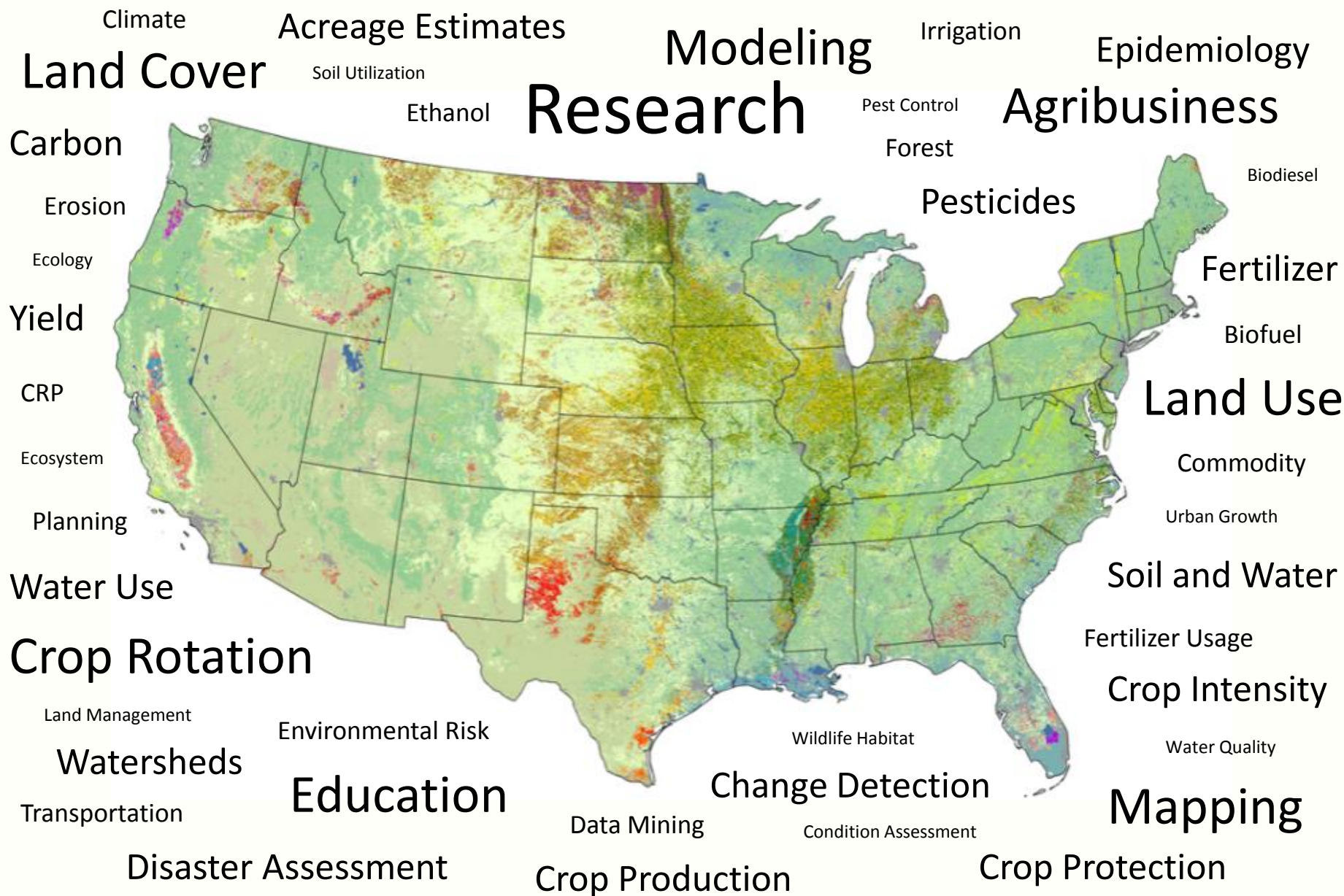
1

7:○ 14:○ 21:○ 28:○

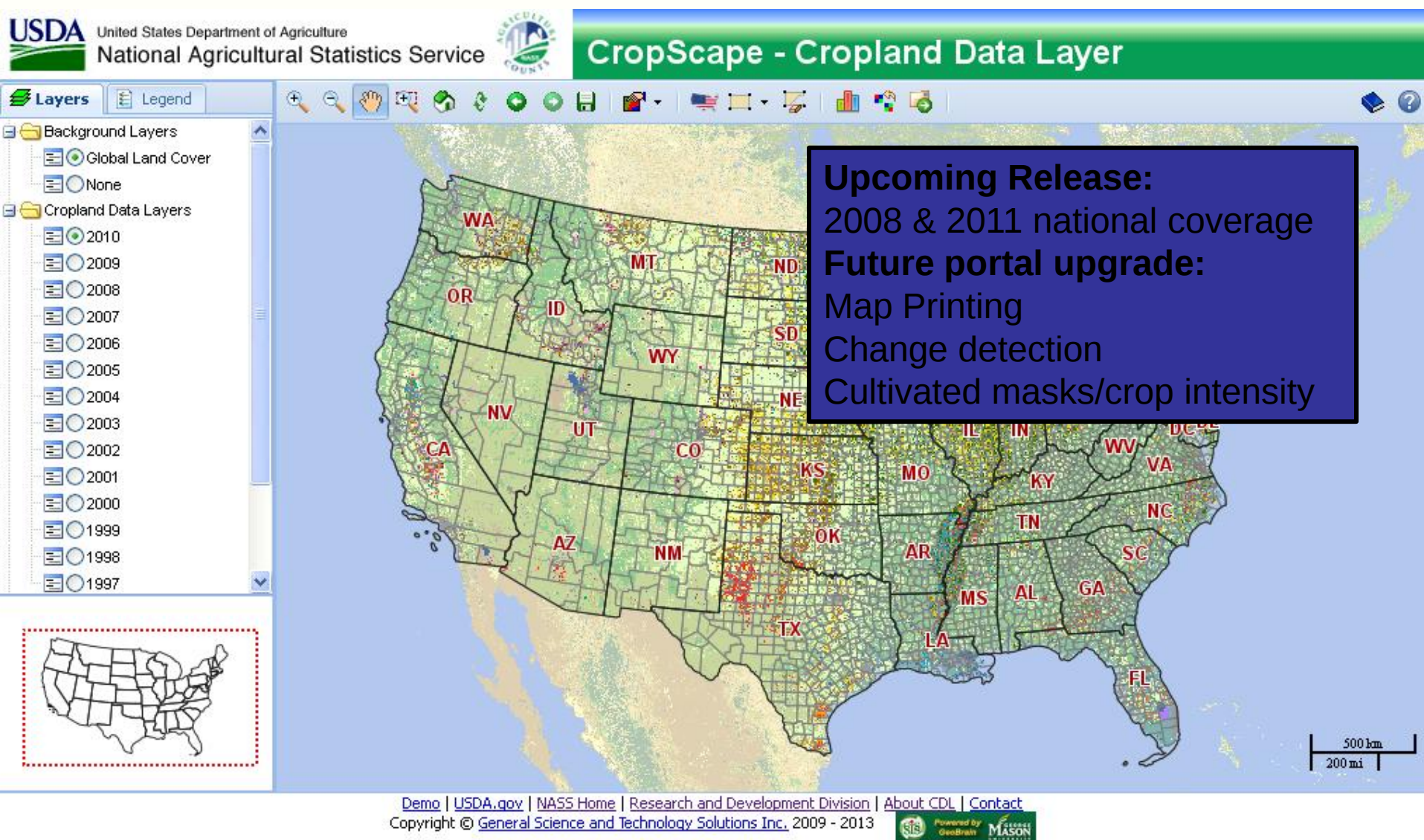
5:○ 13:○ 19:○ 27:○

5:○ 12:○ 19:○ 27:○

NASS Cropland Data Layer Applications

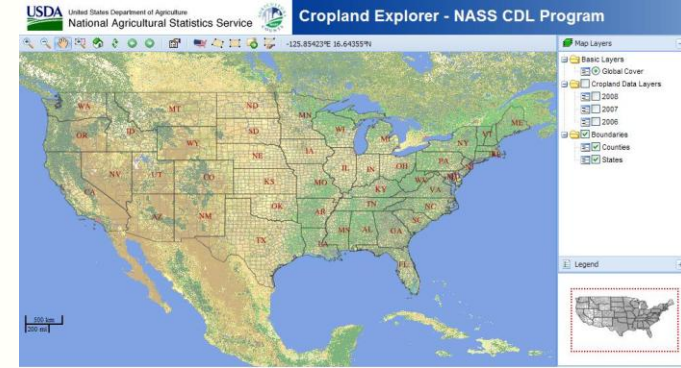


CropScape Portal



nassgeodata.gmu.edu/CropScape

CropScape



- CropScape web portal
- A web service based interactive map visualization, dissemination and querying system for U.S. cropland
 - No burden on users
 - No client software development & installation
 - No special software tools needed
 - Equitable cropland information access, automatic and timely delivery, geospatial navigation, retrieval, queries and dissemination
- Collaboration with George Mason University/ Center for Spatial Information Science and Systems

CropScape Cont.

- State of the art CDL visualization, querying and dissemination tool
- Interactive geospatial statistical analysis tools
 - Online/interactive analytics, charting and mapping
 - Geospatial information access, navigation
 - CDL map and statistical result retrieval and dissemination web services
- Open geospatial standards compliant

CropScape Portal Defined

Visual Tools

Point Query

Stats/Change/Download

Layer/Legend

AOI Query



Map Overview

Layers **Legend**

Background Layers

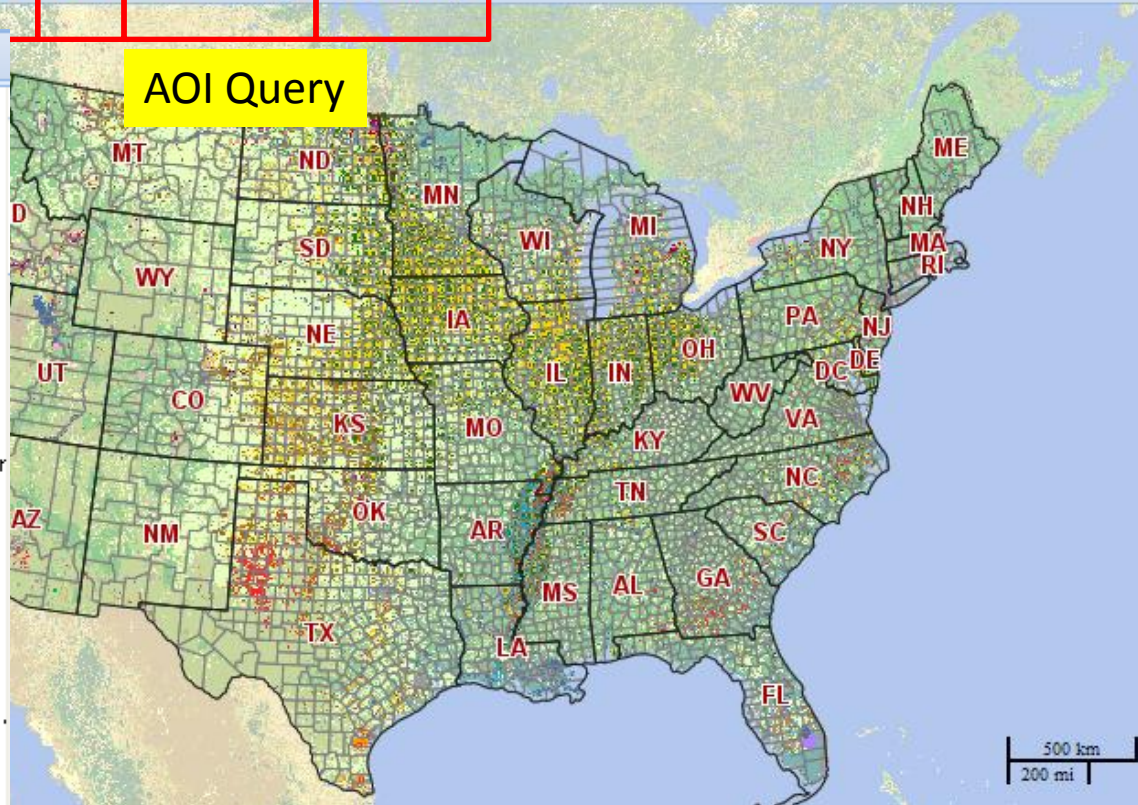
- Global Land Cover
- None

Cropland Data Layers

- 2010
- 2009
- 2008
- 2007
- 2006
- 2005
- 2004
- 2003
- 2002
- 2001
- 2000
- 1999

Cropland Data Layer:

- Corn
- Cotton
- Rice
- Sorghum
- Soybeans
- Tobacco
- Sweet Corn
- Popcorn or Ornamental Corn
- Mint
- Barley
- Durum Wheat
- Spring Wheat
- Winter Wheat
- Other Small Grains
- Winter Wheat/Soybeans Dbl.
- Rye
- Oats
- Millet
- Speltz
- Canola
- Flaxseed
- Safflower
- Rape Seed



Select Area of Interest



Select a State

State:

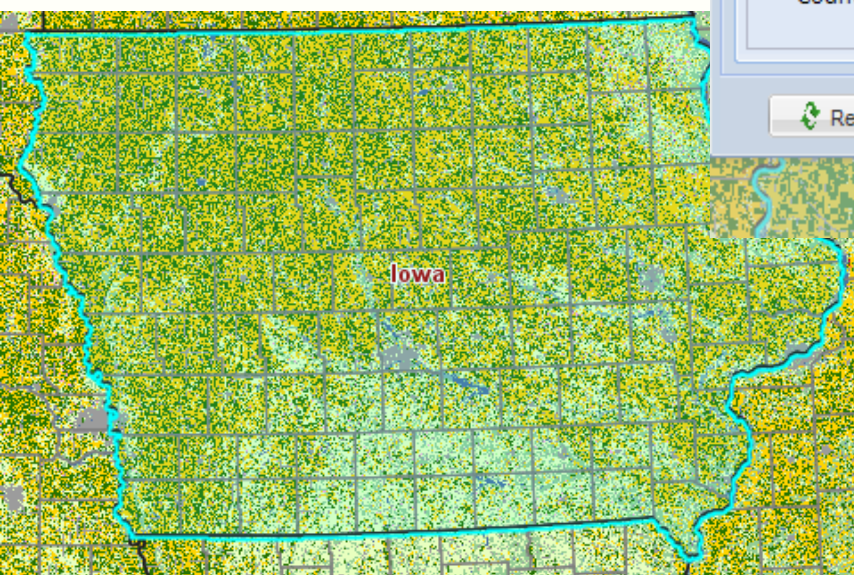
Select an ASD

ASD:

Or Select a County

County:

State



Define Area of Interest By State/ASD/County

Select a State

State:

Select an ASD

ASD:

Or Select a County

County:

ASD

Define Area of Interest By State/ASD/County

Select a State

State:

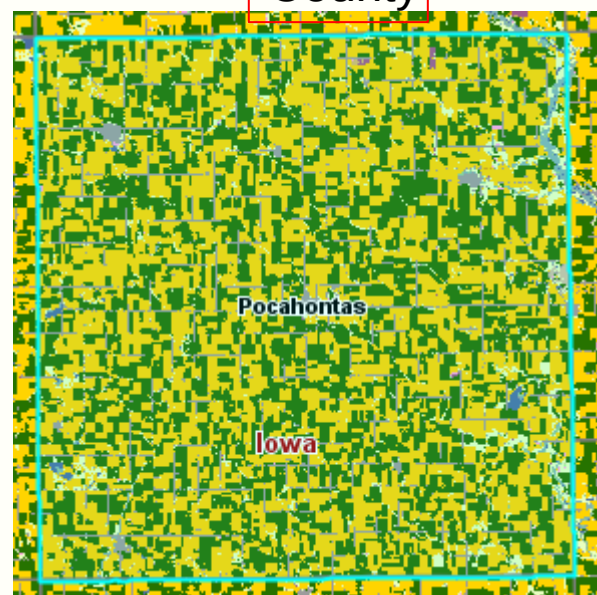
Select an ASD

ASD:

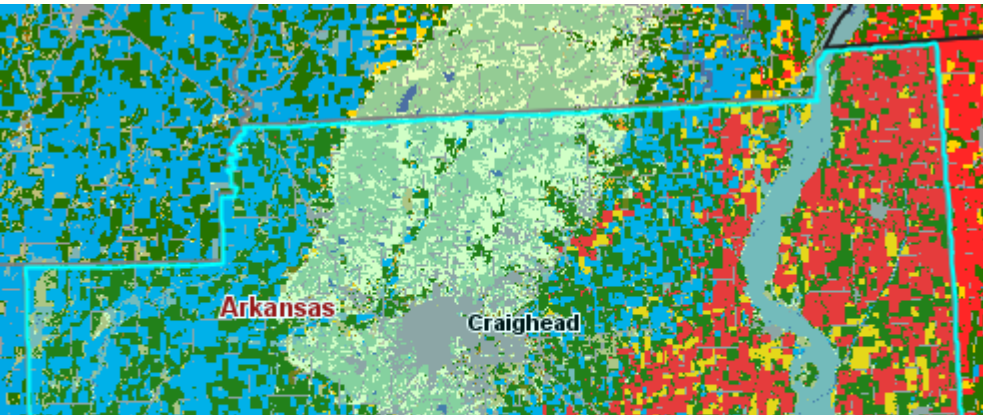
Or Select a County

County:

County



CropScape Change Analysis



Change Analysis

Select the Reference Year: 2009

Select the Other Year: 2008

Submit Cancel

Cropland Data Layer Changes between 2009 and 2008

Note: Pixel counts are not official estimates.

		Pixel Counts	Acreage
2009	2008		
Rice	Soybeans	133502	103453.6
Soybeans	Rice	129916	100674.7
Cotton	Cotton	120872	93666.3
Soybeans	Soybeans	106428	82473.4
NLCD - Developed/Open Space	NLCD - Developed/Open Space	85414	66189.2
NLCD - Woody Wetlands	NLCD - Woody Wetlands	83660	64830
NLCD - Deciduous Forest	NLCD - Deciduous Forest	73312	56811.1
Other Hays	Other Hays	61496	47654.6
Rice	Rice	39116	30311.8
		1177212	912239.6

CropScape Download & Export



CDL Downloading - Please specify your choice(s)

Select Year(s)

Year: ☒ 2010 ☒ 2009 ☒ 2008 ☒ 2007
☐ 2006 ☐ 2005 ☐ 2004 ☐ 2003
☐ 2002 ☐ 2001 ☐ 2000 ☐ 1999
☐ 1998 ☐ 1997

☒ Specify Projection

Projection: **USA Contiguous Albers Equal Area Conic USG**
USA Contiguous Albers Equal Area Conic USGS
Degrees Lat/Lon, WGS84 Datum
UTM Zone 15
UTM Zone 16
UTM Zone 14

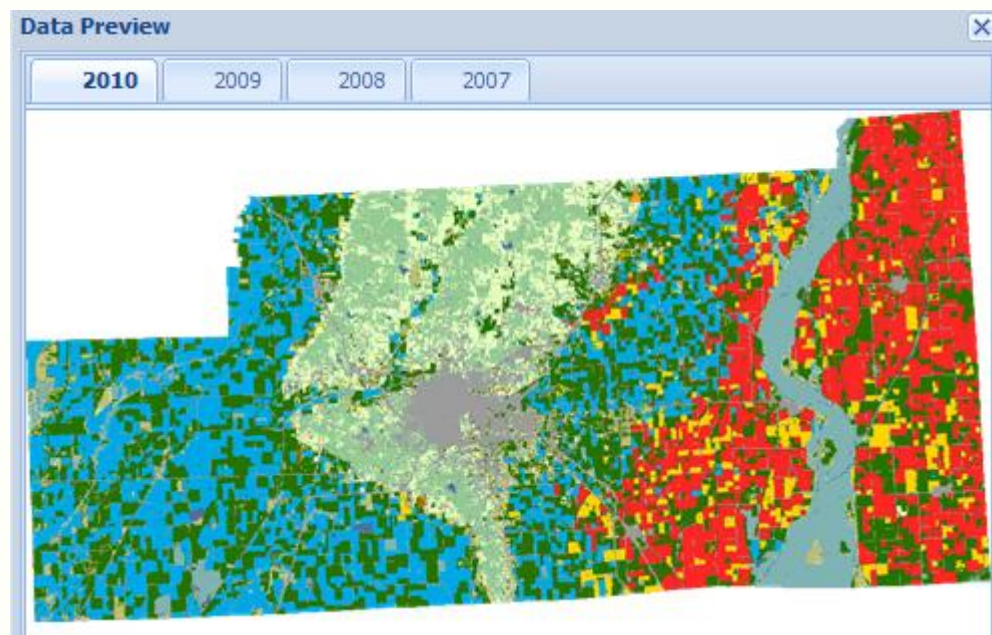
Specify Years and Projection

Download Files from Server

http://129.174.131.228/nass_data_cache/polygonclip_201101180

Download Preview Export as KML

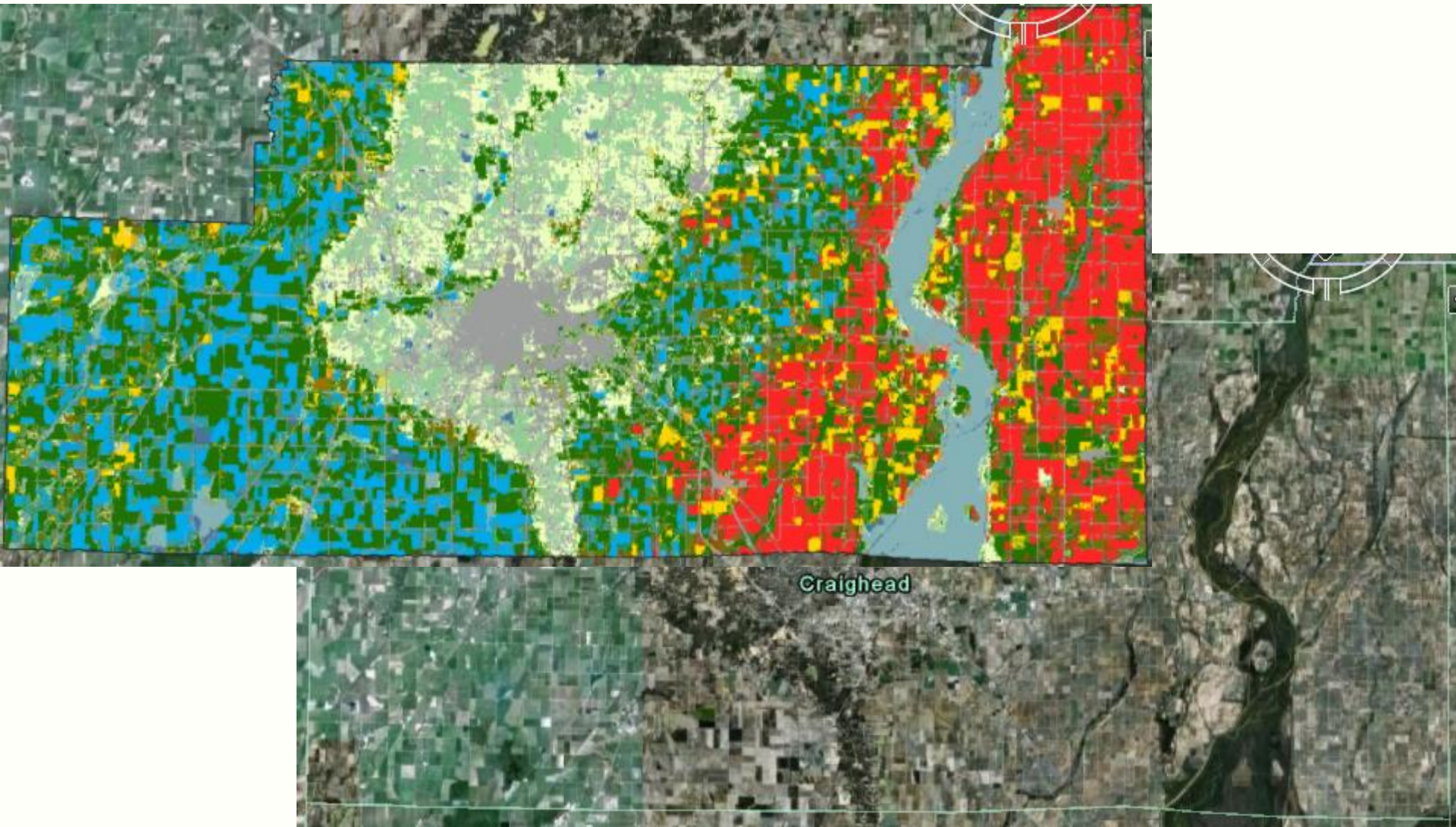
Preview and Download



nassgeodata.gmu/CropScape



CropScape w/ Google Earth

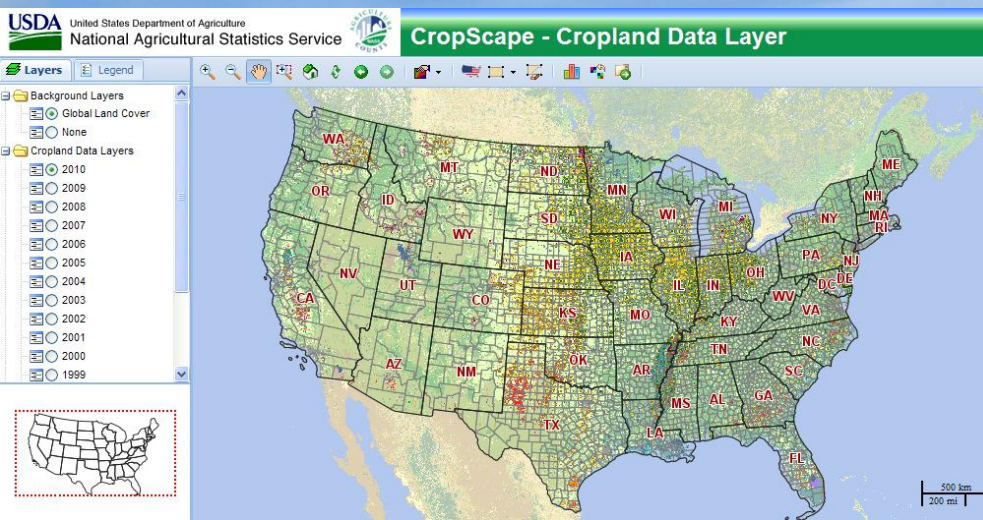


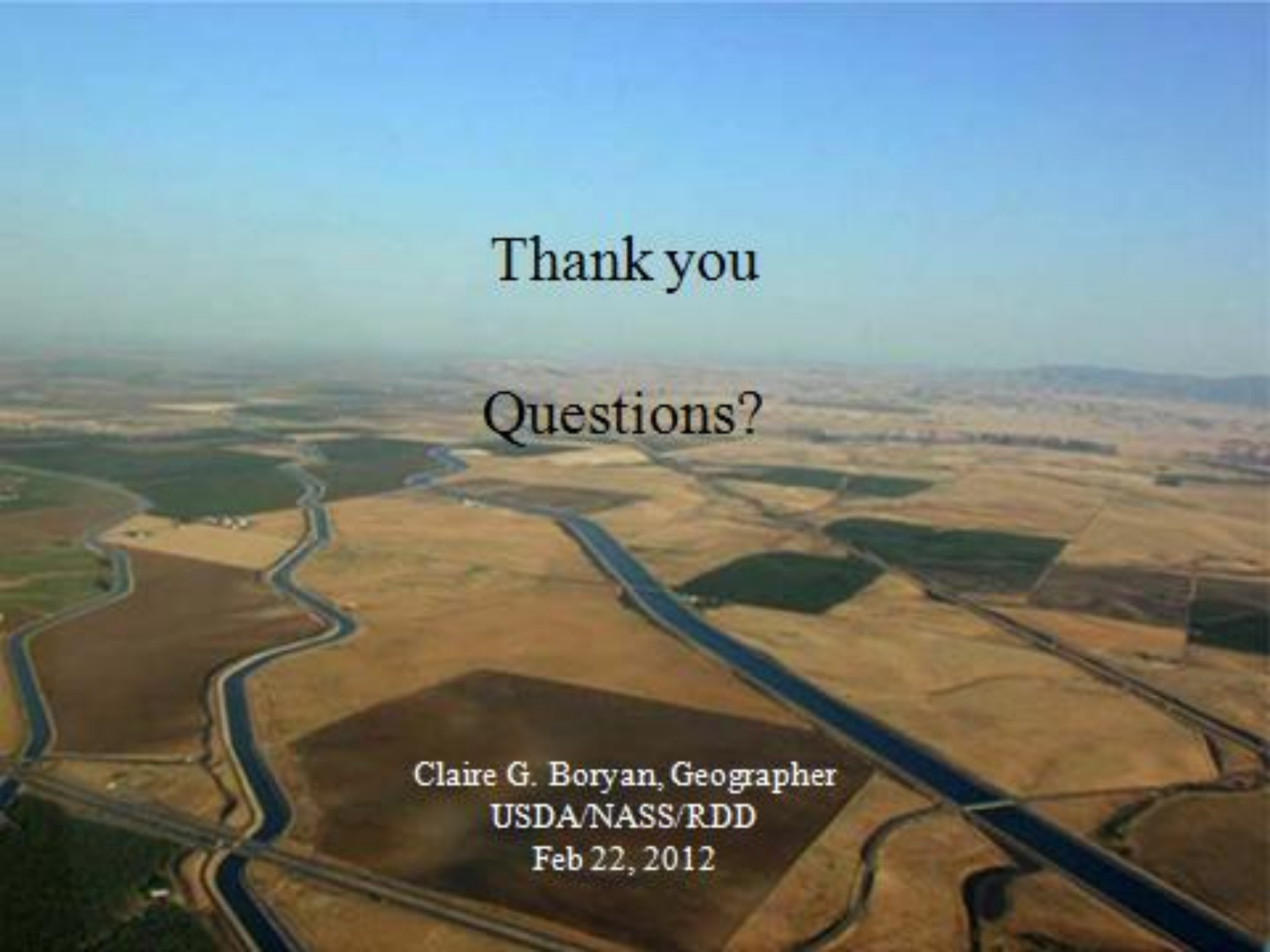
nassgeodata.gmu/CropScape



CDL Distribution

- <http://nassgeodata.gmu.edu/CropScape>
- <http://datagateway.nrcs.usda.gov>
- http://www.nass.usda.gov/Research_and_Science



An aerial photograph showing a wide river flowing through a landscape of agricultural fields. The fields are in various stages of cultivation, with some appearing brown and others green. The river is a prominent blue line winding through the terrain. In the background, a city skyline is visible under a clear blue sky.

Thank you

Questions?

Claire G. Boryan, Geographer
USDA/NASS/RDD
Feb 22, 2012

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H984A1
Agric. Hbk.
294

An aerial photograph of a landscape featuring a winding river or road that curves through fields. A library stamp is visible on the left side of the image, partially overlapping the river. The stamp reads: "LIBRARY RECEIVED DEC 2 1944 U. S. DEPARTMENT OF AGRICULTURE BETHLEHEM BRANCH".

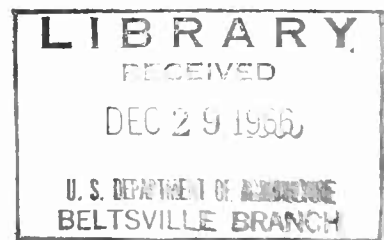
**AERIAL-PHOTO
INTERPRETATION
IN CLASSIFYING
AND MAPPING SOILS**

AGRICULTURE HANDBOOK 294
SOIL CONSERVATION SERVICE
U. S. DEPARTMENT OF AGRICULTURE

Aerial-Photo Interpretation

in Classifying and Mapping Soils

Prepared by
SOIL SCIENTISTS AND CARTOGRAPHERS
Soil Survey Staff
Soil Conservation Service



AGRICULTURE HANDBOOK 294
ISSUED OCTOBER 1966

SOIL CONSERVATION SERVICE • UNITED STATES DEPARTMENT OF AGRICULTURE

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 75 cents

FOREWORD

This manual has been prepared by staff cartographers and soil scientists primarily for soil scientists and others directly engaged in the national cooperative soil survey of the United States. Many of the principles may be helpful to others.

Perhaps the first use of aerial photographs for soil surveying of a whole county was in the soil survey of Jennings County, Indiana, about 1929. Since the middle 1930's soil surveying in the United States has been done on aerial photographs. This technique became available about the same time that the concept of a soil as a profile was extended to the concept of a soil as an individual, three-dimensional body on the surface of the earth.

The use of aerial photographs, first of all, makes possible increased accuracy in plotting the soil boundaries. Since the photographs show many more landscape features than ordinary planimetric maps or planetable sheets, the soil scientists have abundant control for plotting boundaries between soils identified in the field. The field soil scientist is also relieved of a large part of the job of plotting houses, roads, and other features required for users of soil maps. In fact, the features that can be seen clearly on the ground and on the photos serve as control, both for the soil scientist in the field and for the user of the soil maps.

Besides using photographs as a base on which to plot results of their field examinations, soil scientists have developed skill in interpreting photographs for clues to the kinds of soil and to the location of soil boundaries both before and during the field mapping. In low-intensity soil surveys they can make reasonable estimates of soil boundaries in areas between those examined in the field. The best reconnaissance soil surveys are made with aerial photographs. Such soil maps guide the establishment of priorities for the detailed soil surveys needed for operational planning. All these uses require high-quality photographs.

The replacement of planetable sheets by photographs as field sheets also increased the requirements of cartographic engineering skill for accurate compilation. The greater accuracy and the saving of the time of soil scientists more than compensate for the exacting job of map assembly. Published soil maps on controlled photographic mosaics help the user locate himself on the map and thus improve his accuracy of reading the kinds of soil on specific tracts of land.

Great progress has been made in soil mapping by photo interpretation accompanied by full examination of the soils at frequent intervals. While mapping soils, the soil scientist has two immediate problems: (1) With what kind of soil does this individual soil belong? (2) Where are its boundaries?

The photographs can be interpreted more accurately on the location of soil boundaries than they can on the exact classification of the soil. After close field study, however, a highly skilled soil scientist can identify kinds of soil in several kinds of landscape.

Soil scientists must always recall that soils have depth. Many aerial photographs do not show the surface of the soil itself, let alone the several horizons beneath it. Accurate soil maps cannot be made without deep examination of the soils.

Similar patterns on aerial photographs can be misleading. A combination of landform and vegetation that can give accurate clues to kinds of soil can suddenly fail elsewhere because of undetected changes in one or more aspects of climate, lithology, or land use history. What are indicator plants for one kind of soil only a few miles away can be indicator plants for a different kind of soil that is highly contrasting in terms of its use potential. But with a few examinations

of soils in depth, the relations can be clarified and aerial photographs can be used for accurate interpretation.

Variations among the lower soil horizons, or among layers just beneath the soil, may have no associated surface indication under wild vegetation or extensive use. Yet these features are highly significant under more intensive use. In deserts, for example, salt-rich layers and impermeable layers deep within the soil—which have no influence on native plants—can be of the utmost significance if the soils are irrigated. Thus soil surveys of arid land to guide irrigation require many field examinations in depth.

As the purposes of the soil survey require increasing detail and accuracy of interpretations influenced by lower horizons, relatively more dependence must be placed on field examination and less on aerial-photo interpretations. To be satisfactory, the highly detailed soil maps needed for consolidating fragmented holdings and for planning extensive irrigation works, must be developed with many field examinations. Yet in all soil surveys advanced aerial interpretation is extremely helpful for planning and for anticipating the kinds of problems to be dealt with. Experienced soil scientists use photo interpretation a great deal both for estimating soil boundaries and for identifying kinds of soil for low-intensity surveys of rangeland where the mapping units commonly are soil associations.

This manual is based mainly on experience in the national cooperative soil survey during the last 30 years. The highly technical aspects of photogrammetric engineering have been avoided, but references are cited to fuller discussions.

Several illustrations show how keys for correlating photographic images and kinds of soil can be prepared and used in the field.

Although many helped prepare this manual, special credit should be given to F. M. Orsini and C. W. Koechley, who directed its preparation, and to the following, who made major contributions and helped in its organization: M. E. Austin, J. L. Bryson, D. K. Crook, C. M. Ellerbe, R. M. Hooper, B. L. Matzek, A. C. Orvedal, J. D. Rourke, and W. E. White.

CHARLES E. KELLOGG,
Deputy Administrator for Soil Survey.

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Explanation of abbreviations in negative numbers—National Archives and Records Service, NA; Geological Survey, USGS; Agricultural Stabilization and Conservation Service, ASCS; Soil Conservation Service, SCS; and Department of the Air Force, USAF.

AERIAL PHOTOGRAPHY

An aerial photograph is today's most complete and informative, yet most economical, representation of the earth's surface. Aerial photographs give perspective views of the terrain. They reveal hill and dale, soil and water patterns, wonders and ravages of nature, and works of man. The Soil Conservation Service (SCS) was an early pioneer in recognizing the merits of making use of aerial surveying when, in 1934, it contracted for more than 100,000 square miles of photography.

Aerial photographs are widely used in soil surveying, farm and ranch planning, soil and forest conservation, irrigation and flood-prevention studies, timber estimates, crop-area measurement, highway planning, railroad and power-transmission location, geological research, and municipal planning. Through the science of photogrammetry, they are used as the basis for constructing precise topographic, planimetric, and controlled aerial mosaic maps.

No single combination of survey scale and lens focal length can be applied to all situations; many types and scales of aerial surveys are continually being made. In many instances aerial photographs can be used economically

only when the survey is flown at or near a given scale. Accuracy in compiling large-scale maps requires a large-scale aerial survey, whereas economical production of small-scale maps requires smaller scale survey. Also, most stereoscopic plotting instruments require surveys flown with 9- x 9-inch cameras equipped with 6-inch-focal-length lenses. Other plotting instruments require camera lenses with focal lengths of 3.5 to 12 inches, depending upon plotter design and aerial negative format. The longer 8 $\frac{1}{4}$ -inch-focal-length lenses produce photographs that are best for direct use for soil surveys and photo interpretation as used in SCS.

In addition to various scales and lenses, aerial surveys are flown with various cameras and camera angles. Single-lens or multiple-lens cameras can be used. Also, multiple cameras can be mounted with the axes of the lenses inclined to the surface of the earth to obtain converse or convergent low-oblique photography. A vertical aerial photograph, however, is the best base for soil mapping and photo interpretation, and nearly all aerial photographs for soil surveys are made with vertically mounted single-lens cameras that expose a 9- x 9-inch image area.

AERIAL SURVEYS

In the 1930's there were wide differences among surveys being flown by the various agencies of the U.S. Department of Agriculture (USDA). To provide aerial surveys that would suit most needs in agriculture, USDA agencies, in 1937, agreed to adopt a standard scale of 1:20,000 for these surveys. They were to be flown with a vertical camera equipped with an 8 $\frac{1}{4}$ -inch-focal-length lens, which would expose a 7- x 9-inch image area.

To establish conformity among aerial surveys made by these agencies, Standard Specifications for Aerial Photography for General Map Work and Land Studies were developed. Since that time, nearly all of the United States has been flown at the scale of 1:20,000 under these

"standard" specifications. Special surveys, however, are flown at 1:40,000, 1:31,680, 1:15,840, 1:10,000, 1:5,000, and other scales.

SCS modifies specifications for aerial surveys to meet requirements of a particular job and revises them to take advantage of developments in technology and improvements in materials and equipment. Specifications are revised in coordination with other USDA agencies. A summary of the latest specifications follows.

FACTORS TO BE CONSIDERED

Many geographic, physical, technical, and economic factors must be considered before a schedule of advertisement can be prepared for aerial surveys. The ultimate use or objective

of the survey must be known: Is it to be of general use, for which 1:20,000 standard flying is required; or is it to be used primarily for topographic mapping at a larger scale? Does the elevation or the type of photography require special flying equipment? Nearby surveys should be investigated to eliminate small gaps between surveys that would be expensive to fill in later. In addition, Government agencies coordinate their activities to prevent duplication. These factors help determine the survey boundary, scale of photography, and focal length of the camera lens.

TIME FOR FLYING

Contracts that enable contractors to keep their plants and personnel busy throughout the year and to take optimum advantage of favorable seasonal conditions have a direct bearing on the cost of surveys. Therefore, economical planning requires close study of such regional weather characteristics as the anticipated number of "photographic days" for each month for each survey area.¹ Such factors as geographic latitude and solar altitude must be considered to reduce or eliminate objectionable shadows in rugged areas. Generally, photography is undertaken only during that part of the day when the sun is 4 hours or more above the horizon. But in areas of little relief that have only slight differences in tone, the position of the sun may be used to emphasize landforms by introducing shadow patterns.

Most aerial surveys must be flown when the ground is free from snow. This limits the flying season in colder sections.

To show the earth's surface, photographs should be taken when trees are free of leaves and other vegetation is minimal. This limits the flying season to a few weeks in early spring and late fall. Since atmospheric conditions further limit the flying time, restricting flying to seasons when trees are free of leaves is impractical except for projects that require only a few weeks. A large project flown under such limitations would require excessive equipment to complete the job in a reasonable time. In SCS, aerial surveys made specifically for large-scale topographic mapping by stereo-plotting equipment are usually flown when deciduous

trees are bare. Most of these special projects are small.

CAMERAS AND LENSES

Precision 9- x 9-inch cameras and appropriate lenses are specified so the photography will meet minimum requirements and be widely useful. The cameras must be constructed to withstand vibration and temperature changes. Collimation or fiducial markers must be built into the plane of the film and secured to the magazine or to the inner cone of the camera so that negatives will reproduce the markers in each exposure. Fiducial marks are midway on each of the four edges of the photographs. Lines joining opposite members of the two pairs of markers will intersect at the optical center (principal point) of the exposure. Specifications also require a camera that is designed to permit testing procedures. The lens must have high resolving power to provide sharply defined images. Low distortion is required to maintain true perspective. For general use 1:20,000 surveys, the focal length is about $8\frac{1}{4}$ inches (210 ± 4 mm). For topographic mapping surveys, the focal length generally used is about 6 inches (152 ± 3 mm).

Test reports of the camera and lens must be prepared by a testing organization or Government unit approved by SCS. Reports must be submitted before the contract is awarded. These tests determine whether the camera and lens meet accuracy requirements. Test reports include the resolving power, the distortion pattern, the equivalent² and calibrated³ focal lengths of the lens, and the value of distances separating opposite fiducial markers. These fiducial measurements can be used to determine the dimensional stability of exposed negatives and of reproductions processed from them. Also, when compared to corresponding measurements on a reproduction, these distances can be used to determine the precise degree of enlargement.

² The equivalent focal length is the distance measured along the lens axis from the rear nodal point to the plane of best average definition over the entire field used in the aerial camera.

³ The calibrated focal length is an adjusted value of the equivalent focal length computed to distribute the effect of lens distortion over the entire field used in the aerial camera.

¹ A photographic day is one during which there is no more than 10 percent cloud cover.

FILM

The specifications require fine-grained, high-speed, polyester base, panchromatic film, or its equivalent. This type of film gives a good range of densities from black to white of all the colors. Panchromatic film is used for most surveys because of its all-round adaptability and low cost. Polyester base is exceptionally stable and eliminates any problem of dimensional changes caused by the film.

Since color aerial surveys for general use in SCS are not yet practical, the specifications do not list this type of film. Color aerial photography is especially limited because of processing difficulties. The cost for making color prints is now considerably more than that for making black-and-white prints. Color aerial photography has improved the accuracy of certain kinds of photo interpretations, however, especially for the military, for geologic investigations, and for forest-disease studies.

Similarly, infrared aerial photography in SCS is limited, and specifications do not mention this type of film. Infrared aerial film is sensitive to a portion of the infrared spectrum, which is not visible to the human eye. Since the film is also sensitive to a portion of the visible spectrum, true infrared photography is obtained by exposing the film through a deep red filter, which permits recording only the infrared rays. Thus, reproductions from true infrared aerial photography have a distortion of density values of the various reflected color tones. For example, green foliage of deciduous plants appears very light, as though covered by heavy frost. Differences between tones of certain species of trees and vegetation are more pronounced. Bodies of water and areas in shadow appear black. The more drastic effects of true infrared photography may be modified with a minus blue (yellow) filter, which permits recording a portion of the visible spectrum as well as the infrared portion. Modified infrared photography has many of the characteristics of true infrared photography, but it also retains some of the characteristics of panchromatic photography. In USDA, modified infrared photography is used principally by the Forest Service to distinguish between tree species.

ALTITUDE FOR FLYING AND SCALE OF NEGATIVES

The scale of an aerial survey is generally given in terms of a representative fraction or "ratio scale"; for example, 1:20,000. The ratio scale S is determined by the lens focal length f and by the altitude or flight height H above the ground as follows:

$$S = \frac{f}{H}$$

where both f and H are in the same units of measurement. Thus, general-use, 1:20,000 surveys may be flown with an 8¼-inch (0.6875-foot) lens at an altitude of 13,750 feet above ground level. Figure 1 gives the relationship between various lens focal lengths, flight altitudes, ratio scales, and scales in terms of feet-per-inch.

The schedule of advertisement for aerial surveys for SCS specifies the focal length of the lens, the altitudes for flying, and the ratio scale of negatives. The specifications require that flight altitudes do not exceed more than plus or minus 5 percent of specified values. In flat areas the scale of the negatives will vary generally within plus or minus 3 percent but will seldom vary more than plus or minus 5 percent of true scale. In mountainous areas the scale of individual exposures of a flight can range from plus 10 percent to minus 20 percent of the specified ratio scale. Such variances are primarily due to the rise and fall of ground elevation along the flight strip. Higher ground, which is closer to the camera, produces larger scale negatives. It also produces less overlap between exposures and less sidelap between flight lines. Conversely, lower ground produces smaller scale negatives, increased overlap between exposures, and increased sidelap between flights. In some areas flight altitude must be increased to maintain satisfactory sidelap over peak elevations. This action decreases the average scale of the flight and, unfortunately, produces even smaller scales through the lower agricultural areas.

FLIGHT LINES AND SIDELAP

The direction of flight lines is north and south unless special conditions make it necessary to orient the flights in another direction. Some flights are planned in an east and west direction to parallel the higher ground elevations

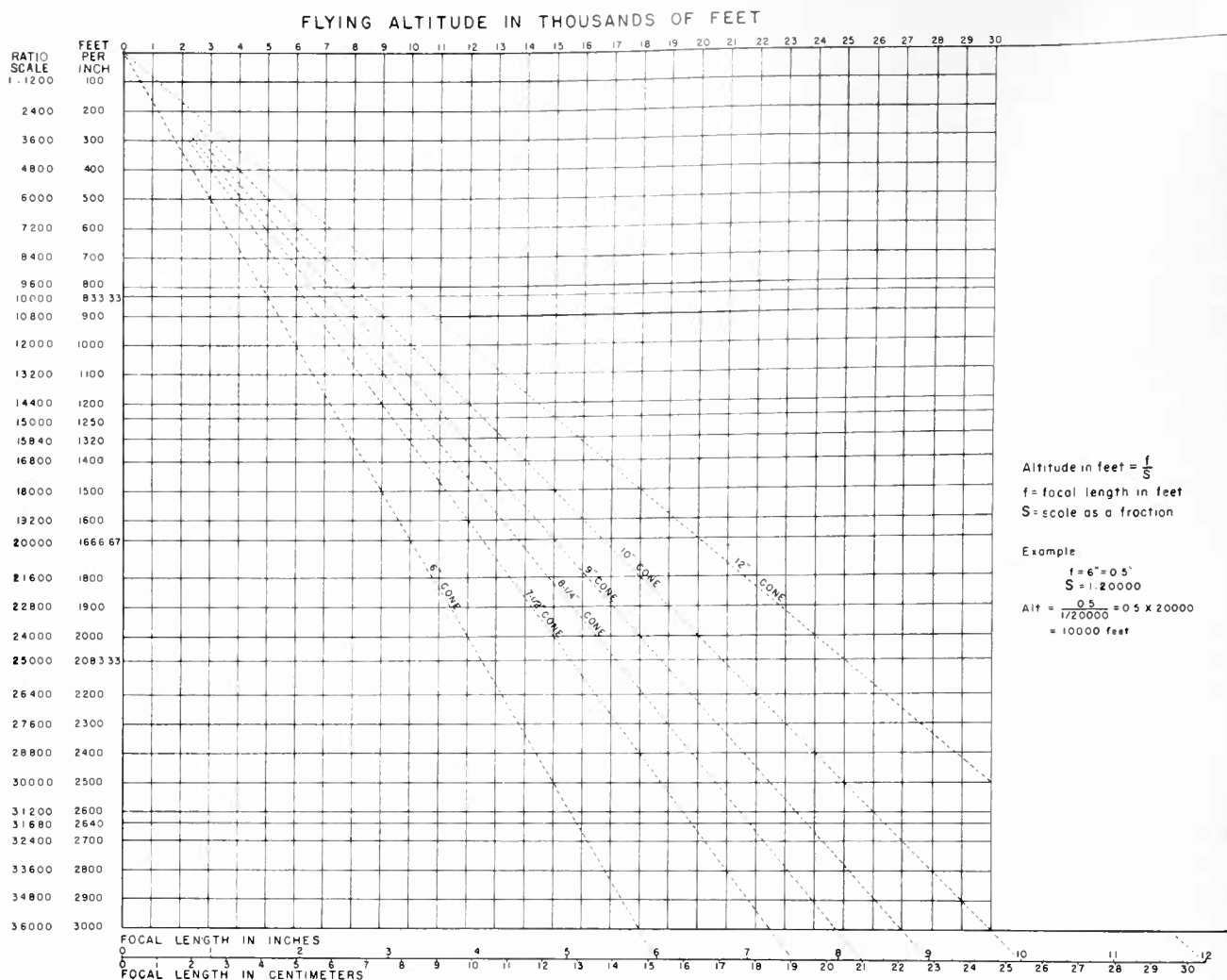


Figure 1.—Altitude chart for aerial surveys.

since flights that parallel the contour direction result in more uniform scale throughout the exposures. East and west flights are also used to parallel the longer dimension of a flight area and thus reduce the number of flights. Flight lines of small areas flown for topographic mapping may be oriented in any direction or combination of directions that will result in photography parallel to the general direction of the streambed.

Spacing and locations of flight lines are also specified. This spacing together with the flight altitudes and the camera and lens combination establishes approximately 30 percent sidelap between flights. Flight lines for general use 1:20,000 photography are spaced at 2-mile intervals. In sectionized areas flight lines are over alternate section lines. Flight-line locations depend upon analysis of such factors as

the location of former flight lines of the area and adjoining areas; exposure locations of new surveys that duplicate exposure locations of former surveys are generally desired. In addition, the location of particular sites of interest may dictate flight-line locations. With proper planning, these sites may fall entirely within a single photograph or within a single flight line. The minimum and maximum sidelap are specified at 15 percent and 45 percent, respectively. Some deviation from these values is permitted: for instance, within an area where there is extreme variation in elevation.

Flight lines are usually required to be continuous across the length of the area to be photographed. Breaks in flight lines are permitted when clouds, insufficient overlap or sidelap, or other conditions require re-flying a portion of a flight line.

OVERLAP

Exposures are made at intervals that result in an average overlap of about 60 percent with the preceding photograph in the flight. A minimum of 55 percent and a maximum of 65 percent overlap is specified. Overlap of 60 percent provides systematic coverage that is adequate for stereoscopic viewing of any point. Greater overlap than necessary increases the number of exposures required and therefore increases the cost. Average overlap of less than 60 percent increases the possibility of stereoscopic gaps. Such gaps cause a loss of stereoscopic views of the areas which eliminates or lessens the value of the survey for mapping. Whenever breaks in flight occur, reflights are necessary and should cover at least 100 percent overlap of end exposures at the break in flight to assure stereoscopic pairs through the "break" area.

BOUNDARY COVERAGE

Where the boundary of an area is perpendicular to the flight lines, the first and last photograph on each flight line will fall outside the project boundary. When the boundary is at an angle with flight lines, exposures at the ends of flight lines will provide stereoscopic coverage to a point at least 1 mile beyond the boundary.

Where the boundary of the area is parallel to the flight lines, the sidelap beyond the boundary will not be less than 15 percent.

CRAB

Crab of an aerial photograph is caused by failure to orient the camera with respect to the ground track of the airplane. As a result, sides of the photographs are not parallel to the line of flight. For general use photography, any two or more consecutive photographs may not be crabbed more than 10 degrees as measured from the plotted flight line. For mapping photography, any two or more consecutive photographs may not be crabbed more than 5 degrees. Within these limits, crab alone does not cause problems in the use of photographs.

TILT

Specifications limit the tilt of any negative to no more than 4 degrees. Tilt may not average more than 2 degrees in any 6-mile section or

more than 1 degree for the entire unit.⁴ Relative tilt between any two successive negatives may not exceed 6 degrees.

Image displacements due to tilt are generally negligible compared to displacements due to ground relief. Tilt of a photograph may cause image displacements that produce scaling errors of as much as 1 or 2 percent; ground relief could cause displacements that produce scaling errors 10 percent or more, depending on the ruggedness of terrain. In an area of flat terrain, displacement caused by tilt can be the principal cause of a small error in scale.

IDENTIFICATION OF EXPOSURES

Each aerial negative is marked with the date of exposure, an alphabetical symbol, the serial number and letters of the roll, and the serial number of the exposure on the roll. For example:

10-8-62

ABC-12DD-112

In addition, the abbreviation of the standard civil time of day of the exposure, the agency initials, and the approximate scale of the negatives are marked on the first and last negatives of each flight line and at each break in a flight line. For example:

10-8-62 12:15 SCS 1:20,000 ABC-12DD-112

The identification is marked within the exposure area along the northern side of the negative for north and south flights and along the western side for east and west flights.

In most exposures the alphabetical symbol alone will identify the county. In some the symbol identifies only the aerial survey project. Further investigation is required to ascertain the county within the project.

Each roll of aerial film exposed in a unified block of flying is numbered in an unbroken series beginning with number 1. A suffix of alphabetical letters is made to the roll numbers to differentiate between multiple surveys of the same county. Each exposure within a roll is also numbered in an unbroken series beginning with number 1. Exposures and rolls are thus numbered in the sequence in which they are flown. Because of weather, rejections, and

⁴ "Unit" means a county, counties, or parts thereof having the same designating symbol.

other factors, flight lines are seldom flown entirely in consecutive order. Therefore, there is no particular pattern to the roll numbers or to the direction of exposure numbers that make up the final coverage.

PHOTOINDEX

Photoindex sheets of each county or area are prepared by photographing an assembly of contact prints from the aerial negatives. Photographs in the assembly are laid so that corresponding images match reasonably well and the numbered edges are exposed to show the identity of each print. This assembly is copied on 20- x 24-inch negatives at a scale of 1: 63,360. Each sheet is identified by a title, which shows the county or area name, sheet number, alphabetical symbol, agency and contractor credit lines, graphic scale, and other data such as survey scale and year of flying. County and unit boundaries are then delineated on the index negatives.

Although the individual contact prints are not

precisely matched, a photoindex is a fair mosaic and can be used for advance planning and broad reconnaissance surveys in many fields. But an understanding of its accuracy is essential to appraise the results that may be expected if the index is used directly as a map base.

Since indexes are a compilation of contact prints, there may be considerable difference between prints of one flight line compared to prints of an adjoining one. Consequently, mismatches and scale differences may be expected in the index assembly. Deviation in the scale of aerial negatives is caused primarily by ground relief; therefore, accuracy that can be expected within an index sheet is generally proportional to the amount of ground relief. For example, in nearly flat areas, most mismatches between prints used in the index assembly should be within 0.10 inch on the final index and no mismatch should exceed 0.15 inch plus that caused by ground relief. For rugged terrain, mismatch between prints used in the assembly may amount to 0.50 inch or more.

PHOTOGRAPHIC REPRODUCTIONS

SCALE OF REPRODUCTIONS

Contact prints, since they are made at the same scale as the negatives, retain all scale deviations of the negatives. Within limitations, enlargements can be made to any desired scale if enlargement factors are computed. To compute an accurate enlargement factor, the scale of the negative must be determined. This scale is usually preferred in terms of feet-per-inch and is determined by the following relationship between horizontal ground distance GD and photograph distance pd , measured between the same two identifiable points:

$$\text{Scale in feet-per-inch} = \frac{GD}{pd}$$

where ground distance GD is in feet and photograph distance pd is in inches. The enlargement factor can now be computed simply by dividing the feet-per-inch scale of negative by the feet-per-inch scale of enlargement desired. A common, though less accurate, way to obtain a ground measurement is to scale the distance from a map. Where accurate scales are required for many reproductions covering a unified area, a slotted-templet radial-control net

may be established. Most aerial surveys flown for general use by USDA agencies have been scaled from radial-control nets. Where control nets have not been established, however, "theoretical" enlargement factors may be used. Theoretical factors are determined by dividing the ratio scale of enlargement desired by the ratio scale planned for the aerial survey. Enlargements made with a theoretical factor have the same percentage of scale deviations inherent in the original negatives. For example, if the scale of the original negative is 5 percent large, the scale of enlargement will also be 5 percent large.

Enlargements projected up to four or more diameters may be made. Film emulsion grain and other conditions cause some loss of sharpness of detail. Therefore, enlargements in excess of this magnitude are not recommended. Table 1 gives average image size of enlargements from the more common survey scales. Although a smaller scale aerial survey will result in fewer photographs for coverage of a given area, a greater enlargement is required to produce a photograph of a given scale when com-

TABLE 1.—Average image size of enlargements

[Approximate quantities of stereoscopic reproductions required to cover an area of 1,000 square miles are indicated within parentheses]

Ratio scale of survey	Scale of enlargement					
	1 inch=400 feet	1 inch=660 feet	1 inch=1,320 feet	1 inch=1,667 feet	1 inch=2,640 feet	1 inch=3,333 feet
1:10, 000	19 x 19 inches (2,600).	12 x 12 inches (2,600).	(1)-----	(1)-----	(1)-----	(1).
1:15, 840	16 x 16 inches (2,060). ² 30 x 30 inches (1,030).	18 x 18 inches (1,030).	9 x 9 inches (1,030).	(1)-----	(1)-----	(1).
1:20, 000	20 x 20 inches (1,300). ² 38 x 38 inches (650).	23 x 23 inches (650).	12 x 12 inches (650).	9 x 9 inches (650).	(1)-----	(1).
1:31, 680	31 x 31 inches ³ (520). ²	19 x 19 inches (520). ² 36 x 36 inches (260).	18 x 18 inches (260).	14 x 14 inches (260).	9 x 9 inches (260).	(1).
1:40, 000	(4)-----	24 x 24 inches ³ (320). ²	23 x 23 inches (160).	18 x 18 inches (160).	12 x 12 inches (160).	9 x 9 inches (160).
1:50, 000	(4)-----	30 x 30 inches ³ (200). ²	15 x 15 inches (200). ² 29 x 29 inches (100).	23 x 23 inches (100).	14 x 14 inches (100).	11 x 11 inches (100).
1:60, 000	(4)-----	35 x 35 inches ³ (140). ²	18 x 18 inches (140). ² 34 x 34 inches (70).	15 x 15 inches (140). ² 27 x 27 inches (70).	17 x 17 inches (70).	14 x 14 inches (70).

¹ Reduction; less than 9 x 9 inches.

² Only physical coverage (nonstereoscopic) in the image size shown. Enlargements are processed in sections by the method given in figure 2.

³ Enlargements in excess of 4.3 diameters.

⁴ Not available.

pared to enlargements made from larger scale aerial surveys.

Where enlargements will produce photographs too large to be handled conveniently and economically, reproductions may be made from sections of each negative (fig. 2). Two sectional enlargements are made from each succeeding negative, namely, a "right-center area" and a "left-center area." The principal advantage of this system is that complete physical coverage is processed from only the more accurate portions of the aerial negatives. Right-center and left-center reproductions are identified merely by adding an R or an L, respectively, to the exposure number. For example, ABC-12DD-112R and ABC-12DD-112L.

The comparison of ratio scales to other equivalents is given in table 2. Equivalents for additional ratio scales may be computed as follows:

$$\text{Feet-per-inch} \dots\dots\dots = \frac{D}{12}$$

$$\text{Inches-per-1,000 feet} \dots\dots\dots = \frac{12,000}{D}$$

$$\text{Inches-per-mile} \dots\dots\dots = \frac{63,360}{D}$$

$$\text{Miles-per-inch} \dots\dots\dots = \frac{D}{63,360}$$

$$\text{Meters-per-inch} \dots\dots\dots = \frac{\text{Feet-per-inch}}{\times 0.3048006}$$

$$\text{Acres-per-square-inch} \dots\dots\dots = \frac{D^2}{43,560 \times 144}$$

$$\text{Square-inches-per-acre} \dots\dots\dots = \frac{43,560 \times 144}{D^2}$$

$$\text{Square-miles-per-square-inch} \dots\dots\dots = \frac{(\text{Feet-per-inch})^2}{(5,280)^2}$$

with *D* the denominator of the ratio scale.

TABLE 2.—Map scales and equivalents

Ratio scale	Feet per inch	Inches per 1,000 feet	Inches per mile	Miles per inch	Meters per inch	Acres per square inch	Square inches per acre	Square miles per square inch
1: 500	41.667	24.00	126.72	0.008	12.700	0.0399	25.091	0.00006
1: 600	50.00	20.00	105.60	.009	15.240	.0574	17.424	.00009
1: 1,000	83.333	12.00	63.36	.016	25.400	.1594	6.273	.00025
1: 1,200	100.00	10.00	52.80	.019	30.480	.2296	4.356	.00036
1: 1,500	125.00	8.00	42.24	.024	38.100	.3587	2.788	.00056
1: 2,000	166.667	6.00	31.68	.032	50.800	.6377	1.568	.00100
1: 2,400	200.00	5.00	26.40	.038	60.960	.9183	1.089	.0014
1: 2,500	208.333	4.80	25.344	.039	63.500	.9964	1.004	.0016
1: 3,000	250.00	4.00	21.12	.047	76.200	1.4348	.697	.0022
1: 3,600	300.00	3.333	17.60	.057	91.440	2.0661	.484	.0032
1: 4,000	333.333	3.00	15.84	.063	101.600	2.5508	.392	.0040
1: 4,800	400.00	2.50	13.20	.076	121.920	3.6731	.272	.0057
1: 5,000	416.667	2.40	12.672	.079	127.000	3.9856	.251	.0062
1: 6,000	500.00	2.00	10.56	.095	152.400	5.7392	.174	.0090
1: 7,000	583.333	1.714	9.051	.110	177.800	7.8117	.128	.0122
1: 7,200	600.00	1.667	8.80	.114	182.880	8.2645	.121	.0129
1: 7,920	660.00	1.515	8.00	.125	201.168	10.00	.100	.0156
1: 8,000	666.667	1.500	7.92	.126	203.200	10.203	.098	.0159
1: 8,400	700.00	1.429	7.543	.133	213.360	11.249	.089	.0176
1: 9,000	750.00	1.333	7.041	.142	228.600	12.913	.077	.0202
1: 9,600	800.00	1.250	6.60	.152	243.840	14.692	.068	.0230
1: 10,000	833.333	1.200	6.336	.158	254.000	15.942	.063	.0249
1: 10,800	900.00	1.111	5.867	.170	274.321	18.595	.054	.0291
1: 12,000	1,000.00	1.0	5.280	.189	304.801	22.957	.044	.0359
1: 13,200	1,100.00	.909	4.800	.208	335.281	27.778	.036	.0434
1: 14,400	1,200.00	.833	4.400	.227	365.761	33.058	.030	.0517
1: 15,000	1,250.00	.80	4.224	.237	381.001	35.870	.028	.0560
1: 15,600	1,300.00	.769	4.062	.246	396.241	38.797	.026	.0606
1: 15,840	1,320.00	.758	4.00	.250	402.337	40.000	.025	.0625
1: 16,000	1,333.333	.750	3.96	.253	406.400	40.812	.024	.0638
1: 16,800	1,400.00	.714	3.771	.265	426.721	44.995	.022	.0703
1: 18,000	1,500.00	.667	3.52	.284	457.201	51.653	.019	.0807
1: 19,200	1,600.00	.625	3.30	.303	487.681	58.770	.017	.0918
1: 20,000	1,666.667	.60	3.168	.316	508.002	63.769	.016	.0996
1: 20,400	1,700.00	.588	3.106	.322	518.161	66.345	.015	.1037
1: 21,120	1,760.00	.568	3.00	.333	536.449	71.111	.014	.1111
1: 21,600	1,800.00	.556	2.933	.341	548.641	74.380	.013	.1162
1: 22,800	1,900.00	.526	2.779	.360	579.121	82.874	.012	.1295
1: 24,000	2,000.00	.50	2.640	.379	609.601	91.827	.011	.1435
1: 25,000	2,083.333	.480	2.534	.395	635.001	99.639	.010	.1557
1: 31,680	2,640.00	.379	2.000	.500	804.674	160.000	.006	.2500
1: 48,000	4,000.00	.250	1.320	.758	1,219.202	367.309	.003	.5739
1: 62,500	5,208.333	.192	1.014	.986	1,587.503	622.744	.0016	.9730
1: 63,360	5,280.00	.189	1.000	1.000	1,609.347	640.00	.0016	1.0000
1: 96,000	8,000.00	.125	.660	1.515	2,438.405	1,469.24	.0007	2.2957
1: 125,000	10,416.667	.096	.507	1.973	3,175.006	2,490.98	.0004	3.8922
1: 126,720	10,560.00	.095	.500	2.00	3,218.694	2,560.00	.0004	4.00
1: 250,009	20,833.333	.048	.253	3.946	6,350.012	9,963.907	.0001	15.5686
1: 253,440	21,120.00	.047	.250	4.00	6,437.389	10,244.202	.0001	16.00
1: 500,000	41,666.667	.024	.127	7.891	12,700.025	39,855.627	.000025	62.2744
1: 1,000,000	83,333.333	.012	.063	15.783	25,400.050	159,422.507	.0000062	249.0977

PAPER AND PAPER FINISHES

Aerial photographs are printed on single- or double-weight paper with glossary or semimatte surface. Single-weight paper is useful where photographs are mounted, as in mosaic assembly, or where prints must be rolled. When photographs must be folded, a special single-weight folding stock generally is used. Double-weight paper can be handled repeatedly and still remain more nearly flat and, therefore, is the paper favored for general use. Glossy finishes are usually reserved for illustrations or for mounted photographs. The semimatte surface is designed to take colored or lead pencil notations and is favored for general use.

Except for special types, photographic paper presents a minor problem of distortion. The paper is fairly stable in one direction; however, atmospheric conditions can cause distortion to 0.5 percent or more across the grain of the paper. This distortion is usually shrinkage.

When dimensional stability of the reproduction is important as in slotted-templet assemblies, photographs may be printed on water-resistant paper or on white semiopaque polyester base material. Polyester base is more stable than water-resistant paper and lies perfectly flat. Because costs are about 30 percent higher for reproductions processed on water-resistant paper and about 90 percent higher for reproductions processed on polyester base materials, reproductions other than contact prints are seldom processed on stable-base material.

SELECTION OF COVERAGE

Either alternate or stereoscopic coverage may be selected for any portion of the surveyed area. Since each exposure within a flight line is made to provide at least 55 percent overlap with the preceding exposure, every part of the surveyed area is covered by at least two overlapping photographs. Thus, a set of alternately numbered photographs will cover every part of the surveyed area. Reproductions from consecutive exposures are referred to as "stereoscopic coverage," whereas reproductions from alternate

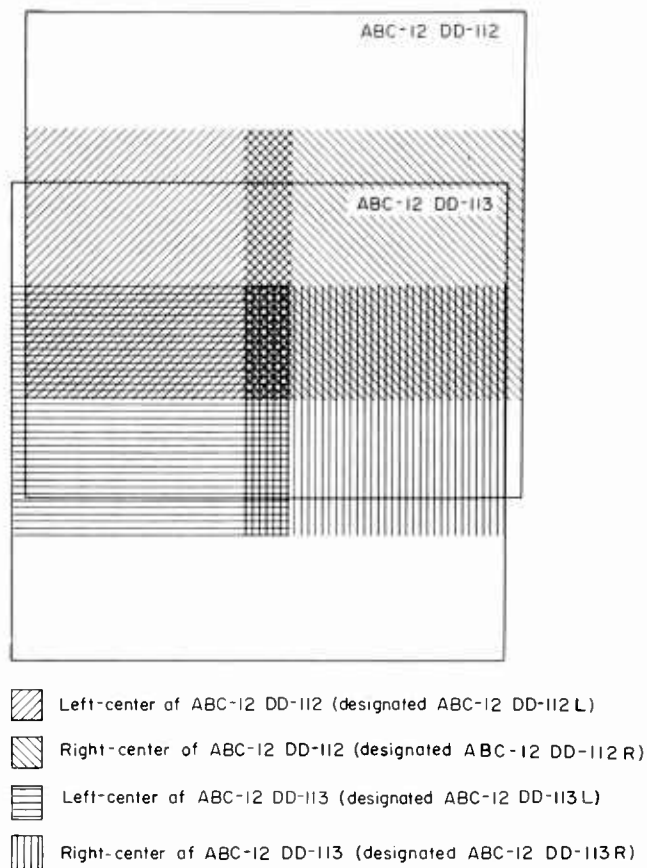


Figure 2.—Method for making sectional enlargements.

exposures are sometimes referred to as "non-stereoscopic coverage," "physical coverage," or "alternate coverage."

Stereoscopic coverage is required for three-dimensional viewing and for reproductions to be used for photogrammetric mapping. Since the center areas of photographs are more nearly like a true map, stereoscopic coverage should also be selected where there are considerable differences between ground elevations. Where the terrain is nearly flat, however, alternate coverage may be selected for general use. Alternate coverage is more economical since only half as many photographs must be processed and used.

PERSPECTIVE CHARACTER OF THE PHOTOGRAPH

As has been stated, an aerial photograph is a perspective picture and does not show all objects in their true positions. Today's precision lenses and stable-base negatives do not cause significant distortion of images in photographs for general use; but photographic papers may. Varying ground elevation within a picture is, however, a major factor of image displacement.

In flat country, image displacement is negligible. In rolling terrain, it is negligible only near the center of the photograph. Change in ground elevation within the photograph area causes continuous change in the scale of the photograph. The tops of the hills are nearer the camera than are the valleys. Because of this, the photographic scale of hills is larger than the scale of valleys. Except in rugged areas, scale variances may not be serious; but to make effective use of photography of rugged areas, the perspective characteristics of the image must be fully understood.

Figure 3 represents image displacement

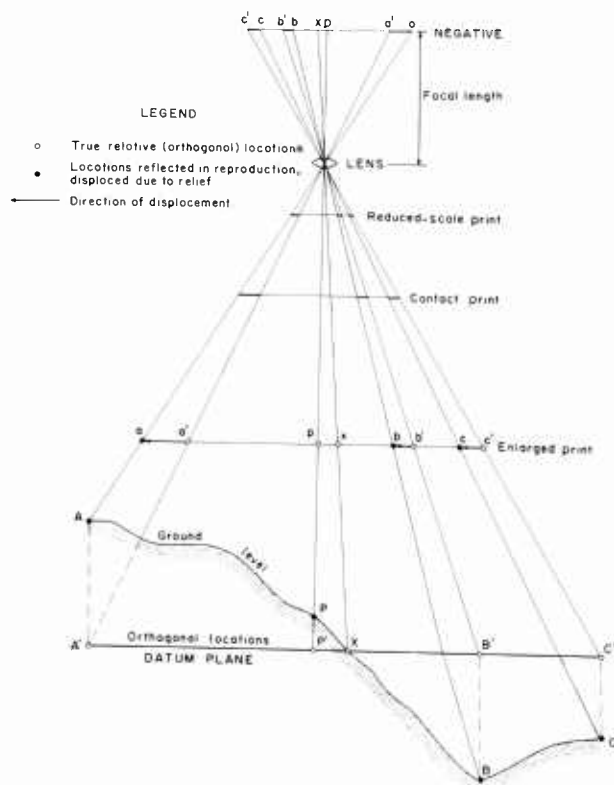


Figure 3.—Displacement due to elevation of the ground.

caused by elevation of the ground. The datum plane shown in the diagram is the level of ground elevation that produces the planned aerial-negative scale. Points A, P, X, B and C , are ground positions. The distortion- and displacement-free (orthogonal) locations of these points are shown at $A', P', X, B',$ and C' . The aerial photograph, however, shows these ground positions at locations a, p, x, b and c , which are displaced in a radial direction from the nadir point.⁵ In a true vertical photograph, the nadir point coincides with the principal point,⁶ or picture center, which is indicated as point p .

The radial displacement of any image point may be computed from the following formula:

$$d = \frac{nh}{H}$$

where d = the amount of displacement measured on the photograph

n = the distance measured from the photograph nadir to the image point

h = the difference in elevation between the ground point and the datum plane (positive if ground point is above datum, negative if below)

H = the height (flight altitude, fig. 1) of the camera above the datum plane

and where d and n are in the same units of measurement, as in inches, and h and H are in the same units, as in feet.

From the formula, ground elevations above the datum plane, such as at A , are displaced outward (positive) from the nadir; but ground elevations below the datum plane, such as at B , are displaced inward (negative). Ground elevations that coincide with the datum plane, such as at X , and ground points directly below the camera, such as at P , are not displaced. The formula also discloses that displacement varies jointly as distance n and difference in elevation h , and inversely as height H .

The net displacement caused by a difference in elevation measured from the ground to the

⁵ The nadir point, or plumb point, is the point on the ground vertically beneath the camera lens.

⁶ The principal point is the optical center of the photograph.

top of an object, such as a silo or tree, also may be computed with the above formula if H is defined as the height of the camera above the base of the object and h is defined as the height of the object.

Because the flight altitude H is equal to the lens focal length divided by the ratio scale of the survey (fig. 1), a longer focal length re-

quires a higher flight altitude to maintain a specified ratio scale. From the displacement formula, a higher flight altitude reduces displacement caused by ground elevation. The $8\frac{1}{4}$ -inch focal-length lens used for 1:20,000 photography for USDA is a compromise based on such factors as the amount of image displacement and estimated cost of surveys.

STEREOSCOPY

Stereoscopy is the science of producing three-dimensional effects from two-dimensional pictures of subjects having three dimensions and the methods by which these effects are produced. In normal vision, each eye focuses on an object from a different position and transmits a slightly different image to the brain. In the mind's eye, the two transmitted images are combined into a single three-dimensional counterpart of the original object. If one eye is closed and the object is viewed with only the open eye, however, no more than a two-dimensional image is achieved. For all practical purposes, depth or distance factors are lost and actual distances can only be judged by the comparative size of the viewed object or by the relative positions of familiar objects.

This stereoscopic principle is used to produce a three-dimensional image of the earth's surface with pairs of vertical aerial photographs. The opportunity to study vegetation, culture, drainage, and other features of the land in three dimensions gives greater value to aerial photography.

Almost anyone with good sight in both eyes, or whose eyesight can be corrected, can acquire the ability to view pairs of aerial photographs stereoscopically. Skill in stereoscopic study is gained only through practice. Initial attempts may be frustrating, but as facility in the procedures increases the stereoscopic examination of aerial photographs becomes routine.

PARALLAX

Parallax is defined as any apparent displacement of an object due to a change in position from which the object is observed. The eyes view an object from two slightly different positions because they are separated. This separation is called the interpupillary distance and is about $2\frac{1}{4}$ inches for most people but ranges

from 1.97 inches to 2.85 inches for different persons. Parts of a three-dimensional object seen by one eye are not seen by the other. Furthermore, the image of near objects seen by each eye alternately appears displaced or removed laterally in relation to background objects. This lateral displacement is "parallax." Parallax is an important factor in determining the relative distances of objects in a scene. When the eyes scan a solid object the different planes of the object are separated through parallactic displacement and the impression of relief is obtained.

BINOCULAR VISION

Most people can distinguish between well-defined vertical lines if the distance between the lines subtends a convergence angle of at least 1 minute of arc (fig. 4). A highly trained observer, however, may distinguish between lines that subtend an angle as small as 15 to 20 seconds of arc.

A person with an interpupillary distance of 1.97 inches may perceive depth in an object up to a distance of about 570 feet; a person with an interpupillary distance of 2.85 inches may see depth in objects up to a distance of about 800 feet. The highly trained observer could perceive depth to about 1,700 feet if he had an interpupillary distance of 1.97 inches, or to a little over 2,400 feet if he had an interpupillary

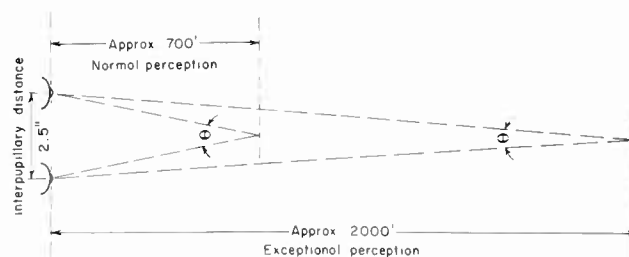


Figure 4.—Interpupillary distance and depth perception.

distance of 2.85 inches. Beyond this even the trained observer is unable to perceive depth or see relief. For this reason mountainous or rough terrain looks nearly flat when flying at a considerable altitude.

The following relationship between interpupillary distance PD and angle of convergence θ may be used to approximate large distances R to viewed objects:

$$R = \frac{PD}{\theta}$$

where R and PD are in the same unit of measurement, as in feet, and θ is expressed in radians.⁷

SEEING STEREOSCOPICALLY

Anyone with normal eyesight in both eyes or with corrected vision can see three dimensions, or see stereoscopically. This ability may be tested by looking at a small object at eye level about 20 feet away. Extend the forefinger of each hand and raise each to eye level. Without changing the focus of the eyes on the distant object, bring the fingertips together slowly on the line of sight. If you see an "ocular weinerwurst" between the fingertips (fig. 5), you can learn to use a stereoscope successfully.

Many persons are able to experience three-dimensional impressions while viewing pairs of aerial photographs without benefit of lenses, prisms, or mirrors, but simply with the eyes alone. This ability is acquired only by special effort and continued practice. While this ability is sometimes helpful, use of a stereoscope is more satisfactory.

Ordinarily, the eyes converge on the subject being viewed. To view a stereoscopic pair of photographs, however, the lines of sight must be about parallel so that the right eye views

the right-hand photograph and the left eye the left-hand one. At times a three-dimensional image is inverted. This inverted or pseudoscopic effect is caused by viewing the right-hand photograph with the left eye and the left-hand photograph with the right eye. The condition may be corrected by reversing the photographs to their proper positions or, if the effect is caused by looking cross-eyed, by making sure that the lines of sight do not cross.

KINDS OF STEREOSCOPES

There are several kinds of stereoscopes made by a number of optical and photogrammetric equipment manufacturers. The principal difference between stereoscopes is the optical method used to prevent lines of sight from converging at the focal plane or point of focus. The basic types are: *prism* stereoscope, *lensatic* stereoscope, reflecting or *mirror* stereoscope, or a combination of these. Some mirror stereoscopes are equipped with binoculars which magnify the image. This attachment is considered unsatisfactory for general use because the field of vision is reduced drastically. Binocular attachments, however, help to identify land survey stations and other minute detail.

The old-fashioned parlor stereoscope (fig. 6) is probably the best known prism stereoscope. It has thin wedge-shaped prisms that spread the lines of sight, slight magnification with a limited field of vision, and a critical focal distance.

A simple folding, pocket-sized, lens stereoscope (fig. 7) extends the focal length of the eyes and helps overcome normal convergence. Figure 8 illustrates the difference in the lines of sight between the spherical lens and the pris-



Figure 5.—Ocular weinerwurst.

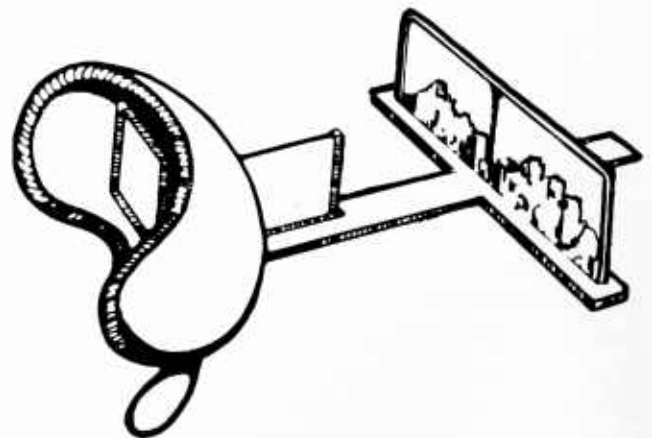


Figure 6.—Prism stereoscope.

⁷ 20 seconds of arc is 0.0000965 radians.

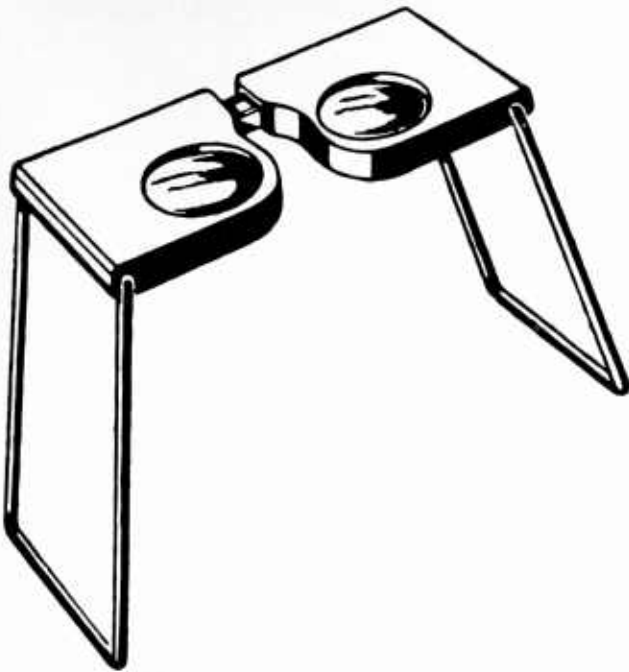


Figure 7.—Lens stereoscope.

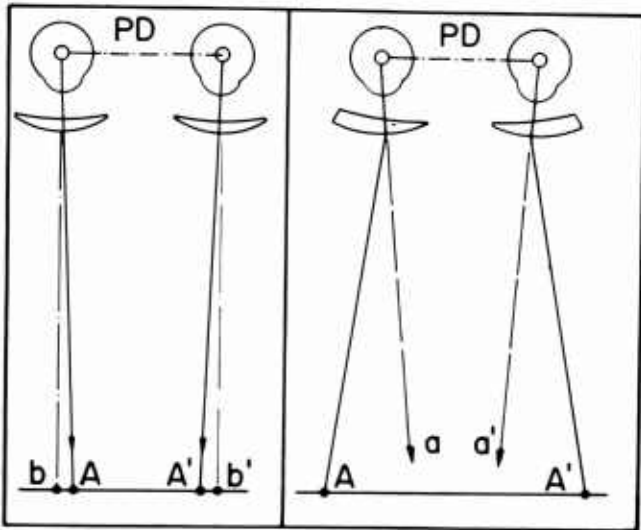


Figure 8.—Line of sight through lens stereoscopes: Left, through simple spherical lenses the distance between image points (A and A') is usually less than pupillary distance (PD)—maximum separation does not exceed $bb' = PD$. Right, prismatic lenses permit the distance between image points (A and A') to be greater than pupillary distance (PD)—prismatic deviation causes A and A' to be seen in the directions a and a' .

matic lens stereoscope. The photographs are placed at a distance from the lens equal to the focal length of the lens. Since this is much like



Figure 9.—Mirror stereoscope.

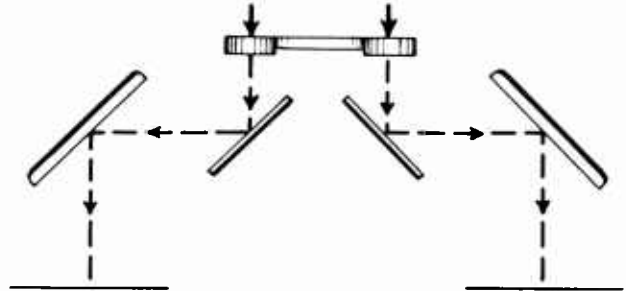


Figure 10.—Lines of sight through a mirror stereoscope.

placing the photographs at or near optical infinity of the eye, the lines of sight are nearly parallel. Most lens stereoscopes are inexpensive. They can be used effectively with 9- by 9-inch contact prints and 4-inches-equal-1-mile enlargements from 1:20,000 aerial surveys. They magnify the image about $1\frac{1}{2}$ to 2 times and are convenient for general use.

The mirror stereoscope (figs. 9 and 10) has prisms or mirrors, or both, to spread the lines of sight. The lens-mirror assembly usually can be raised or lowered until the photographic image is focused sharply. The lines of sight at the point of focus are usually about 9 inches apart. Because of this a much larger photographic area may be examined without moving the photograph or the stereoscope. Reflecting or mirror stereoscopes may be used to view 9- by 9-inch contact prints and enlargements.

OTHER WAYS TO PRODUCE A STEREOSCOPIC EFFECT

In addition to stereoscopes and pairs of overlapping photographs, anaglyphs or vectographs give a three-dimensional impression.

An anaglyph is a composite of superimposed stereoscopic images in complementary colors. This kind of composite is used to obtain the three-dimensional view in most stereo photogrammetric plotters such as the Multiplex and

the Kelsh. The overlapping portion of one aerial exposure of a stereoscopic pair is projected or printed in a color such as blue. The overlapping portion of the adjacent aerial exposure is projected or printed in a complementary color such as red which is superimposed over the blue image. Usually the image of one color is slightly offset from the image of the other color. The composite image is then viewed through a pair of spectacles which has one red lens and one blue lens. One eye sees only the blue image because the red lens neutralizes the red image; the other eye sees only the red image because the blue lens neutralizes the blue image. Thus, a three-dimensional view is achieved.

A vectograph uses polarized light rays to achieve image separation. Polarized light, the basis for the process, vibrates in only one direction within a plane, whereas ordinary light vibrates in all crosswise directions. A composite of superimposed images is prepared by transferring dyed images of the aerial exposures to a sheet of polaroid vectograph film. One side of the vectograph film polarizes light in one direction; the other polarizes light in the opposite direction. The overlapping image of one aerial exposure is dye-transferred to one side of the vectograph film; a reversed, overlapping image of the adjacent aerial exposure is dye-transferred to the other side of the vectograph film. The composite image is viewed through a pair of polarized spectacles, which has the axis of one lens at right angles to the axis of the other; one eye sees the image of only one of the pictures of the overprinted pair; the other eye sees only the other. The mental fusion of the two images forms a three-dimensional view.

STEREOSCOPIC VIEW FROM AERIAL PHOTOGRAPHS

For general use 1:20,000 surveys, exposures within the line of flight are made about 1 mile apart. In effect, the eye base is enlarged to 1 mile from the normal between-the-pupils distance of $2\frac{1}{4}$ inches. This makes possible a three-dimensional view even though the photographs were taken from a height of more than $2\frac{1}{2}$ miles. When viewing a stereoscopic pair each eye assumes a position of the camera station at the instant of exposure and the impression of slope is greatly exaggerated (fig. 11).

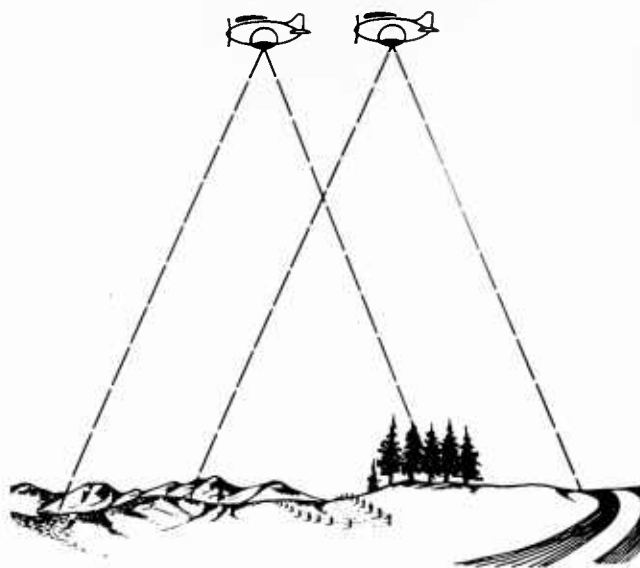


Figure 11.—Camera station and eye position.

This exaggeration increases as the distance between the two camera stations increases. It can be of considerable benefit when interpreting ground slope from photographs.

SELF-TRAINING

The lenses of a stereoscope must be accurately spaced and adjusted for each individual's eyes if he is to see a stereo model properly. If the lenses are spaced too far apart, the model appears concave or saucer shaped. If they are spaced too close, they give a convex or mound appearance. Either improper spacing can lead to mistakes in delineation of drainage or in other interpretations.

To adjust the stereoscope lenses, place two identical prints under the lenses of a stereoscope so that the same area can be viewed on both photographs, like a regular stereoscopic pair. Both photographs must be flat. The concave or convex effect can be noted readily by moving the lenses to the extremes, wide apart or close together, and adjusting the duplicate photographs accordingly. When the lenses and photographs are moved back and forth until an area of about 4 square inches directly under the stereoscope appears to be perfectly flat, the lenses are properly spaced for viewing stereoscopically. Mark the stereoscope so that the lenses can be set to this spacing without testing each time the instrument is used. A stereoscope with adjustable lenses that can be spaced to each individual's eyes should be used for

photo interpretation rather than one with fixed lenses.

To see stereoscopically, some control of the eyes not exercised in ordinary vision is essential. One of the simpler ways to develop this control requires but two sheets of paper with a horizontal line drawn on one and a vertical line on the other. Place one sheet below the left-hand lens of a stereoscope and the other below the right-hand lens. Focus each eye on the line appearing directly below. Hold the left-hand sheet in place and move the right-hand sheet slowly to the left or right (fig. 12). When the horizontal and vertical lines appear in the form of a cross rather than as two separate lines, the view is stereoscopic. Blinking first one eye and then the other while bringing the two images into focus may help.

A piece of cardboard placed perpendicularly between the stereoscope lenses may help keep the lines of sight parallel and help train each eye to focus separately on its subject. This exercise may tire eye muscles but will not harm them.

To practice, after the cross appears move the left-hand sheet until the vertical and horizontal lines again separate. Then, shift the sheets until the lines join once more in a cross. Repeat until "fusing" is done rapidly. Note the location of each sheet with reference to the stereoscope lenses when the lines are fused into a cross.

The centers of the lines should be 2 to 3 inches apart under the pocket stereoscope and about 9 inches apart under the usual mirror stereoscope.

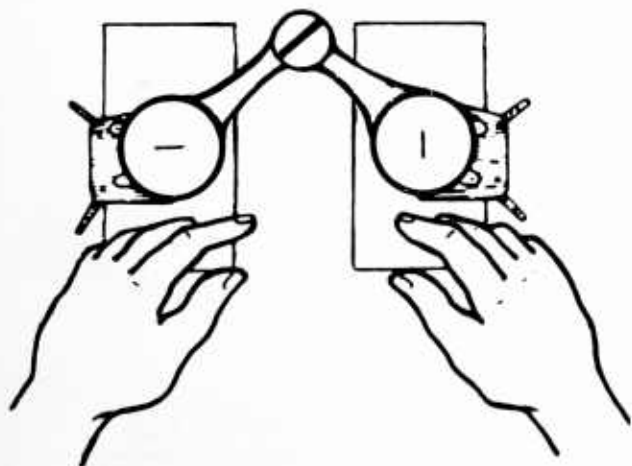


Figure 12.—Location of sheets under stereoscope.

Removing and replacing the sheets trains the eyes to focus on the lines. When the lines can be rapidly fused into a cross, stereoscopic viewing of aerial photographs may be started.

Mounted pairs of stereoscopic pictures are helpful to practice viewing aerial photographs. They can be made by cutting 2-inch-wide strips covering the same ground area from adjoining aerial photographs. The strips are cut perpendicular to the line of flight. They are mounted on stiff paper so that images of identical ground points are opposite one another and about 2 inches apart. (See figures 20, 21, and 22.) Of course, the strip from the left photograph must be mounted on the left side. Mounted pairs that show particularly interesting terrain are especially helpful.

Stereoscopic pairs showing land with moderate relief and a distinct pattern of surface features should be selected for practice. The photographs should have equal tone and identical ratio scale. The optical center of each photograph is marked with a small cross (P_1 and P_2 , fig. 13). Next, the optical center of each photograph is transferred to the other (P_1' and P_2'), and a straight line is drawn between the two crosses of each photograph. This line very closely represents the flight path of the aircraft. Because of crab, the lines may not be perpendicular to the photograph edges they intersect. The pair of photographs is now placed under the stereoscope so that the center-to-center line on one photograph is a continuation of the line on the other, and the photographs are overlapped so that the center of one photograph as at P_1 and its transferred location on the other photograph as at P_1' are separated by about 2 inches. Also, these lines must be parallel with an imaginary line drawn through the centers of the stereoscope lenses.

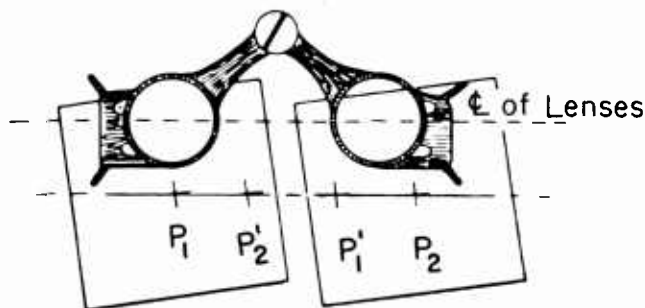


Figure 13.—Orientation of photographs for viewing.

The photographs should be moved toward or away from one another until the crosses and connecting lines are fused under the stereoscope. As soon as this occurs one of the photographs should be shifted until fusion is lost and then moved again until fusion is recovered. This should be practiced until many of the more prominent features can also be fused rapidly. One of the more difficult and most important steps is placing the two photographs in the proper position relative to one another and to the stereoscope. Even a slight twist from parallel creates additional distortion and causes eyestrain. Viewing at an oblique angle also increases the distortion. As skill develops, however, images are fused by observing the physical features rather than by matching the crosses and lines, and photographs without such lines can be used.

OTHER PROCEDURES AND DEVICES

Many details and devices will be discovered and developed as proficiency in stereoscopic work is increased. For example, each photograph should be equally illuminated without glare, and the light should be behind the stereoscope. Photographs should be oriented so that shadows extend toward the viewer and away from the light. Shadows extending away from the viewer may invert the stereoscopic image.

The inside edge of the top photograph is frequently lifted or rolled upward to view stereoscopically part of the bottom photograph otherwise obscured by the top photograph. Figure 14 shows a convenient holder for stereoscopic pairs which systematically bends upward the overlapping portion of the top photograph. When prints are too large to bend all the excessive overlap upward, a slot may be made in a table top or supporting base, through which the excess parts may be inserted and bent downward. Or this slot may be an inch gap between two tables. Except to provide the stereoscopic view, photographs should be kept flat.

Several devices for supporting the stereoscope over the photographs have been proposed. One device mounts a vertical rod at the rear of a table and has a horizontal arm to support and swing the stereoscope over the work surface (fig. 15, top). Another attaches the stereoscope to the flexible standard of a gooseneck lamp. A third uses an accordion telephone ex-

tension unit that has a terminal support with casters at the stereoscope end. Still another method attaches the stereoscope to a storm sash friction adjuster (fig. 15, bottom); the friction disks at the three hinge points eliminate wobble but allow horizontal movement of the stereoscope over the photographs.

A very handy method of supporting a stereoscope is shown in figure 16. Simple stereoscope lenses are mounted on a drafting lamp. The stereoscope may be moved over the photographs and the light is always in proper position for excellent illumination.

A desk stand for mounting a simple pocket stereoscope may be constructed as shown in figure 17. The legs of this support occupy positions beyond the stereoscopic working area.

For field use, a shelf has been designed for attachment inside the right-hand door of a pick-up truck. The surveyor raises the shelf and puts photographs in position for stereoscopic study (fig. 18). Excess parts of the photographs are bent downward through a 1-inch slot. With this shelf a stereoscope may be used conveniently; the shelf is easily raised or lowered, and the car door can be opened or closed at any time; aerial photographs can be carried in place while the shelf is either up or down; the entire unit can be installed or removed without marring any part of the vehicle.

Figure 19 gives details for making an easy-to-use stereogram for field use.

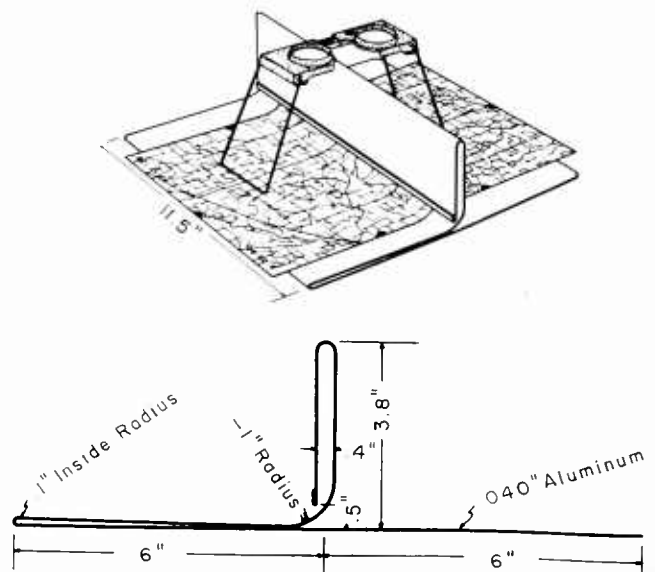
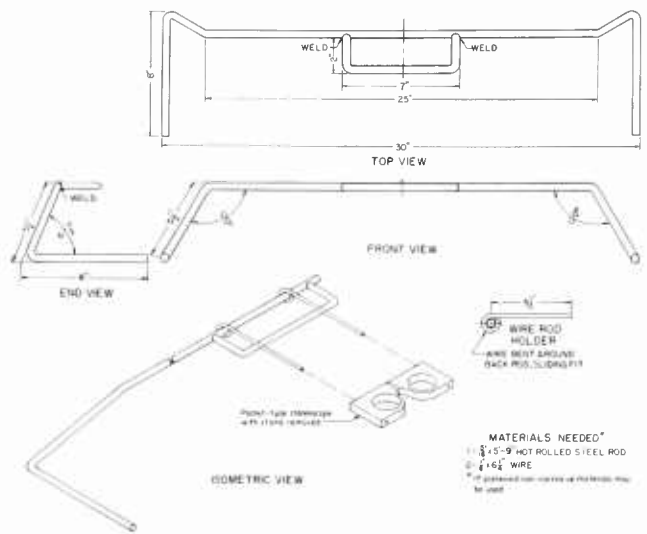
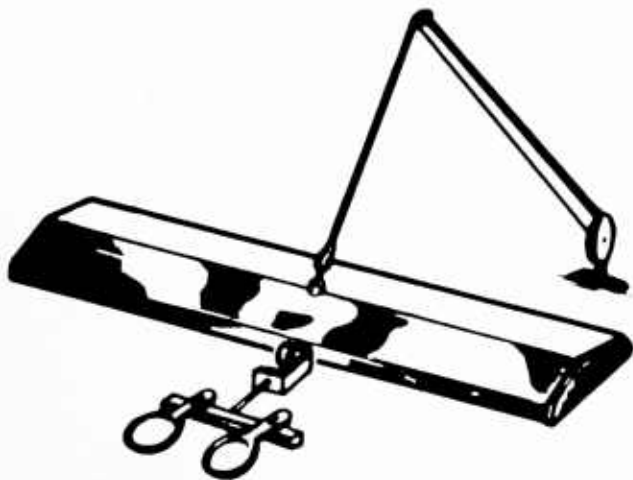


Figure 14.—Holder for stereoscopic pairs.



A technical diagram of a mechanical linkage system. It features a vertical wooden post on the left. A horizontal arm is attached to the post via a pivot. The arm is connected to a lever mechanism on the right, which has two circular openings. This lever is positioned above a large rectangular plate that is divided into two sections by a diagonal line. The entire assembly is mounted on a base plate.



17

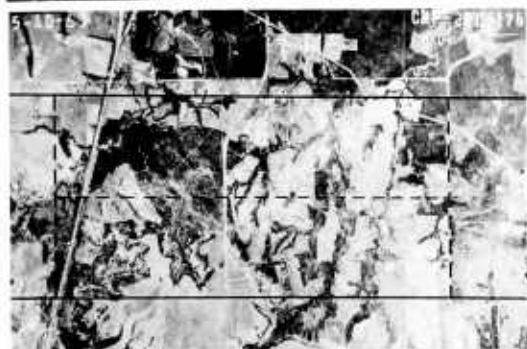
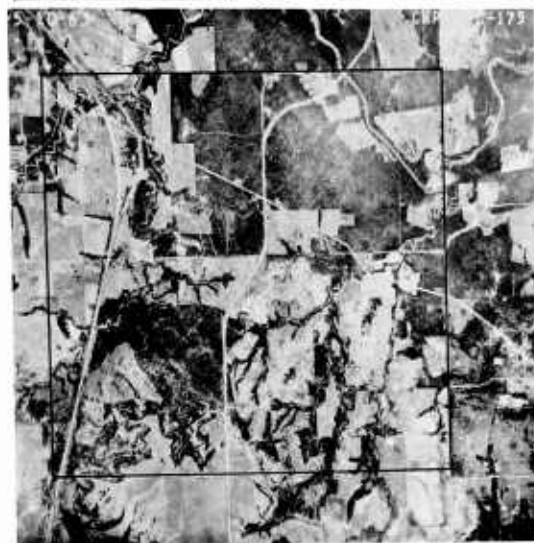


Figure 19.—Steps in preparing aerial photographs for easy stereoscopic viewing in the field: Mark match lines on mapping photograph (left center). On alternate adjacent photographs sketch exactly half of the mapping area (left top and bottom). With a sharp instrument, trim upper and lower lines on alternate photographs. Cut through the emulsion only across the center of each trimmed section (dashed lines, left top and bottom) and fold along the cut line with the emulsion side out. Position the trimmed sections for stereoscopic viewing (right center) and tape them outside the viewing area (right bottom). Fold under for viewing the edge of the mapping photograph (right bottom) and out for viewing the center.

SOIL INTERPRETATION FROM AERIAL PHOTOGRAPHS

Aerial photographs are widely used as a base on which to plot data about soils and to draw boundaries between kinds of soil with or without the aid of a stereoscope. Stereoscopic interpretation of aerial photographs gives a soil scientist additional clues about the kinds of soil he is likely to find and especially about where the soil boundaries lie. There are of course limitations. No one can "see" a soil on an aerial photograph. A soil is a three-dimensional unit of the landscape. It has depth. From the picture the soil scientist can see only the surface—and that imperfectly. He can see the third dimension only by digging a pit.

Yet the study of aerial photographs gives important clues about the shape of surfaces, the vegetation, and the soil color. Often these patterns are repeated over large areas. By studying examples of landscapes that make up patterns along with excavations and borings, and supplementing these with laboratory data, the soil scientist can learn the local relationships between specific kinds of soil and patterns in the photographs. This helps him in plotting soil boundaries more accurately and rapidly. It helps him with exploratory or reconnaissance soil surveys that are often made before detailed soil surveys of specific parts of a large area or region. Even so, limitations in such observations can only suggest soil identification in detailed surveys. Many soil surveys are used as a basis for predicting the systems of soil and crop, range, or forest management that can be carried economically on a sustained basis. This involves specific predictions about adapted crops and the yields that may be expected of these crops by kinds of soil under alternative systems of management. To be reliable, the kinds of soil and the soil mapping units must be identified from ground observations. The principle here is not one of "either-or." Even though we cannot make a reliable soil map from examining aerial photographs alone, the photographs should not be ignored; soil maps can be made more accurately and more rapidly with good photo interpretation than without it.

Exploratory or reconnaissance soil surveys have an important place in areas having little soil suitable for cropping or in areas where the proportion of soils suitable for cropping is unknown. If sizable areas of soils suitable for

intensive use are discovered by these surveys, they can be covered by detailed soil surveys for planning such use. Approximate identification of the kinds of soil can be made by interpretation of aerial photographs, and a suitable soil map can be produced provided that adequate examples of each kind of soil have been studied on the ground.

It is extremely important that the limitations of photo interpretation in soil mapping be understood. Some so-called "soil maps" have been made with little or no groundwork by soil scientists. Since soil maps made in this way are bound to be misleading if used for giving the definite recommendations that land users require, such work discredits both soil science and photo interpretation of aerial photographs.

There are several reasons why one cannot expect to produce accurate soil maps from aerial photographs alone. For example, certain kinds of trees and other native plants in one combination of climate and landform indicate a soil suitable for agriculture; in another combination of climate and landform the same or similar plants are not reliable guides. Man has played an important role in altering the relationships of vegetation, climate, and landform. He has removed or drastically altered the original vegetation in many places. Even though wild plants have been allowed to return, they may not be the same kind of plants as were there earlier. The soils in the northern Lake States illustrate how misleading vegetation can be. If the soils have been cut over and not burned, one type of forest comes back. If they have been cut over and burned, another type appears. If the burning continues for many years, still another type will occupy the soil for some time. Other areas of these soils may have been cultivated a while and then abandoned to wild plants of still a different association. Some places take 200 to 300 years for anything like the original vegetation to return. Unless these matters are made clear through ground study and unless the interpreter is familiar with this detailed knowledge the chances for error are great.

Most soil maps are made for giving information to land users about how the soils respond to management that involves substantial changes in the soil. On the whole, crop plants require a considerably higher nutrient status of soil

than do wild plants. Many soils that appear to be infertile in a wild landscape can be made productive through the use of chemicals, water-control practices, and proper plant species. Other soils that look the same to a casual observer cannot yet be made productive perhaps because of certain characteristics beneath the surface or perhaps because science has not yet found out how.

All soil scientists and students of plant geography are familiar with the close relationship in many places between kinds of soil and nature of the parent material, relief, climate, vegeta-

tion, and age of the landform. Thus broad soil zones do correspond roughly to broad climatic and vegetation zones. Yet near the margins between these zones some small factor such as wind velocity or amount of calcium carbonate in the parent rock may throw the soil along one course of development or another. In large parts of western Alaska for example wind velocity has probably kept the trees much farther east than they would otherwise have been. And in the Mediterranean region, differences in hardness of the calcareous rock cause sharp contrasts in soils lying side-by-side.

IDENTIFICATION ON AERIAL PHOTOGRAPHS

Before aerial photographs can be interpreted, the ground features on the photographs must be identified. Identification is by direct recognition or deduction or a combination of the two.

Objects that make well-defined or familiar images can be identified by their shape, size, and tone on single photographs or on stereoscopic pairs. Road networks, farm buildings, fields, vegetation, and bodies of water can be identified on a single photograph by shape and variation in tone. Position of objects in relation to other features helps identify the objects. Information about land use and management practices also can be learned from single photographs. Additional features are likely to be identified if stereoscopic pairs are viewed through a stereoscope.

VARIATION IN TONE

The tone of an image on a photograph depends on the amount of light reflected by the object that forms the image. Objects that reflect most of the light striking them appear light on a photograph; those that reflect a small amount of light appear dark. On photographs the tones are mainly shades of gray, but they may cover the complete range from black to white.

The amount of light reflected from an object depends on the nature and color of the surface of the object, the degree to which the object is exposed to the sun, and the angle of reflection from the object to the camera. The smooth surfaces of roads and of dry, bare soil photograph almost white from a wide range of camera positions because they reflect much light in many directions (fig. 20). Bare, moist soils photograph

darker than do bare, dry soils. Mirror-smooth bodies of water reflect a high proportion of light in a single direction and photograph white if the light is reflected directly into the camera (fig. 21). They may appear very dark or black on aerial photographs (fig. 22) if the camera lens is moved out of the line of reflected light. Most objects in the landscape, however, reflect at least a small amount of light.

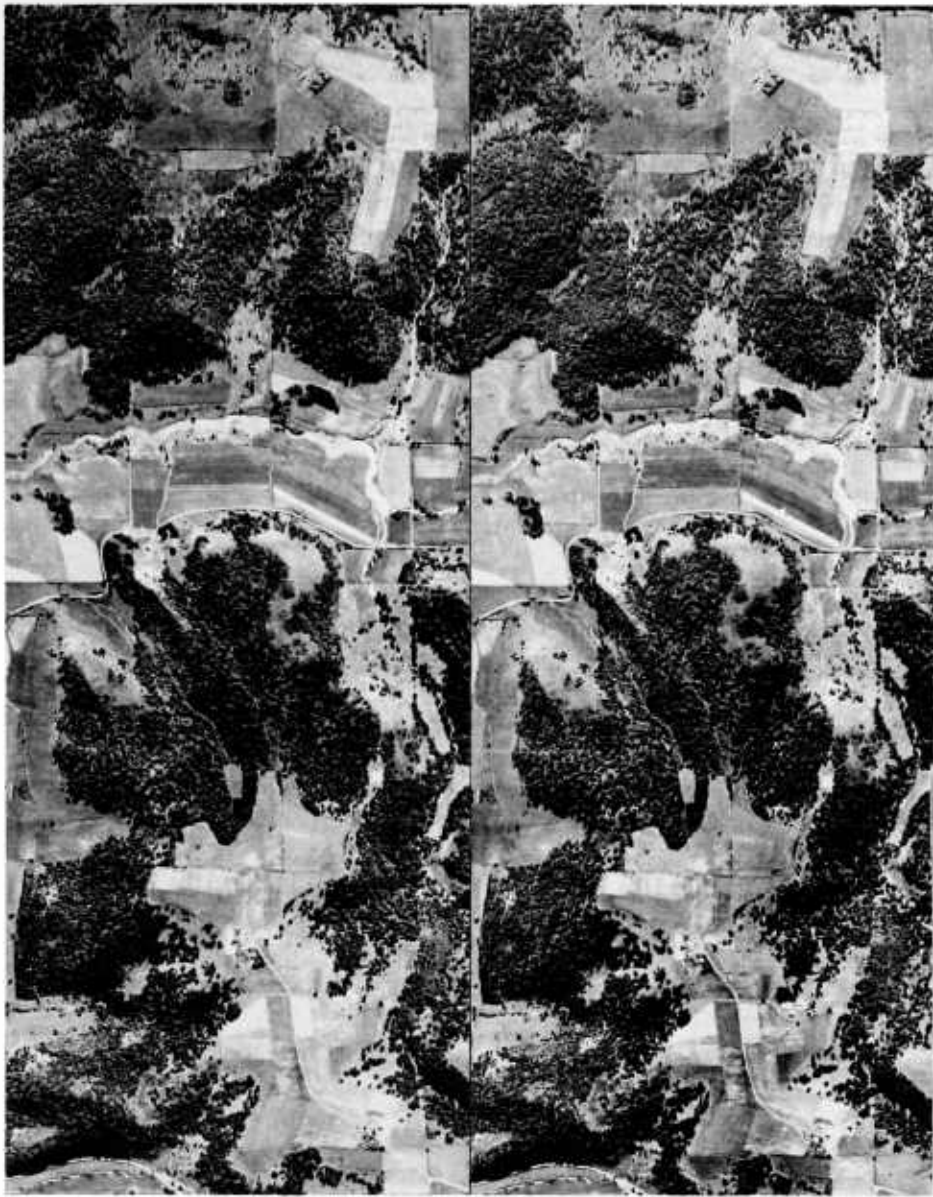
EVIDENCE OF SLOPE

A surface reflects the greatest amount of light when its slope reflects the sun's rays directly into the camera and photographs lightest at this time. Thus, in any single photograph, if differences in slope of the landscape are sufficient, these differences cause variations in tone on the photograph. From the difference in tone, slope can be inferred. Frequently differences in slope not disclosed by inspection of a single photograph can be discerned by comparing two photographs of the same area taken at different times. The change in position of the sun changes the angle of reflection and shows evidence of slope.

Evidence of slope derived by comparison of tone is particularly useful in forested areas where minor variations are obscured by trees and do not show in stereoscopic observation. Trees appear lighter in areas sloping toward the sun than in areas sloping away from the sun.

SHADOWS

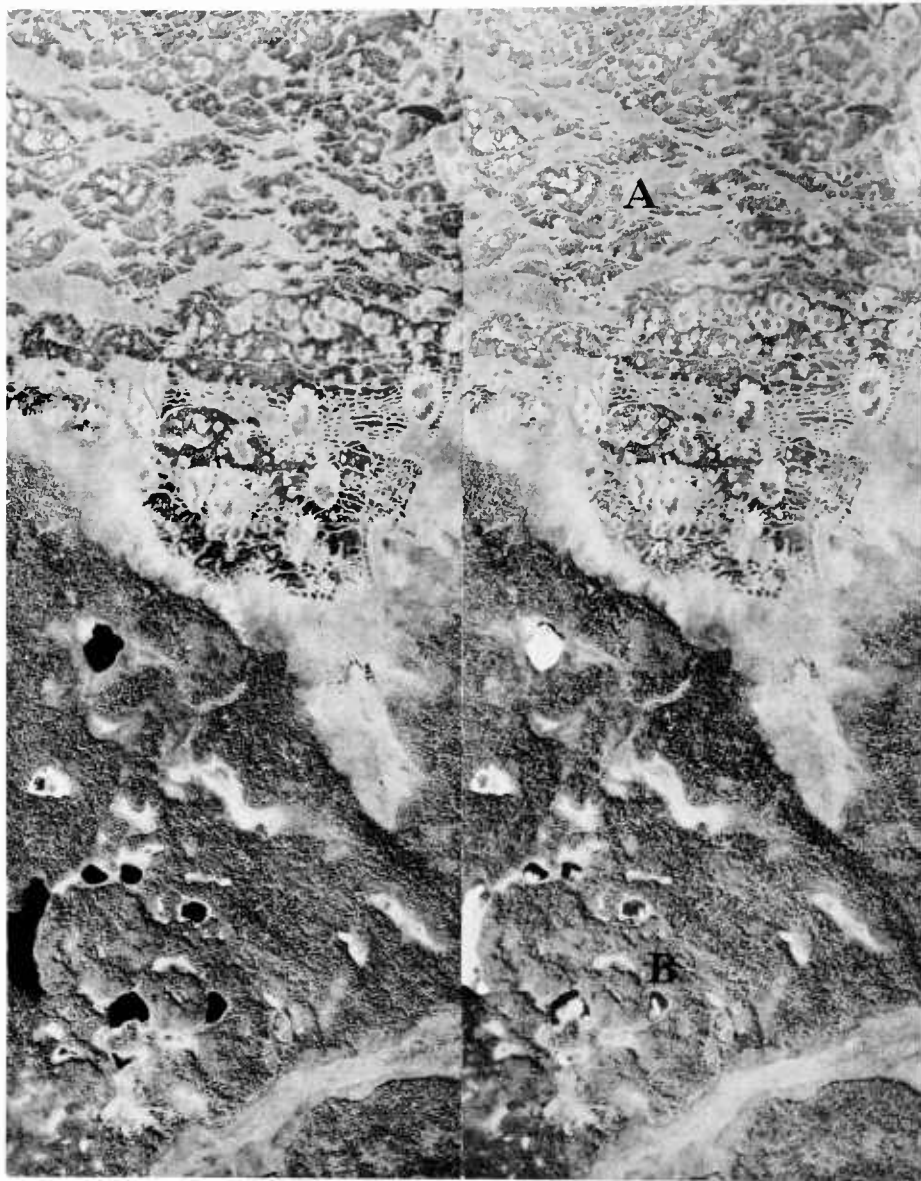
Shadows covering relatively large areas suggest that the landscape has steep slopes and high landforms (figs. 23 and 24). The length of shadows varies with season of year as well



SCALE 1: 20,000

NA—SP-1A-36; SP-1A-37

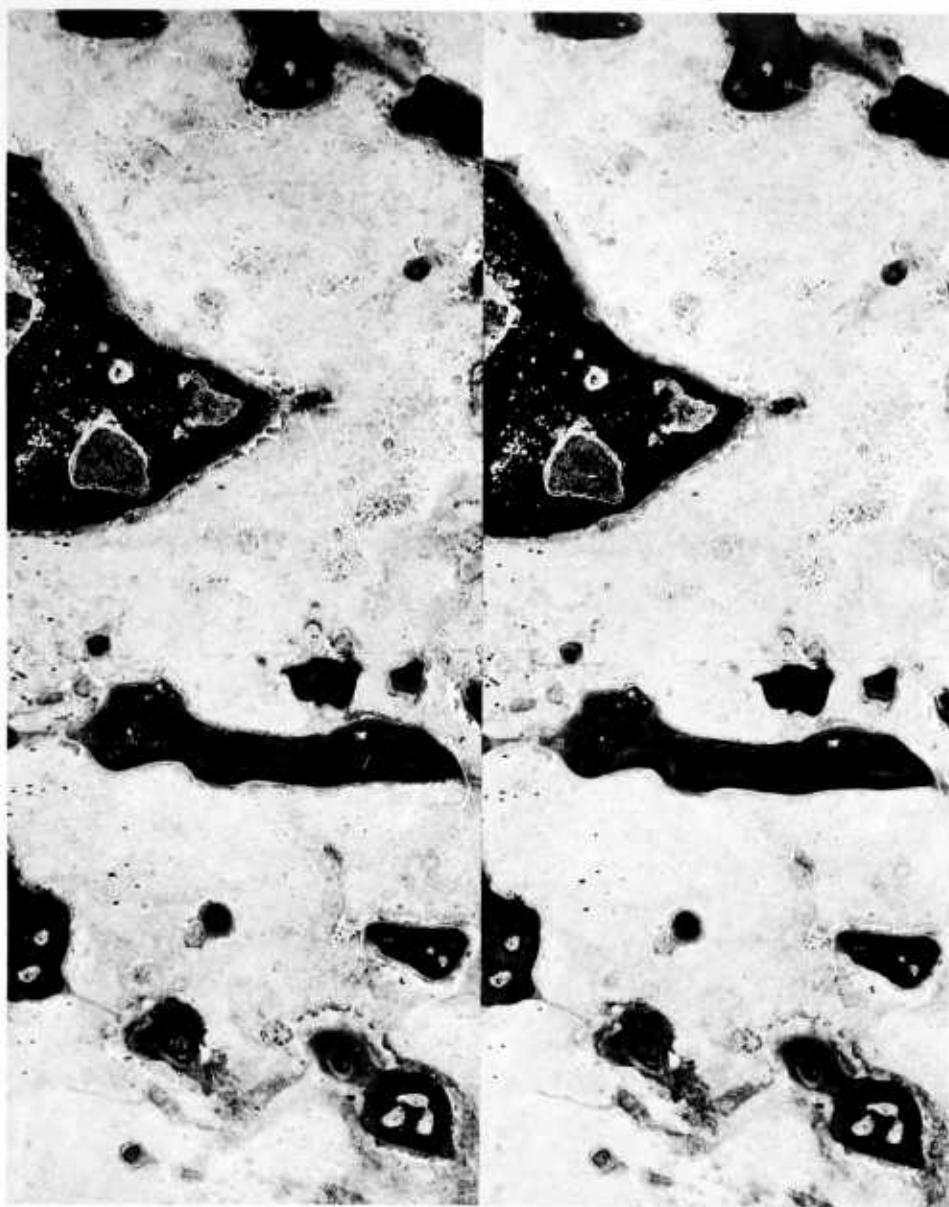
Figure 20.—Roads photograph as narrow white lines with sharp boundaries. Light tones of unforested uplands and stream terraces represent Gray-Brown Podzolic soils. The mottled dark tones represent forested areas mainly of rough stony land or limestone outcrop land.



SCALE 1:40,000

USGS—M-351-88, M-351-87

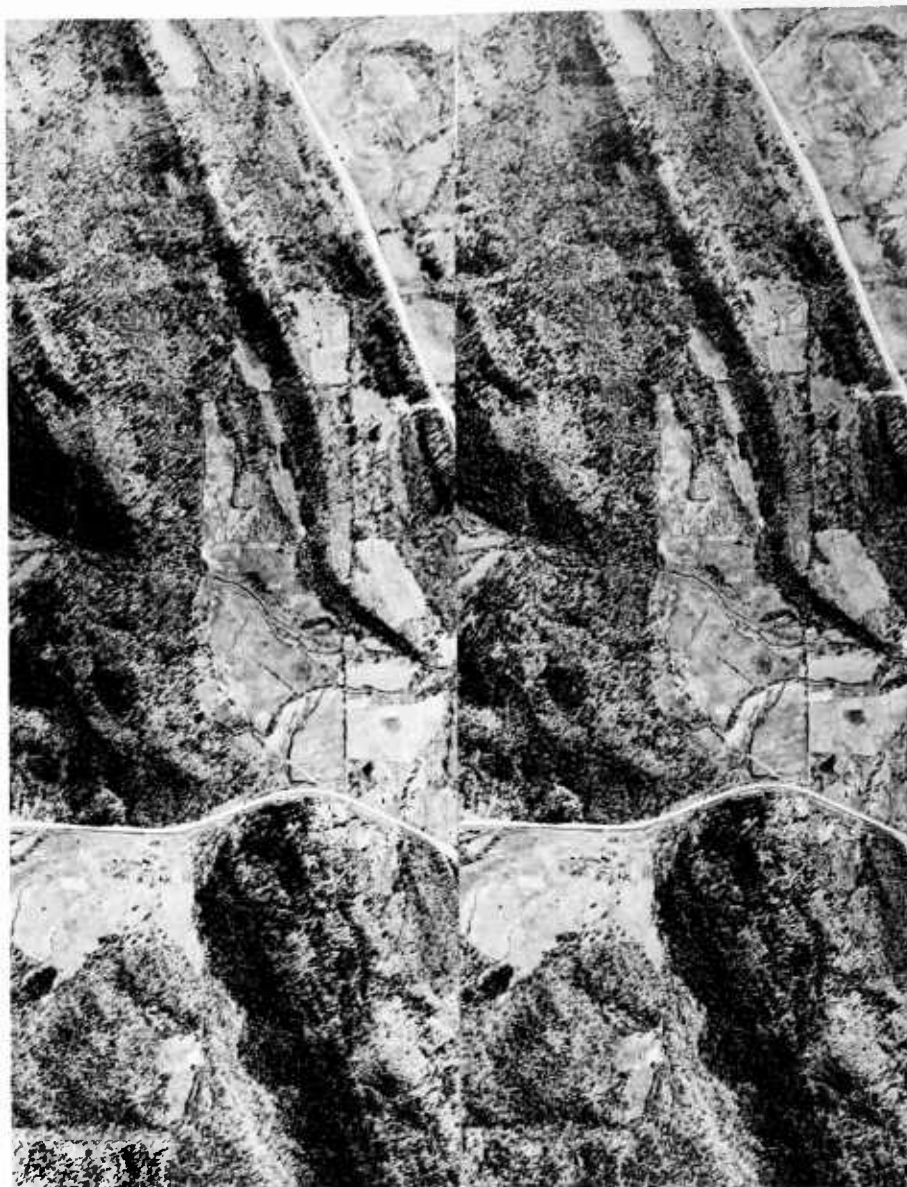
Figure 21.—Contrasting tones of two images of the same body of water in Alaska, one white and one very dark gray, show the effect of shift in camera position. In the upper part, labeled A, is the typical mottled image that represents sphagnum peat (muskeg) without permafrost. The part labeled B represents hilly glacial moraine with lakes and smaller muskegs.



SCALE 1:20,000

ASCS—CYW-4H-90; CYW-4H-89

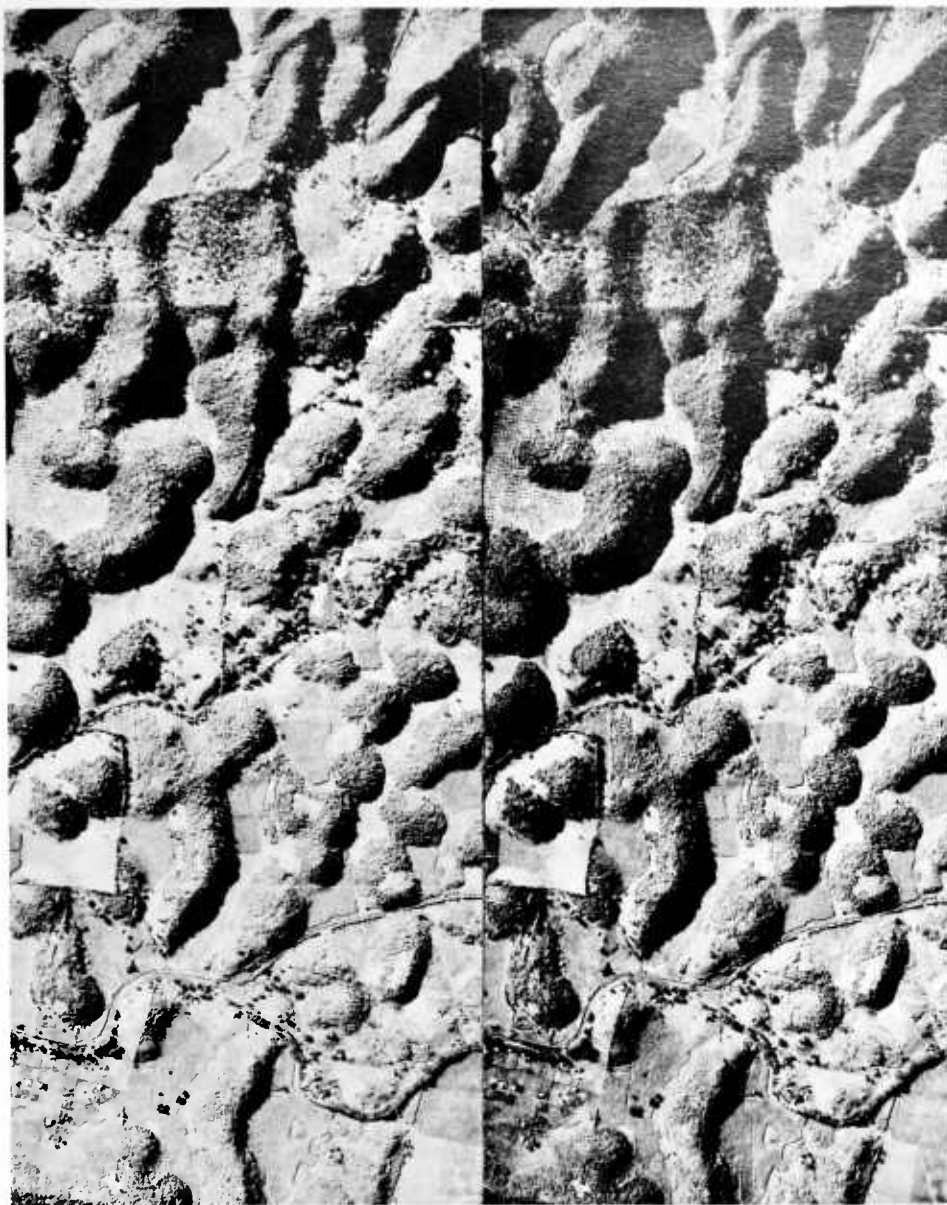
Figure 22.—The light and dark tones on these photographs of acid sandy flatwoods in southern Florida indicate soil differences and bodies of water. The large black areas are images of water. The mottled, very dark, small, rounded spots represent basins of Low-Humic Gley soils and the light-gray background, Ground-Water Podzols between the depressions.



SCALE 1:20,000

ASCS—BPV-3G-80; BPV-3G-79

Figure 23.—Shadows in dark tones on northwest slopes (north is to the left) suggest steep slopes and high landforms in an area of shale and sandstone in Arkansas. Knowledge of the soils on opposite slopes, which differ in lithology, permits a soil scientist to make reasonable deductions about the soils photographed.



SCALE 1:15,000

DEPT. OF PUB. WORKS, SANTURCE, P.R.
GS-LR-5-20; GS-LR-5-21

Figure 24.—The pronounced relief of this area in north-central Puerto Rico is apparent from the shadows of the forested hills and the topographic contrast is striking even without a stereoscope. Most of these extremely steep hills have rounded tops; a few are somewhat elongated.

as with time of day. The forms of shadows can be used to identify some structures and certain other cultural and natural features. For example, the image of a bridge may not show whether the bridge is supported by a trestle or an arch, but the shadow cast by the bridge may.

CONTRAST

Contrast refers to distinctness of tones as opposed to gradations in tones. Black and white are the extremes of contrast. Photographs with very dark and very light tones and only a few middle tones have high contrast.

The amount of contrast is determined partly by variations in the capacity of objects to reflect light and partly by the clearness of the atmosphere and by the photographic techniques used. Atmospheric haze scatters light and reduces contrast. The contrast in photographs taken on bright days is greater than in photographs taken on dull days. Soil when wet absorbs light and photographs darker than when it is dry. Contrast changes from season to season but not uniformly from region to region.

A land surface broken by variations in kinds of slope, by differences in soil, vegetation, and land use, and by manmade objects will have more contrast than a land surface fairly uniform in topography, soil, and land use. A hilly landscape in the Southeast that is marked by forests, fields in crops, freshly plowed land, and severely eroded patches produces a photograph with more contrast than a smooth area of rangeland or desert in the Southwest.

Contrast can be increased or decreased by varying the exposure time or the time for developing film and by the paper used for making prints.

SHARPNESS OF BOUNDARIES

The sharpness of boundaries between tones is affected somewhat by the photographic techniques used, but the distinctness of boundaries will differ for different objects. Boundaries of forests, wet areas, and topographic features are generally diffused; boundaries of fields, bodies of water, highways, and railroads are usually sharp.

TONE PATTERNS

Certain landforms and culture have characteristic tone patterns on aerial photographs.

Forests, fields, crops, and orchards frequently show distinguishing patterns as do networks of streams, roads, or ditches. The photo interpreter learns the characteristic patterns of the area—for example, dendritic or parallel patterns of drainageways—and uses these to help him identify objects. Figures 25–34, 39, 45, 46, and 56 illustrate various tone patterns.

PERCEPTION OF DEPTH

Some topography difficult to deduce on a single photograph may be seen readily by viewing stereoscopic pairs (figs. 32, 33, 34, and 35). Many items not identified readily on a single photograph are easily recognized; items distinct on a single photograph can be observed in greater detail. Everything that reveals itself by shape and even slight differences in tone generally can be identified with greater certainty.

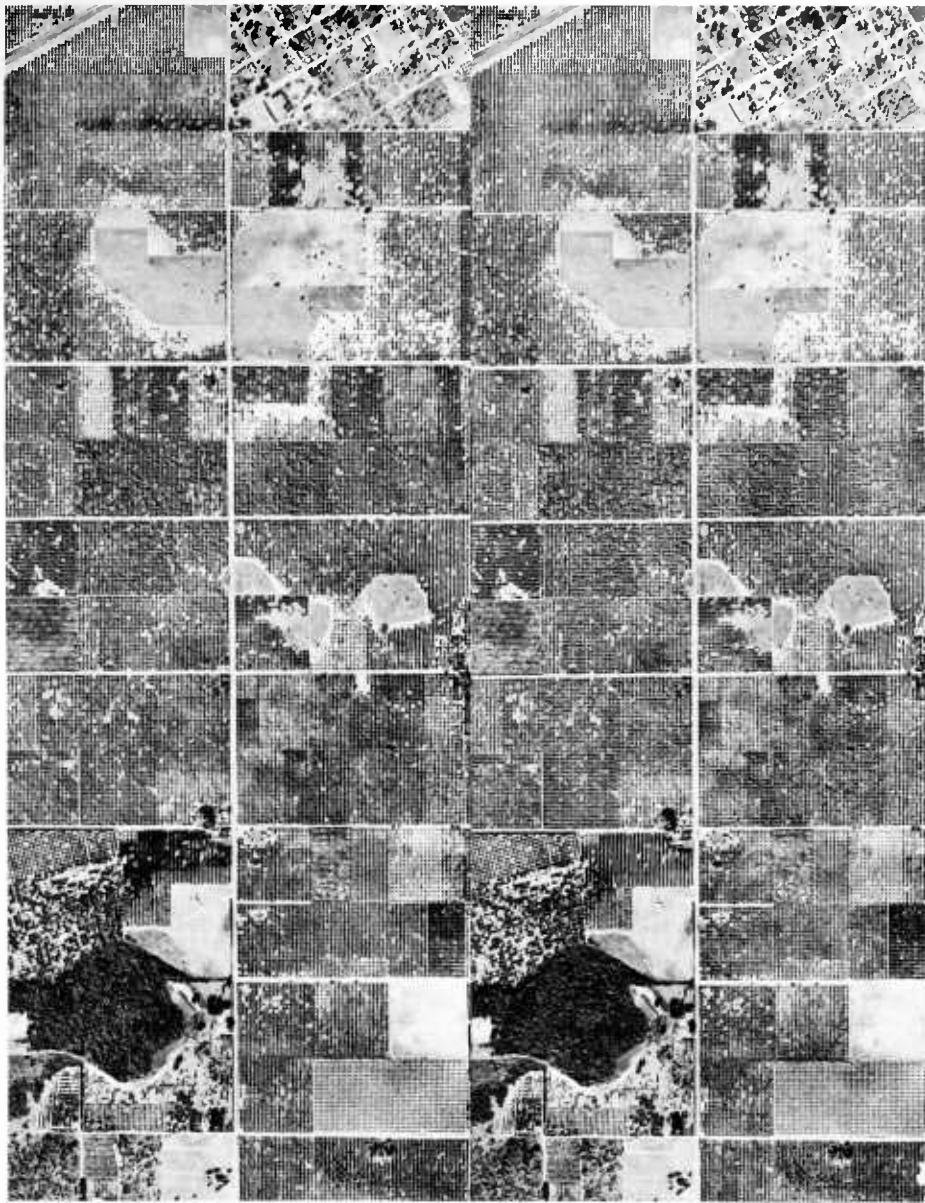
With depth perception to aid him, the soil scientist needs only a little practice to distinguish rough mountains and steep, hilly, rolling, or level areas. He can improve his ability to recognize certain landscapes by frequently comparing the topography as it appears on stereoscopic pairs with its appearance on the ground.

IDENTIFICATION OF LANDFORMS AND OTHER NATURAL FEATURES

Natural features are generally more difficult to detect than are manmade objects or cultivated fields and other areas where man has disturbed the native cover. Low natural hills, for example, generally are more difficult to detect than are embankments because embankments have steeper slopes and more regular lines.

Some simple landforms such as terraces, flood plains, and sand dunes (fig. 36) can be identified by their shape, relative height, slope, and drainage pattern. Identification of features such as ground moraines, shale plains, and limestone uplands is difficult and can be inferred only in part by studying aerial photographs.

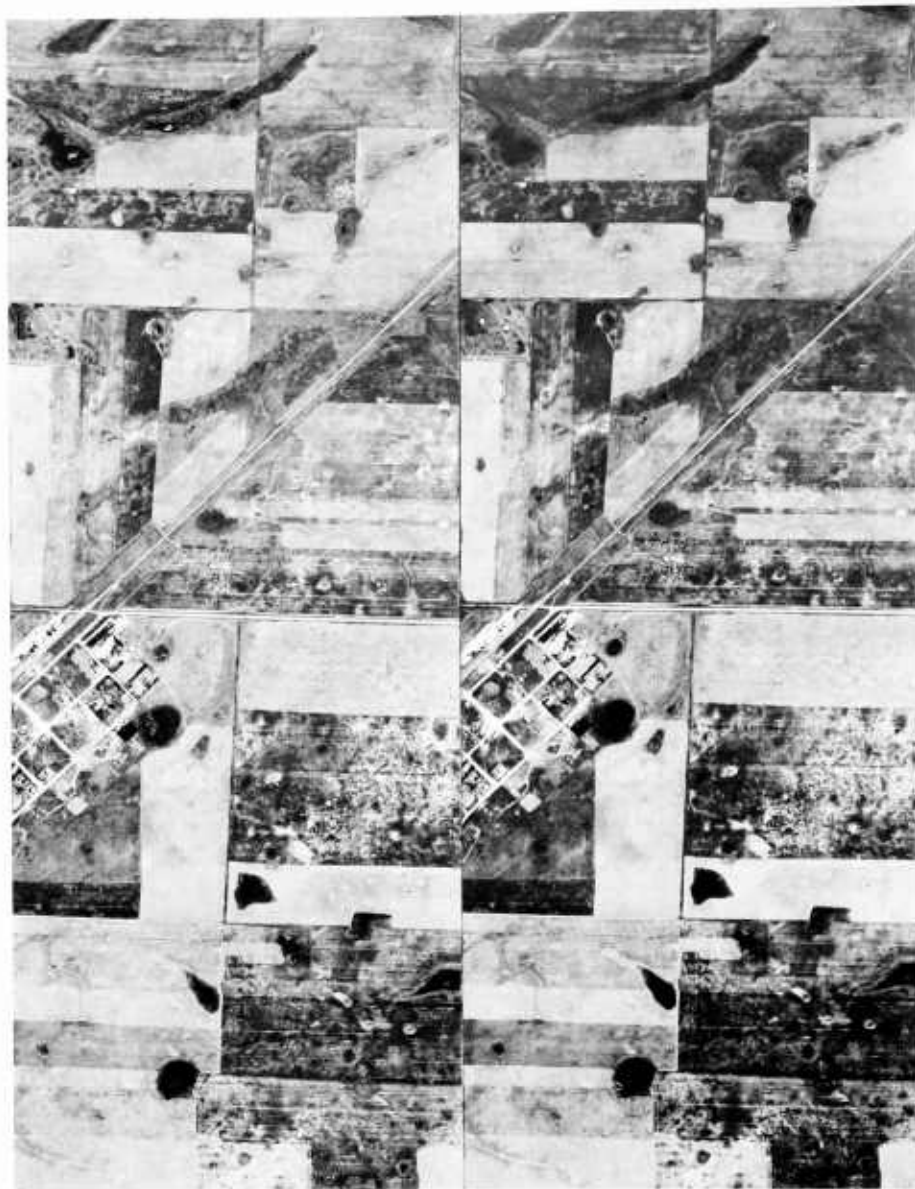
Ground Moraines.—Ground moraines in many places produce contrasty photographs because they have many small, shallow, irregularly shaped depressions and intervening gentle slopes. The slight difference in elevation between depressions and intervening slopes can be discerned on a stereoscopic pair. Soils in the depressions photograph dark; others photograph light. (See figure 45.) If there is a



SCALE 1:20,000

ASCS—CTU-13H-55; CTU-13H-56

Figure 25.—These photographs show the characteristic field patterns of Florida citrus orchards on acid, coarse-textured soils. The citrus trees photograph as black dots within the rectangular fields.



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ASCS—BAM-9M-136; BAM-9M-135

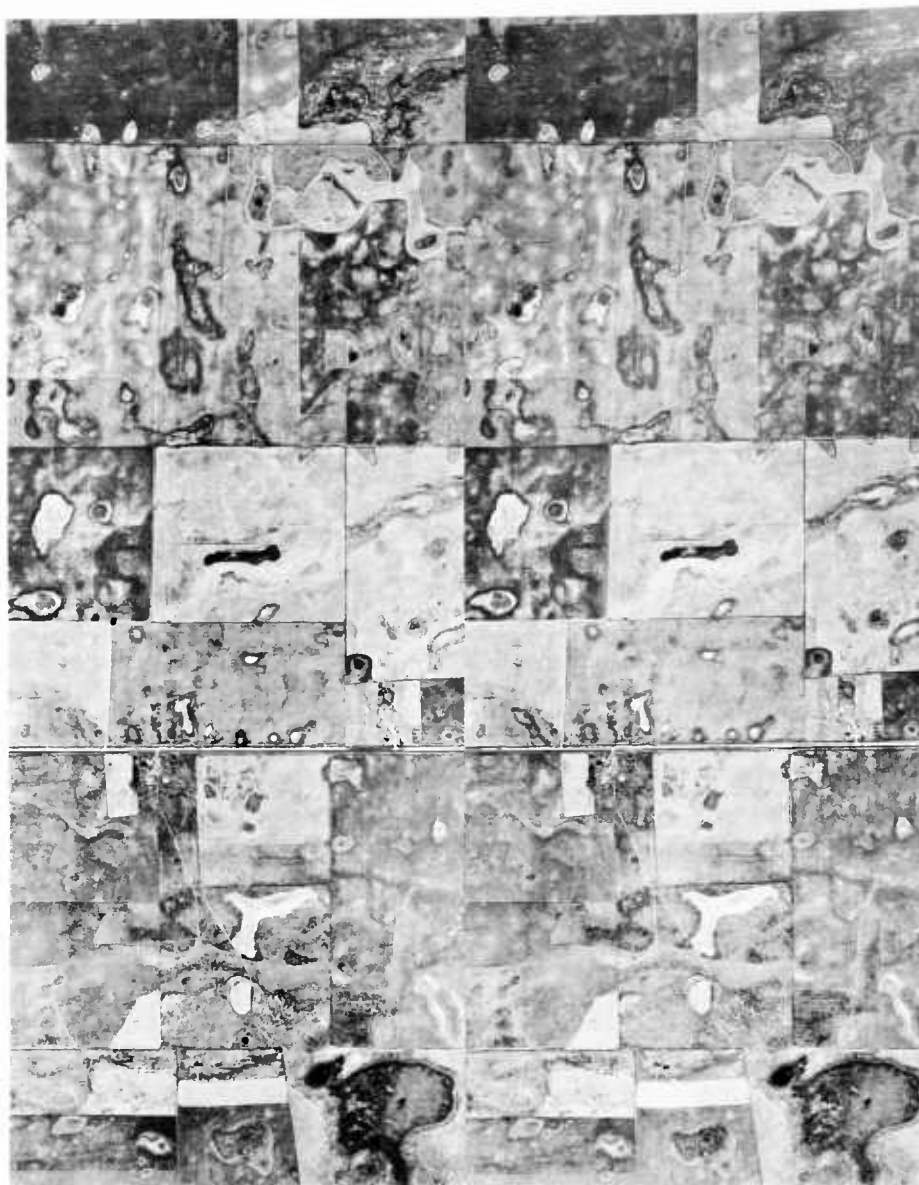
Figure 26.—In these large rectangular fields in North Dakota the speckled pattern of very light tones against a darker background shows a complex association of Solonetz soils (light tones) and Chernozems (gray background). Where the speckled pattern is absent the soils are mainly Chernozems. The isolated, very dark spots indicate somewhat poorly drained to poorly drained Planosols in depressions. The cluster of small rectangles in the center represents a small town.



SCALE 1:20,000

NA—BCM-1-47; BCM-1-46

Figure 27.—In this area of uniform lithology in Ohio, distinctions between soils are closely related to topographic variations readily recognized under a stereoscope. Soils on flood plains, on drainage divides, and on steep valley sides can be easily delineated. White streaks with feathered edges and orientation with slope are likely to indicate eroded areas. White streaks oriented laterally on steep valley sides may indicate rock ledges.



SCALE 1:20,000

ASCS—CWM-3K-183: CWM-3K-182

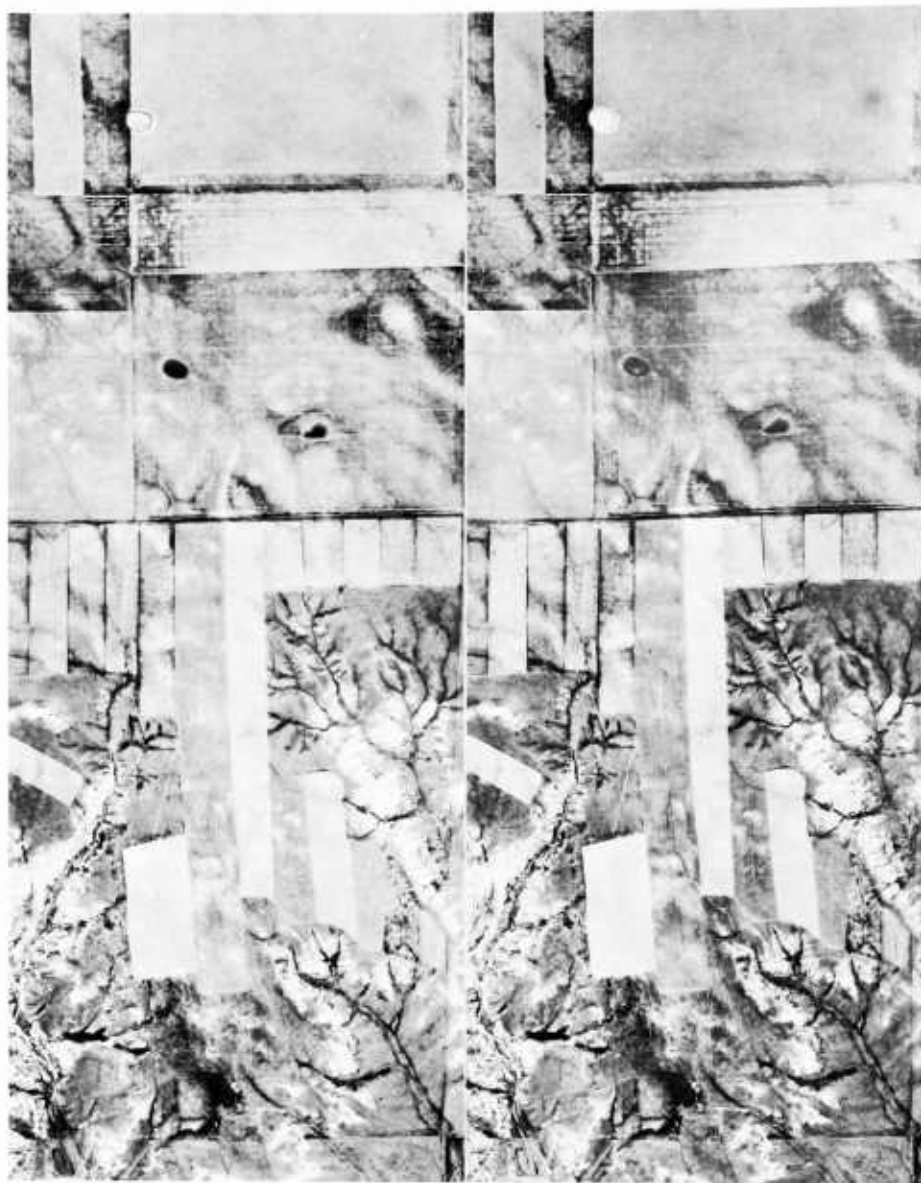
Figure 28.—The mottled pattern of light and very dark tones on a gray background represents an association of calcium-carbonate Solonchak soils, Humic Gley soils, and Chernozem soils on the till plain in North Dakota. The Solonchak soils photograph light. Those somewhat poorly or poorly drained have a finely mottled appearance and are within or adjacent to kettles. Humic Gley soils, which usually register dark, occupy the deepest parts of the kettles. Kettles are small subrounded spots with sharp boundaries. The moderately well drained Solonchak soils have a patchy appearance and are in with Chernozem soils, the gray background in the photograph; the lightest shades indicate tops of low knolls or undulations. Compare the sharp outlines of the roads, fields, and images of buildings with the diffuse soil boundaries.



SCALE 1:20,000

ASCS—1Z-5G-181; 1Z-5G-182

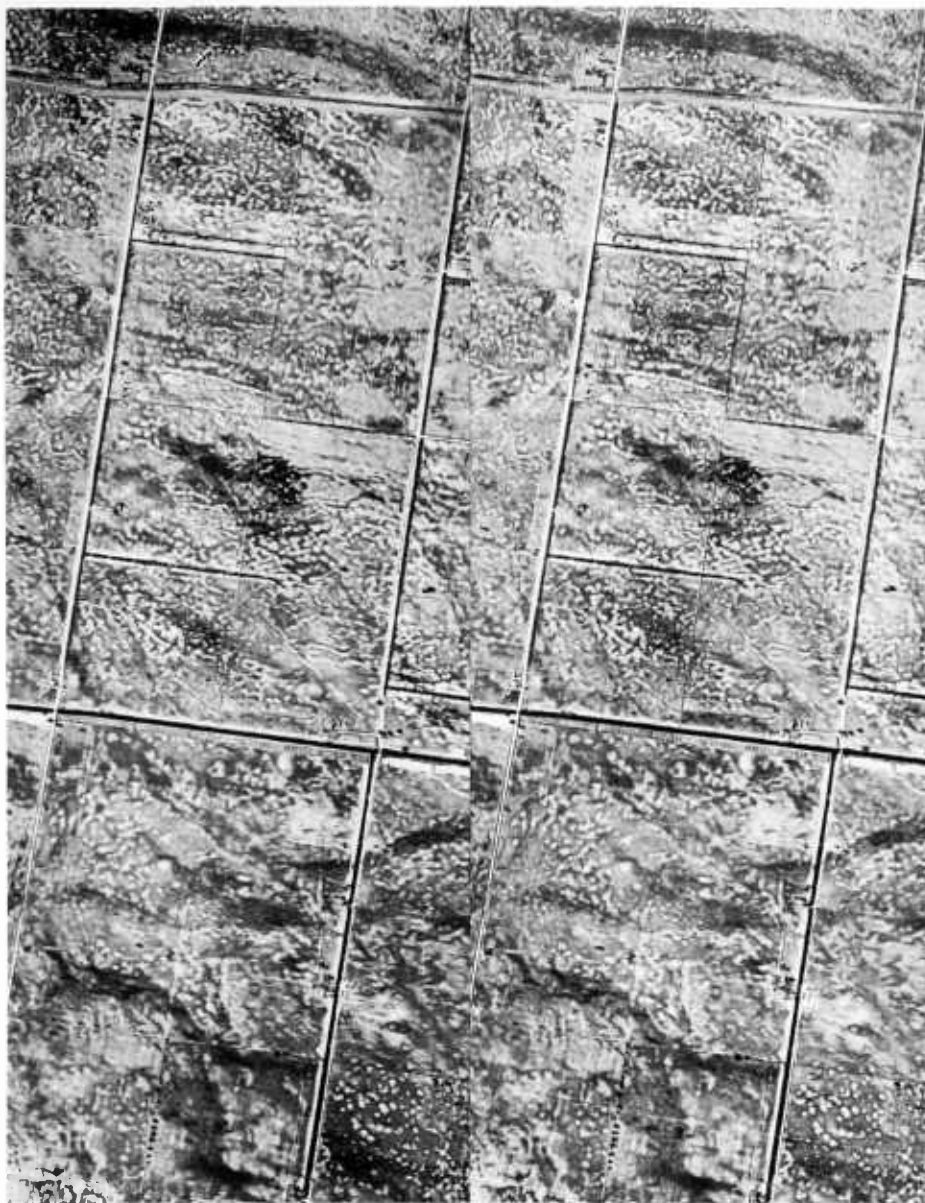
Figure 29.—This pair of photographs of an area in Georgia illustrates differences in topography, land use, and drainage pattern between soils in limestone valleys and on adjacent ridges of metamorphic rocks. At B are Lithosols in residuum from schist. They are strongly sloping to steep and are forest covered; the drainage pattern is dendritic. Light areas marked L are mainly Red-Yellow Podzolic soils and Alluvial soils. The Red-Yellow Podzolic soils, mainly on uplands, are in limestone residuum and are gently sloping to hilly. The Alluvial soils, on bottom lands along streams, are nearly level; the drainage pattern, modified by local sinkholes, is indefinite except along large streams.



SCALE 1:20,000

ASCS—CAW-2N-125; CAW-2N-124

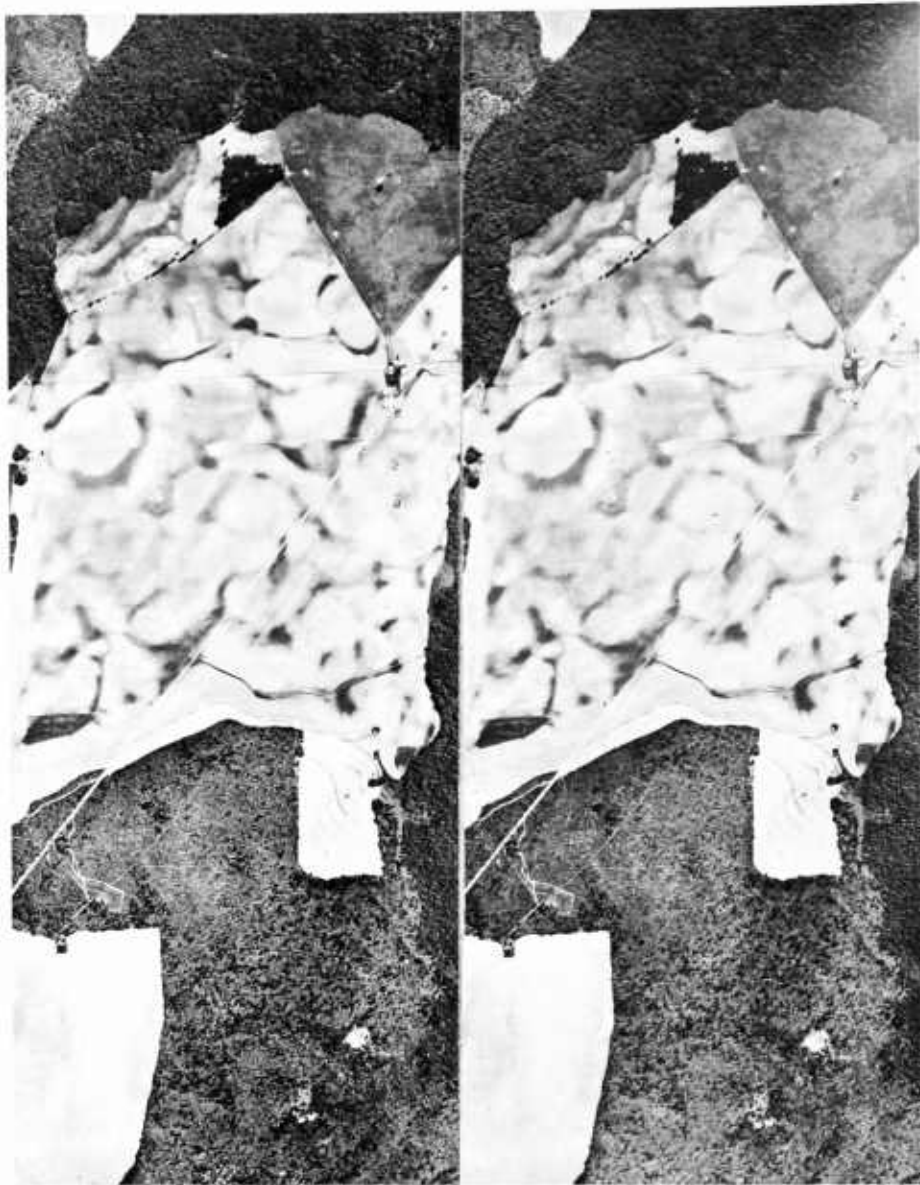
Figure 30.—The gray tone in most of these photographs represents moderately dark-colored Chestnut soils in thick deposits of loess in western Nebraska. The intensely mottled light-colored pattern in the lower part represents Lithosols, exposed residual parent materials, and rock ledges on the walls of narrow, steep-sided valleys. Narrow stream bottoms form a dark skeletal network. A gorgelike cross section is easily distinguished under a stereoscope as are hard rock ledges on the valley sides.



SCALE 1:20,000

ASCS—EK-2F-79, EK-2F-80

Figure 31.—The intricate pattern of light and dark tones shows a complex pattern of rapidly drained very sandy soils and poorly drained soils in Arkansas. The sandy soils register light and the poorly drained soils, occurring in flat or slightly depressed areas, register dark.



SCALE 1:20,000

ASCS—KM—JE—13F—12; KM—JE—13F—11

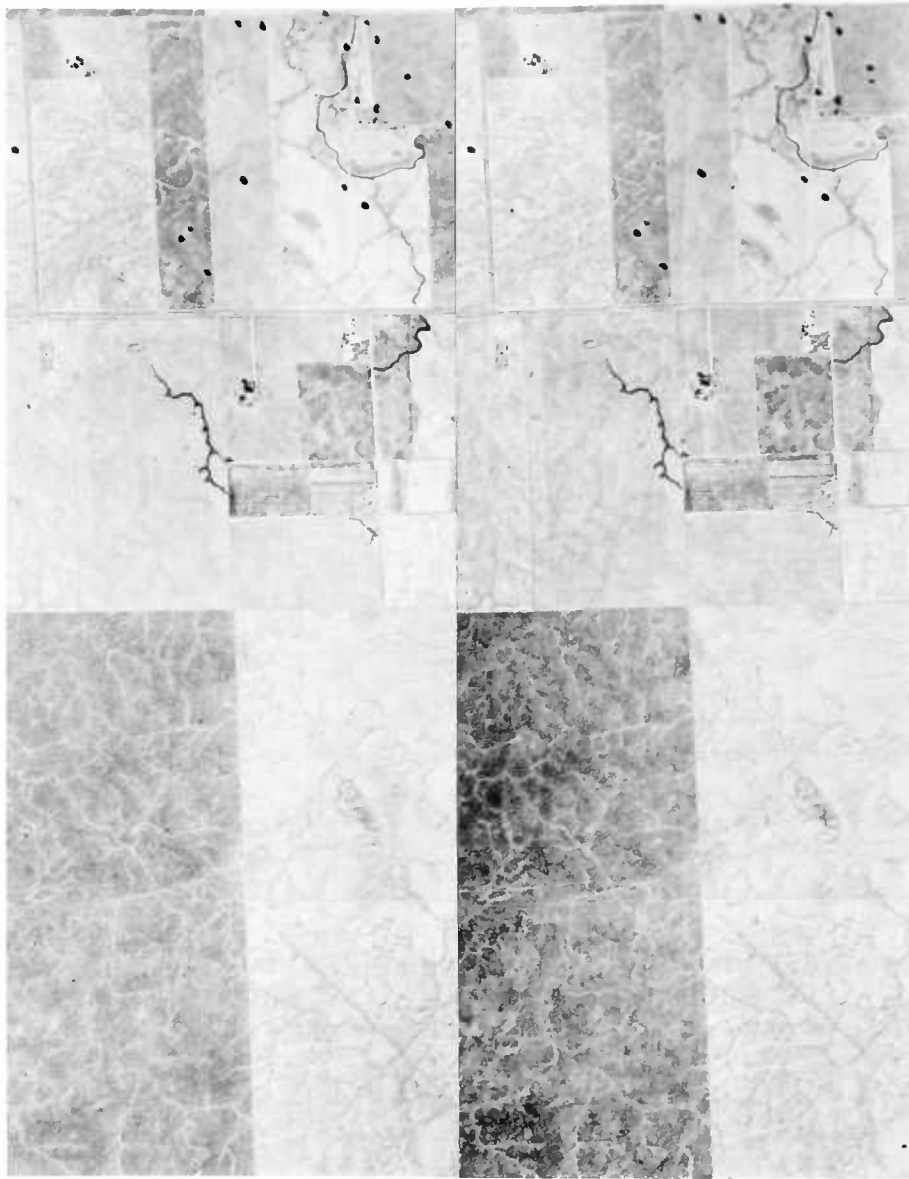
Figure 32.—The relationship of microrelief to soils on sandy terraces in parts of the Coastal Plain of the Southeast is apparent from the marbled pattern of these photographs. Well-drained soils that have fine-textured subsoils and raised flat to slightly convex surfaces are represented by the light tones, and poorly drained Low-Humic Gley soils in the slight depressions by the dark streaks. The microrelief cannot be seen without a stereoscope.



SCALE 1:20,000

ASCS—LH-3F-38; LH-3F-37

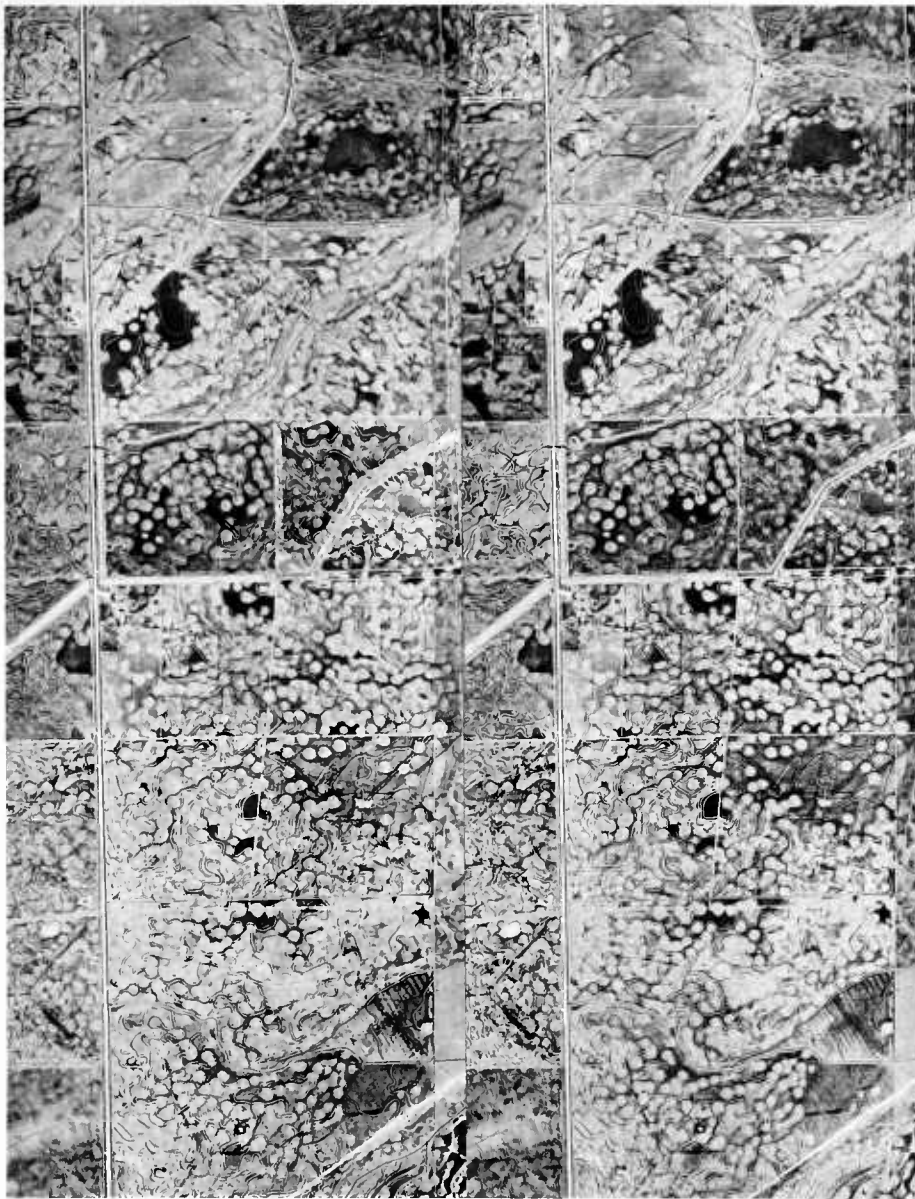
Figure 33.—As in figure 32, the marbled pattern illustrates the relationship of microrelief to soils on sandy terraces in parts of the Coastal Plain of the Southeast. These soils, however, are sandy throughout and lack the fine-textured subsoil of those in figure 32.



SCALE 1:20,000

ASCS—ABD-2K-129; ABD-2K-128

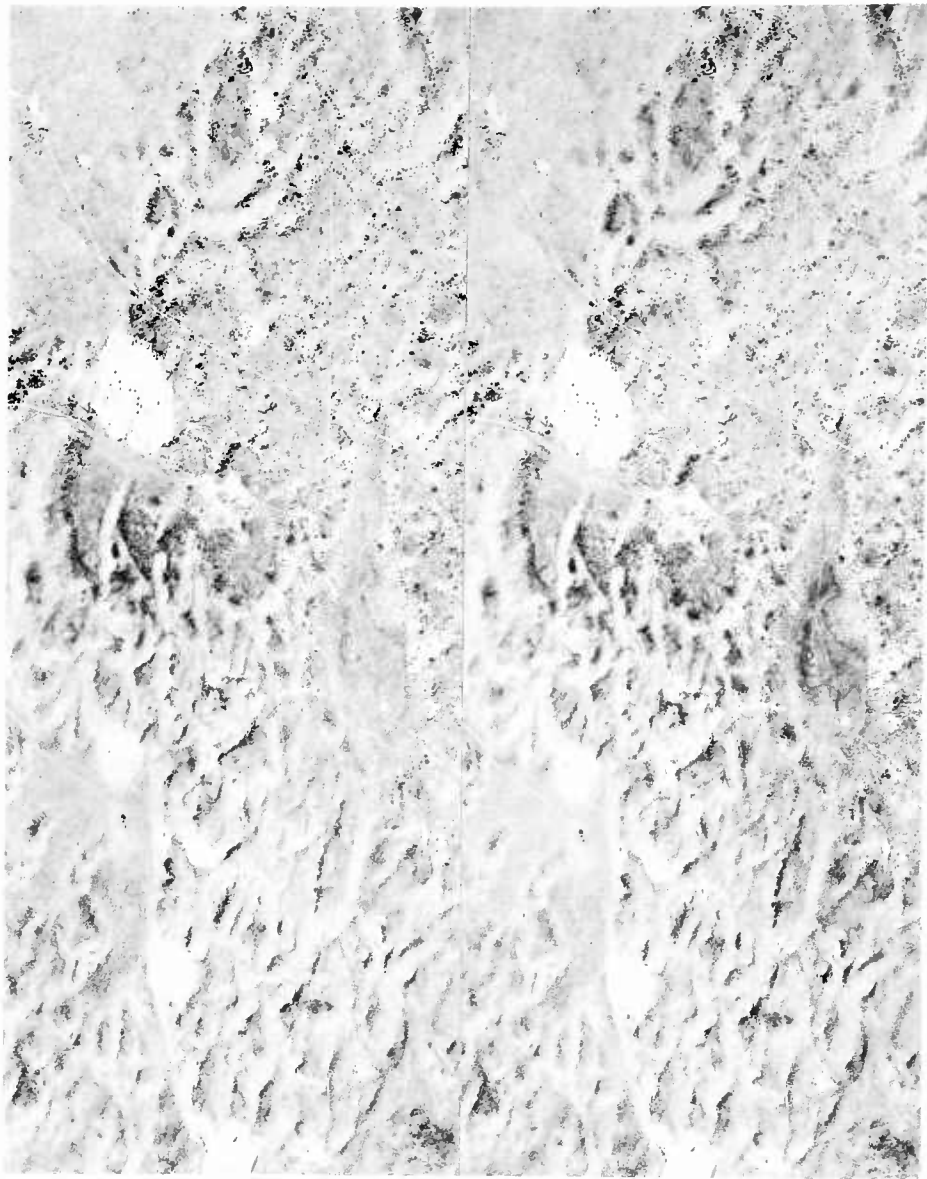
Figure 34.—The reticulate pattern of small drainageways and intervening low mounds in these photographs of an area in California illustrate soils with hardpans at depths of 1½ to 2½ feet.



SCALE 1:20,000

ASCS—CJY-1H-200 CJY-1H-201

Figure 35.—The mottles on these Louisiana photographs identify mounds 30 to 75 feet in diameter and 1 to 5 feet high. Most of the soils are medium textured; those in the mounds are sandier than those between mounds. The vertical shape of the mounds show under a stereoscope.



SCALE 1:20,000

ASCS—CIK-4F-140, CIK-4F-141

Figure 36.—This pair of aerial photographs taken in eastern New Mexico provides a striking example of how dune topography is revealed with stereoscopic viewing. The soils are sandy Regosols.

drainage pattern, it is weakly expressed and generally coarsely dendritic. Ground moraines that have few depressions and soils that photograph mostly in gray shades do not produce contrasty photographs. Instead of having many irregular depressions they have a dendritic drainage that is not strongly expressed.

Shale Plains.—Shale plains appear more rugged and dissected in a photograph than do ground moraines. Where shale is level bedded the drainage pattern is dendritic. Valleys are steep sided, and all except those of many major streams are V-shaped. Slopes of valleys, hills, and divides are influenced by climate and relative hardness of the shale. In arid areas, where rainfall quickly runs off and vegetation is sparse, soft or clayey shale carves into badlands that have angular valley walls. In humid areas, the hills in shale have rounded tops and the divides are narrow and winding. Hills are lower and more rounded in soft shale than in hard shale.

Limestone Uplands.—Limestone uplands produce a different picture than do shale plains. The differences are most apparent on stereoscopic pairs. Most landforms underlain by limestone with little siliceous material have many sinkholes. Hills are more rounded than in shale plains, streams are fewer and more widely spaced, and stream valleys are more U-shaped. In siliceous limestone there are fewer sinkholes and more tributaries to main streams, and valleys—except those of major streams—tend to be narrower and more steep sided than those in pure limestone.

Rock Outcrops.—Rock outcrops, except those of very dark color, appear as light spots. A shadow is often a clue to an escarpment; on a stereoscopic pair escarpments show as abrupt changes in elevation. Stone fences are clues to stoniness, but on aerial photographs they are difficult to distinguish from other fence rows or field boundaries.

Alluvial Fans.—Alluvial fans may photograph lighter than do adjoining flood plains. But the fans will appear darker if they contain more moisture than adjacent areas. If the outer rim of the fan is wet by seepage, it will appear darker than the inner part.

Alkali and Saline Patches.—Alkali and saline patches in arid regions appear as light spots when dry and as dark spots with white rims when wet. Where there is no white encrusta-

tion or other direct evidence of alkali or salts, the salinity of the area may be inferred from the absence of vegetation or from change in appearance of vegetation. Greasewood, for example, is a large shrub that grows in saline areas where other native plants may not survive.

Drainage Patterns.—In a single photograph, main streams ordinarily can be identified easily, but the irregular curved line of tributary drains are more difficult to recognize. Success in identifying the drainage pattern depends on the relief of the area, the number of tributaries, how easily they can be seen on the photograph, and their orientation to the main stream. Tributaries can be recognized by depth and shape of valleys and slope of valley sides. Figure 37 illustrates drainage patterns.

Under the stereoscope, stream courses in heavily forested areas can be located from the topography of the valley (fig. 38). Where the gradient is steep the direction of flow can be determined stereoscopically by noting vertical differences along the stream. If a single photograph is used, direction of flow has to be deduced from studying other evidence. The width, depth, and shape of a stream channel are best observed by stereo (fig. 39). Drainage patterns are more easily detected stereoscopically even in areas of weak dissection or otherwise subdued relief. Where there are no shadows in such areas, only the larger streams can be recognized in single photographs.

Eroded Soils.—A knowledge of local climate, topography, and soils aids in recognizing sheet erosion and gulying on aerial photographs.

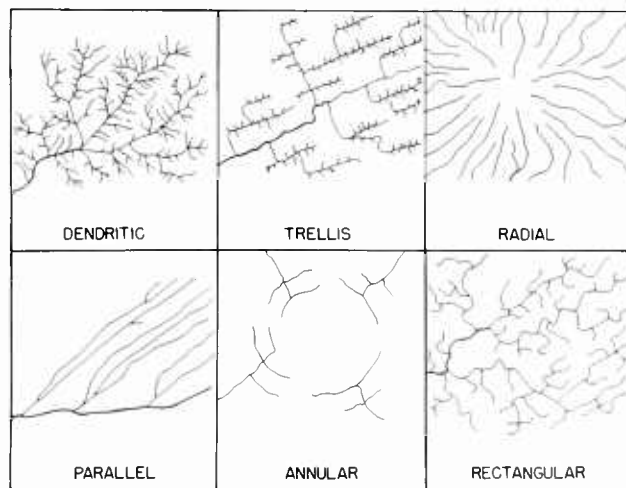


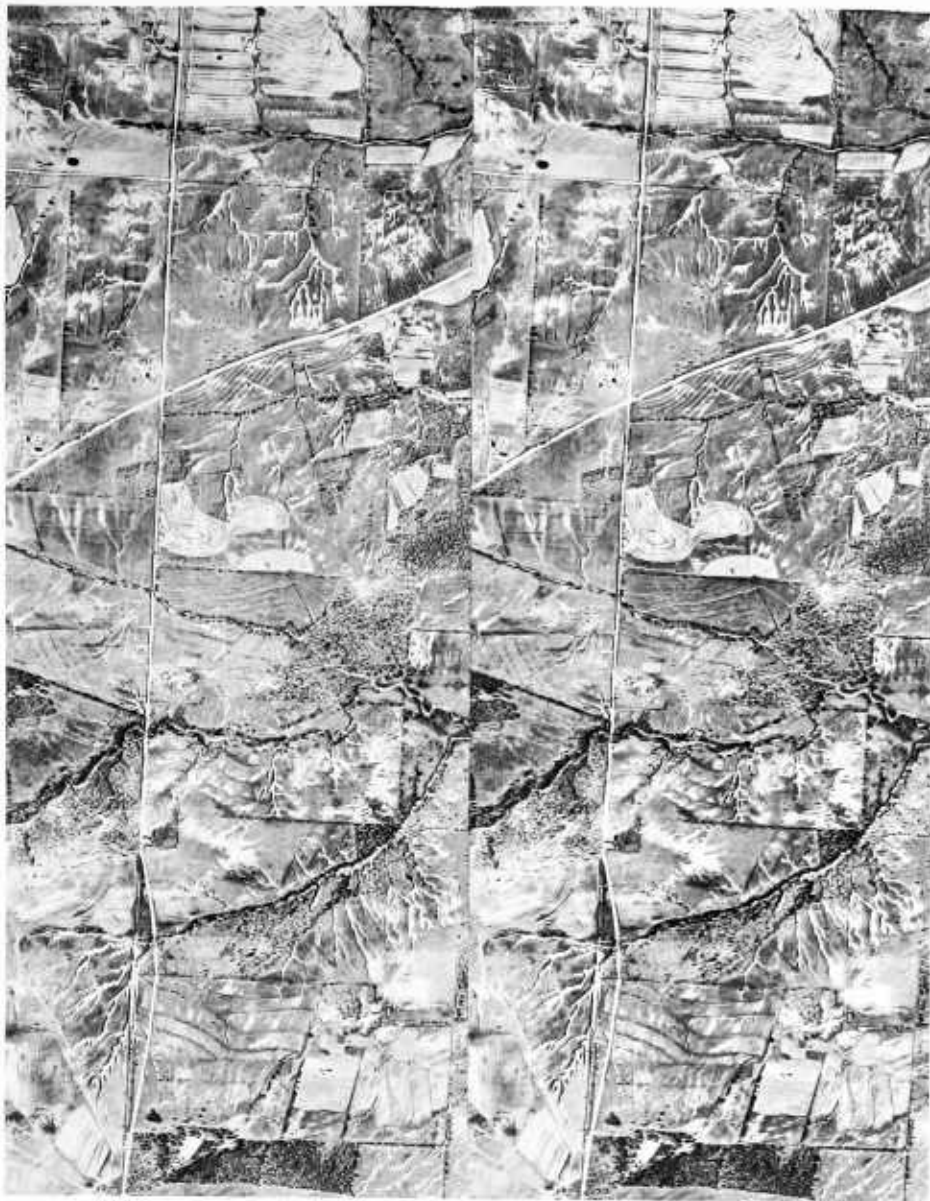
Figure 37.—Six drainage patterns.



SCALE 1:20,000

NA—AVP-1-44; AVP-1-43

Figure 38.—These Arkansas photographs illustrate how a stereoscope helps in delineating soils whose differences are related to topography. Red-Yellow Podzolic soils occupy the smooth upland, Regosols the forested steep valley sides, and Alluvial soils the flood plains of major streams.



SCALE 1:20,000

ASCS—BRG-1E-184; BRG-1E-185

Figure 39.—This stereoscopic pair of an area in Texas provide an excellent example of how erosion appears on photographs. Sheet erosion registers as light and very light areas with diffuse edges and gullies as white networks of long scars with irregular borders. Gullies and stream channels from weakly developed to deep and U-shaped are readily recognized under a stereoscope.



SCALE 1:20,000

NA—CCO-203-42; CCO-203-43

Figure 40.—These photographs show eroded soils and complexes of solodized-Solonetz soils and Chestnut soils from shales in southwestern North Dakota. Light tones that have diffuse borders represent eroded Lithosols or thin weakly developed Chestnut soils. The complex shows a reticulate pattern of light and dark, particularly in the upper parts of the photographs.

Sheet erosion may register in tonal differences and light patches. Seriously eroded areas not covered by vegetation photograph light (figs. 39 and 55). Light tones, however, are not always indications of sheet erosion. The soil scientist takes into account that steeply sloping soils are more likely to erode than those gently sloping, that in areas of subdued relief erosion is likely to occur at the crests of low ridges, and that eroded areas may be covered by crops or native vegetation. He applies his knowledge of plant succession and his ability to recognize different kinds of vegetation on aerial photographs. For example, where the climax vegetation is hardwoods, patches of young pines may mark eroded areas that have been abandoned and are revegetating.

Gullies appear as long scars with definite irregular borders (fig. 39); they contrast with sheet-eroded areas, which have more diffuse and smoother outlines (fig. 27). Gullies are common in natural drainageways and at the boundaries of fields.

Certain characteristics of gullies are related to soils (fig. 41). The gradient and cross section may indicate the kind of parent rock and the soil texture.

Gullies in well-drained sandy soils are V-shaped in cross section and have steep gradients; those in poorly drained fine-textured soils are apt to be saucer shaped in cross section and to have gentle gradients. Gullies in stratified soils have irregular side slopes and abrupt changes in gradient.

Vegetation.—Vegetation is identified on a single photograph mostly by tone, but some that cannot be distinguished by tone alone can be through a stereoscope. Prairies, forests, and cultivated fields are distinct on single photographs (fig. 42). Forest and nonforest, deciduous and coniferous trees, and young and mature growth generally can be distinguished by tone. Many foresters can identify dominant species in forest types by comparing heights of trees and sizes and shapes of crowns. By comparing the image of trees on the photograph with trees in the forest, the soil scientist improves his ability to identify kinds of tree cover.

The appearance of vegetation changes with the season. Deciduous trees photographed in winter have a lacy appearance and a lighter tone than that of coniferous trees.

Tall, short, and mixed grasses are difficult to distinguish from each other even in large areas of native vegetation. Sparse desert vegetation is easier to recognize.

To identify vegetation, the soil scientist should be familiar with plants in the area and their relation to the environment. A knowledge of plant succession furnishes clues helpful in identifying soils.

IDENTIFICATION OF MANMADE OBJECTS

Since manmade objects have sharp boundaries they are generally easier to recognize on aerial photographs than are natural features, and they are also more emphasized than natural features on stereoscopic pairs.

Farm Forests, Fields, and Orchards.—From manifestations of tone, the photo interpreter can tell how land is used. Forested areas appear mottled (fig. 20). Fields can be identified by their distinct boundaries and their patterns of dark and light (fig. 43). Harvested crops of hay, small grains, and corn in shocks can be identified by regularly spaced dark spots. Orchards have a more open pattern of larger spots. Terraced fields and stripcropping have alternate light and dark strips.

The arrangement, size, and shape of fields vary according to the type of agriculture. Fields are larger and more uniformly spaced in dry-farming areas than in humid areas. Field boundaries may appear as straight lines between patches of contrasting tone. The dark tones of hedgerows and other vegetation often

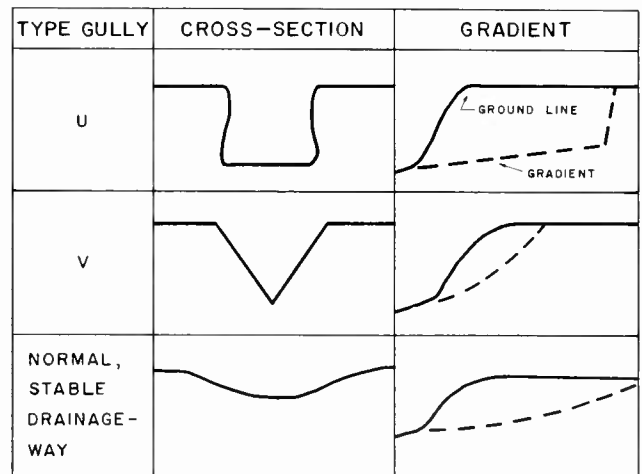
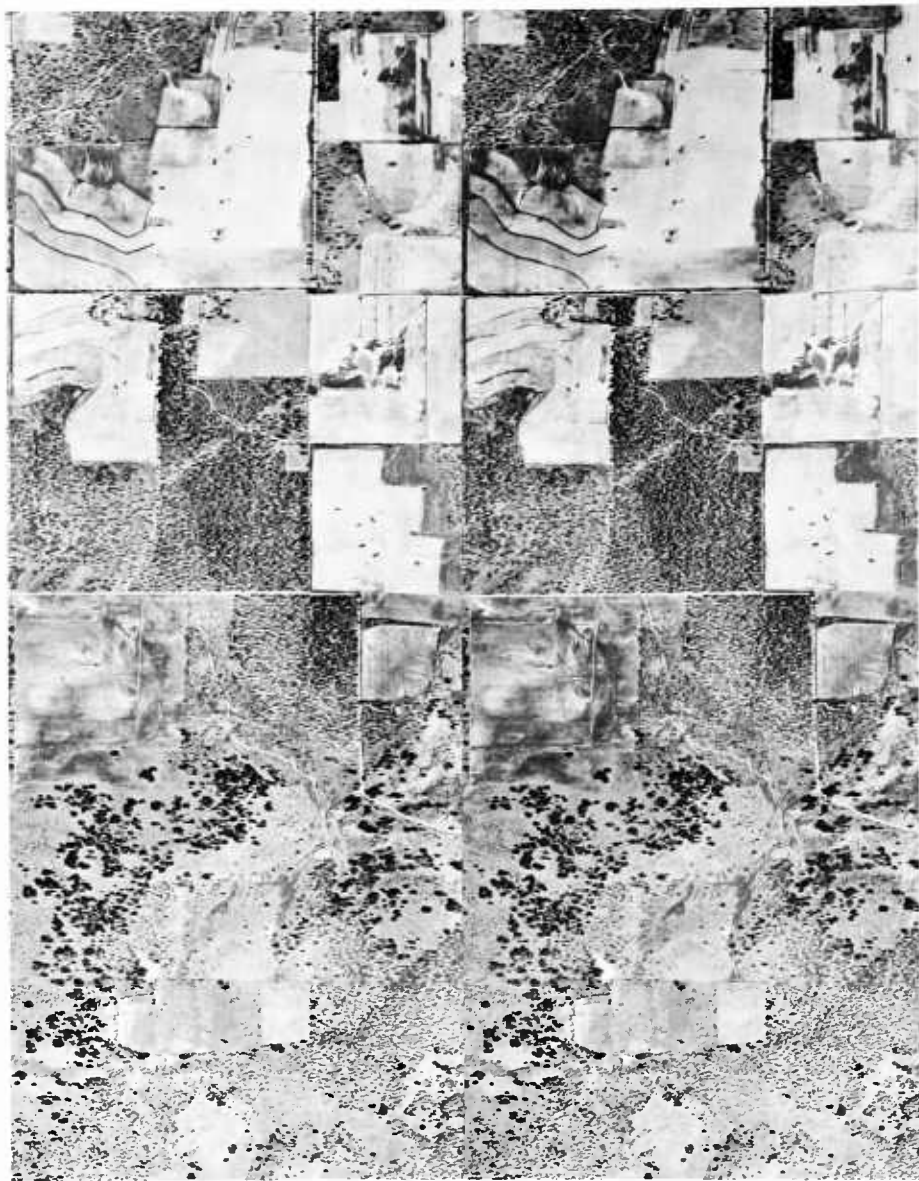


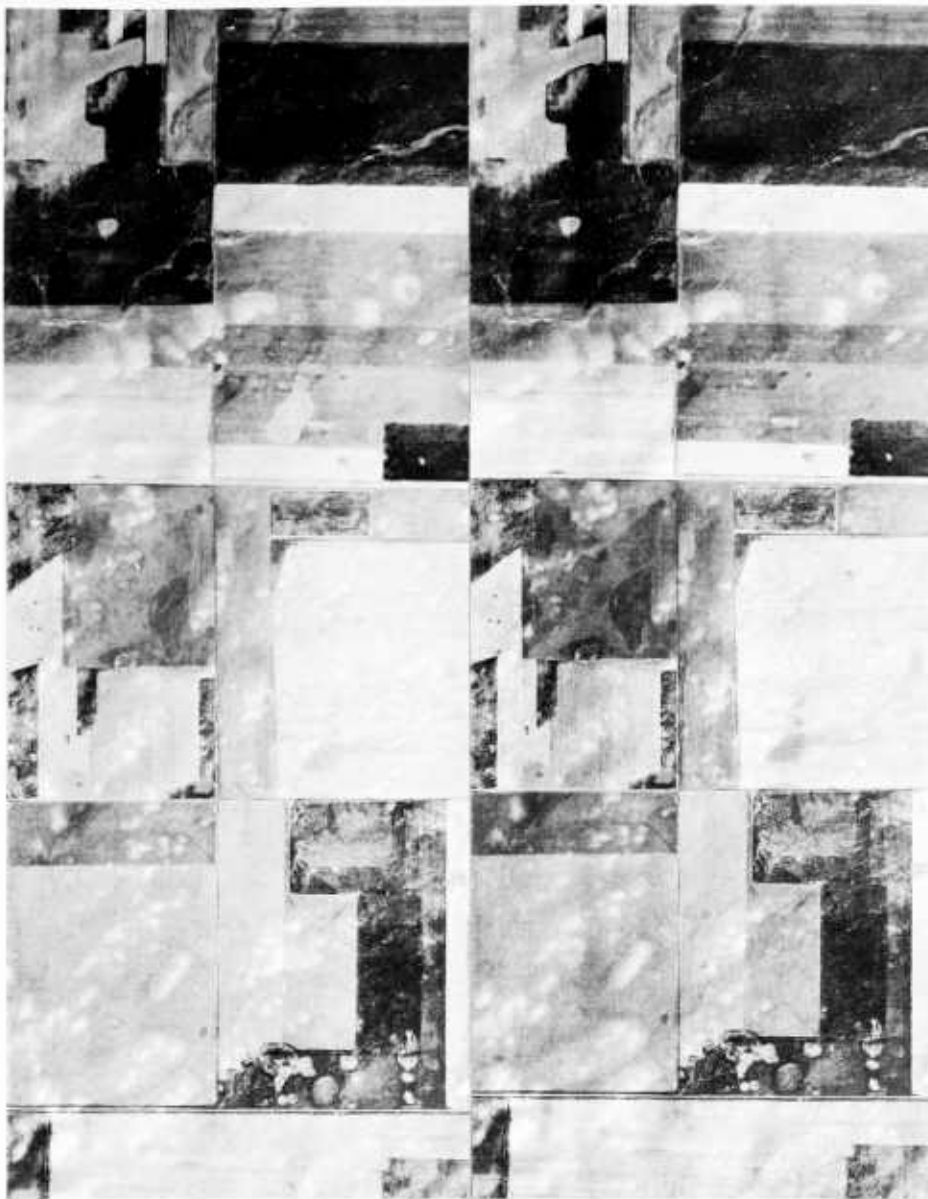
Figure 41.—Typical gully characteristics.



SCALE 1:20,000

ASCS—BRG-1E-94, BRG-1E-93

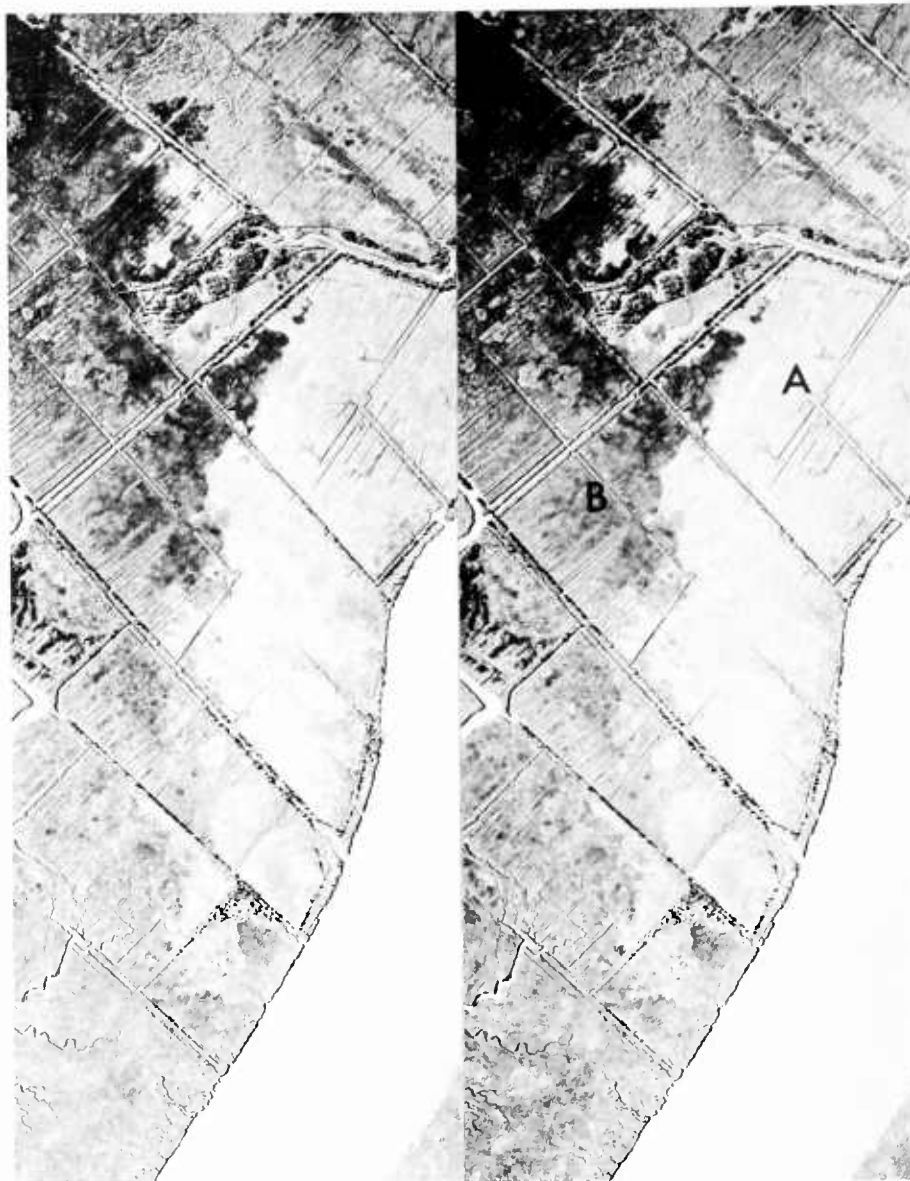
Figure 42.—In these photographs of north-central Texas forested areas produce a speckled light and dark pattern; coniferous trees appear as dark specks; the gray faintly mottled background represents native prairie vegetation; and cultivated fields produce light areas with sharp boundaries (upper part). Reddish prairie soils are under native grasses and Red-Yellow Podzolic soils under deciduous forest that has scattered coniferous trees.



SCALE 1:20,000

NA—CU-100-72, CU-100-73

Figure 43.—The scattered light spots on these photographs of dry-farmed tablelands in Nebraska represent thin soils in residuum from siltstone and sandstone; the dark background represents deep and moderately deep Chestnut soils in loess. Outlining the bases of the low ridges or knobs under a stereoscope shows the abrupt and wavy boundary between the soils in loess and those in residuum.



SCALE 1:20,000

SCS—DSF-2L-186; DSF-2L-185

Figure 44.—These photographs of an area in Georgia illustrate the contrast in appearance of mineral soils and organic soils under cultivation. The very light gray areas marked A represent Low-Humic Gley soils intergrading to young marine clays of the salt-water marsh. The dark-gray or black areas marked B suggest organic soils. Hedgerows produce the very dark irregular lines along field boundaries.

mark boundaries and fences (fig. 44), but generally the photographic scale is too small to show fences.

Buildings.—Buildings can be recognized by their angular shapes and contrasting tones. The part of the roof directly exposed to the sun photographs light and contrasts sharply with the shadow cast by the building. Farm buildings are usually in small rectangular groups beside or at the end of roads. In the arid southwest they are isolated; in the Great Plains they may be in groves of trees or among scattered trees; in the dissected or mountainous section of the humid Southeast they may be in cleared patches surrounded by forest.

Roads, Trails, and Streets.—Roads and trails commonly photograph as light lines. Improved roads have uniform width, straight stretches, and smooth, gentle curves; unimproved roads are more irregular in width and have sharper curves. Large uniform squares bounded by roads suggest sectionized rural areas, clusters of small rectangles indicate towns or cities (fig. 26).

Railroads.—Compared to roads, railroads are narrower, have longer and smoother curves, and are darker on aerial photographs. Along the right-of-way large cuts and fills, spurs, stations, and warehouses can be detected.

Bridges.—Bridges can be located by following the course of a road or a railroad until it crosses a stream or by following a stream and noting the interruption of tone caused by the

bridge. The kind of bridge can often be identified from its shadow.

Tunnels.—Tunnels can be identified by the dark spots of their portals, by the spoil near the portals, and by the sharp termination of the road, railroad, or canal.

Power Transmission Lines.—Transmission lines are difficult to detect in open areas on some photographs used in soil surveys. On photographs of very large scale, towers or their shadows can be seen. In wooded areas, power lines are long, narrow, cleared stretches that have angular changes in direction rather than curved changes.

IDENTIFICATION ON PHOTOGRAPHS TAKEN AT DIFFERENT TIMES

By comparing photographs of the same area taken several years apart, the extent and rate of erosion, especially gully and streambank erosion, can be estimated. The meandering of streams can be traced, and changes in land use noted. Damage from range and forest fires can be assessed.

Pictures taken before and after floods are often used to appraise flood damage. "Before" and "after" pictures also indicate changes caused by the construction of a large dam and by the filling of the reservoir that is formed. The extent of the encroachment of urban development, highway construction, or powerline installation on agricultural land can be estimated. During periods of drought or draw-down, sedimentation studies can be made.

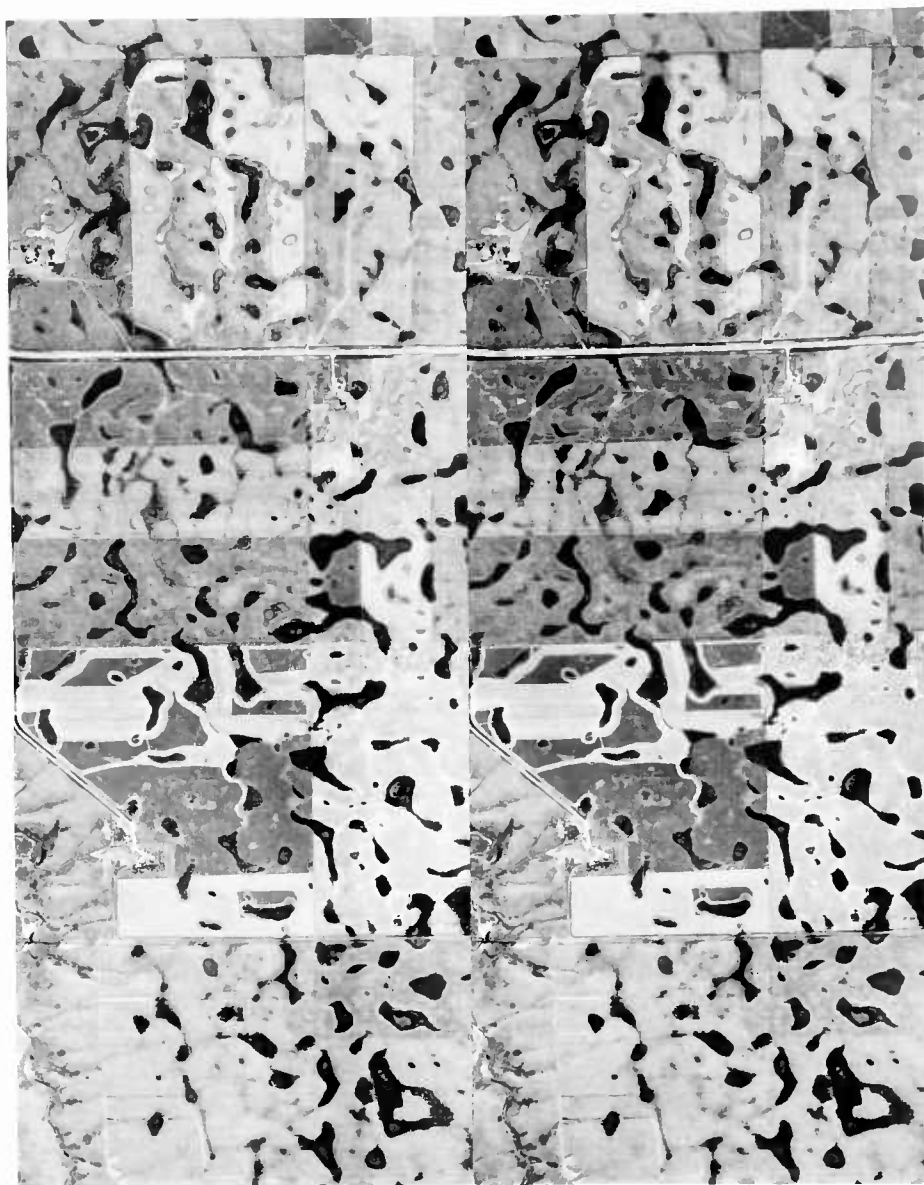
INFERENCES FROM FEATURES IDENTIFIED

To make reliable inferences the soil scientist must correlate features on the aerial photograph with soil characteristics observed in the field. A knowledge of soil genesis, especially as it relates to geomorphology, assists in understanding correlations made in the field. A person who is well versed in the phases of soil science and who has a good understanding of the soils in the area studied can obtain much more from aerial photographs than one less well versed.

SOIL DIFFERENCES

Some differences among soils can be detected from variations in tone on the aerial photograph; some can be inferred from analysis of surface features that reflect soil differences.

Clues to these differences are found in such features as landforms, stream dissection, drainage networks, vegetation, and land use. Combinations of these features may coincide with the morphological characteristics used in separating soil classes such as great soil groups or soil series. Thus, soils on uplands that have distinct horizons may be distinguished from alluvial soils with faint or no horizons on flood plains. Poorly drained soils appearing dark in depressions may be set apart from well-drained soils on convex slopes (fig. 45). Several morphological features and chemical properties are neither expressed nor implied by features apparent on an aerial photograph. These can be



SCALE 1:20,000

ASCS—BAM-2M-121; BAM-2M-122

Figure 45.—The mottled dark-gray to black pattern against a lighter background represents an association of Chernozems and Humic-Gley soils on the till plain of North Dakota. Humic-Gley soils, which photograph dark, are in the small closed morainic depressions; Chernozems in the light intervening areas.

distinguished only by field investigation or perhaps laboratory analysis.

Differences in tone that give clues to differences in soil can be seen in figures 32, 46, 47, and 48. Differences in tone, however, do not always indicate significant differences in soil, and differences in soil are not always revealed by differences in tone (fig. 49). The soil scientist must be able to distinguish change in tone caused by the angle of reflected light from that caused by some feature on the ground. The best way for him to prevent errors in identification and inference is to work out the local relationship between the landscape and the patterns on the photograph.

Dark-colored soils are dark toned on the photographs and light-colored soils are light toned (fig. 50). A lightening of tone usually indicates better natural drainage of the soils, stronger slope, more severe erosion, or coarser texture. A light-toned area, however, may be a poorly drained soil covered by a light film of water when photographed. On the other hand, dark-toned areas may be from soil plowed shortly before the photograph was taken.

In many places, differences in landform and drainage patterns indicate broad differences in soils and their parent materials. Experienced field soil scientists recognize bottom lands, terraces, alluvial fans, upland plains, hills, and mountains on aerial photographs of most regions. Generally, soil and slope boundaries coincide with boundaries of landforms and can be accurately located on aerial photographs. The soil scientist must remember, however, that many of the boundaries highly significant to accurate soil classification and mapping are not related to landforms.

Patterns are often misleading, and interpretations are found to be incorrect when the soils are examined in the field (fig. 51). Patterns that appear the same may represent unlike landscapes or associations of soils. Color patterns may be associations of eroded and uneroded soils, coarse- and fine-textured soils, well-drained and imperfectly drained soils, and other combinations. The soil scientist who is aware of these possibilities will determine which are most likely through both field examination and photo interpretation.

If it can be determined from an aerial photograph, the type of vegetation cover may indicate

what kind of soil to look for and where to look. In some areas rather consistent correlations of vegetation and soil can be made; in others the probable correlations are few. In a dominantly agricultural area, one would expect soils in a patch of woods to be different from soils that have been cultivated for a long time. But in some areas aerial photographs of vegetation do not reflect soil characteristics that would be important if the soil were cultivated (fig. 52).

Fires modify vegetation without immediately affecting the soil. Also, clues that show on one photograph may be masked by vegetation on another. This makes it necessary to work out the relationship between elements of the landscape and the pattern on the photograph by direct observation in the field.

Different patterns of native vegetation imply differences in soils. For example, concentric rings that progress from grasses and sedges to low bushes and trees as they extend outward from the borders of a pond indicate that the soils are increasingly better drained as the distance from the pond increases.

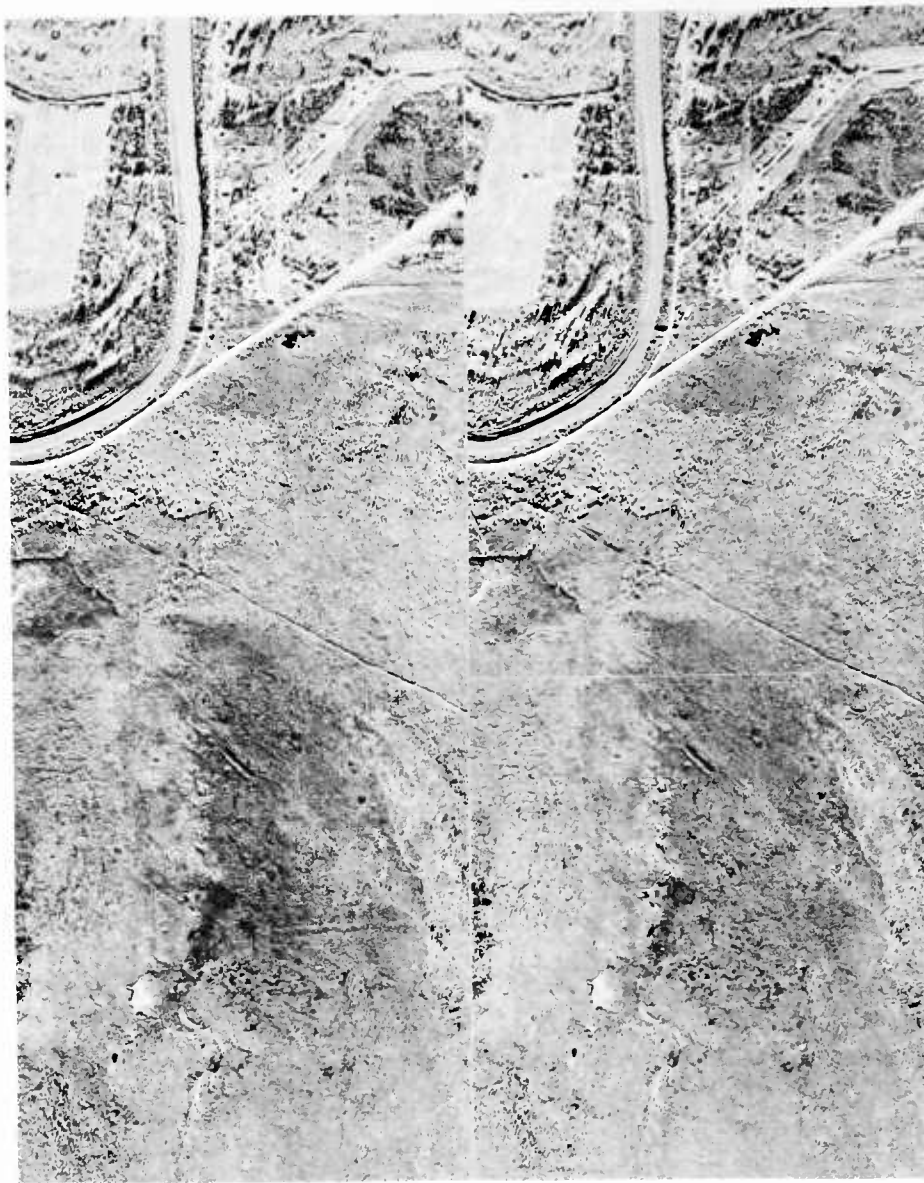
EXPRESSIONS OF FACTORS OF SOIL FORMATION

Relief and vegetation as they were at flight time can of course be seen on an aerial photograph. Preexisting relief and vegetation that had a profound influence on soil formation can only be inferred. This is true also of parent material, climate, and age of landforms.

Relief.—Relief changes slowly, and probably has changed very little from the earliest stages of soil formation up to the time the photograph was taken. Allowance must be made, however, for erosion and other changes brought on partly by the activities of man.

Vegetation.—To evaluate the relationship of vegetation and soil, the soil scientist should become familiar with local ecological environment, including plant succession. He can then compare present with past vegetation and determine whether the vegetation he identifies is representative of earlier types. The soil scientist will be aware, for example, of how the original forest was altered by burning or cutting.

Identification of native vegetation may lead to inferences about soil and soil genesis. Pine forests in Maine, northern New York, and Michigan are clues to Podzols or to the formation of Podzols. Mixed deciduous and pine forests on



SCALE 1:20,000

USAF—M-878-503, M-878-502

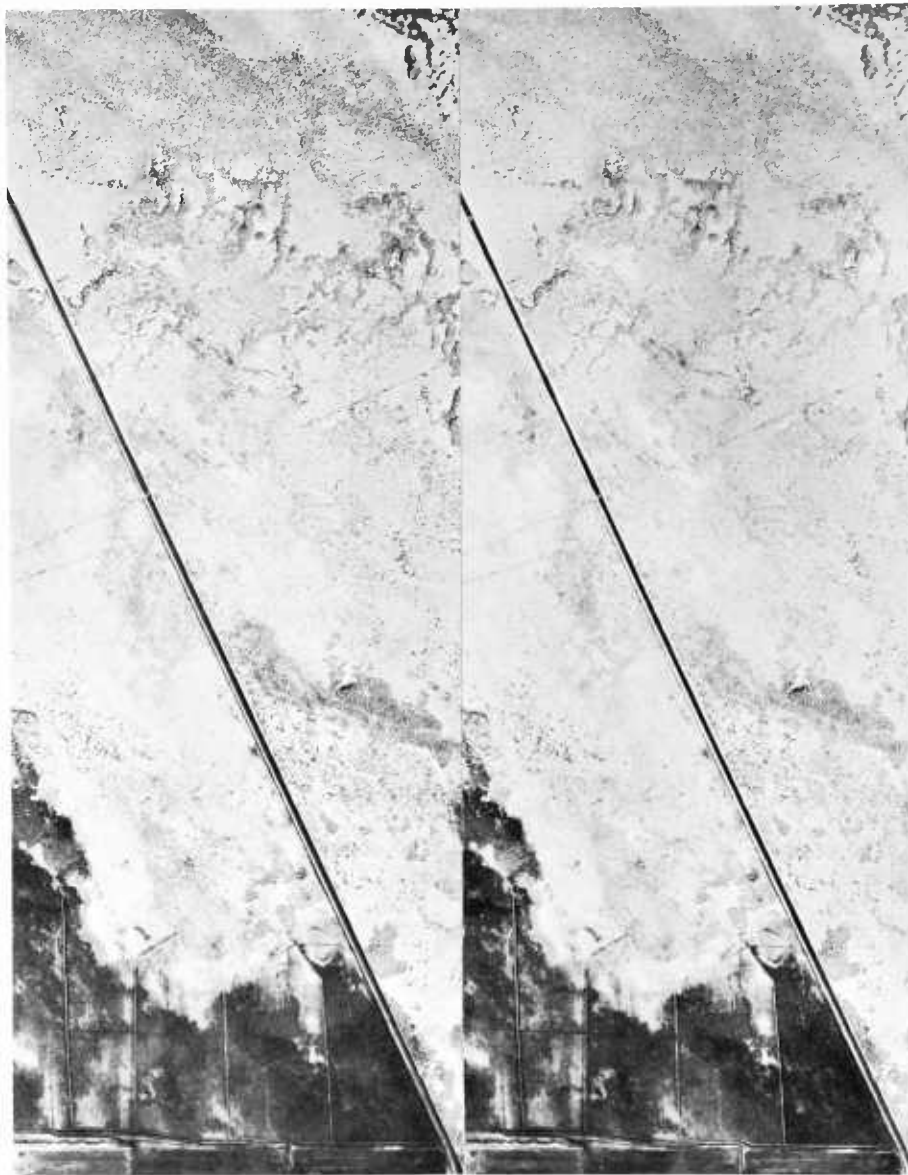
Figure 46.—The slight tonal differences and the polygonal pattern on the lower half of these photographs of river flood plains of interior Alaska indicate soil differences. The darker areas represent Bog soils covered with sphagnum moss; the somewhat lighter areas and the polygonal pattern, Humic Gley soils. Note the indefinite boundaries of areas of sphagnum moss in contrast with the distinct outlines of roads and images of buildings.



SCALE 1:20,000

ASCS—OV—3E—83; OV—3E—82

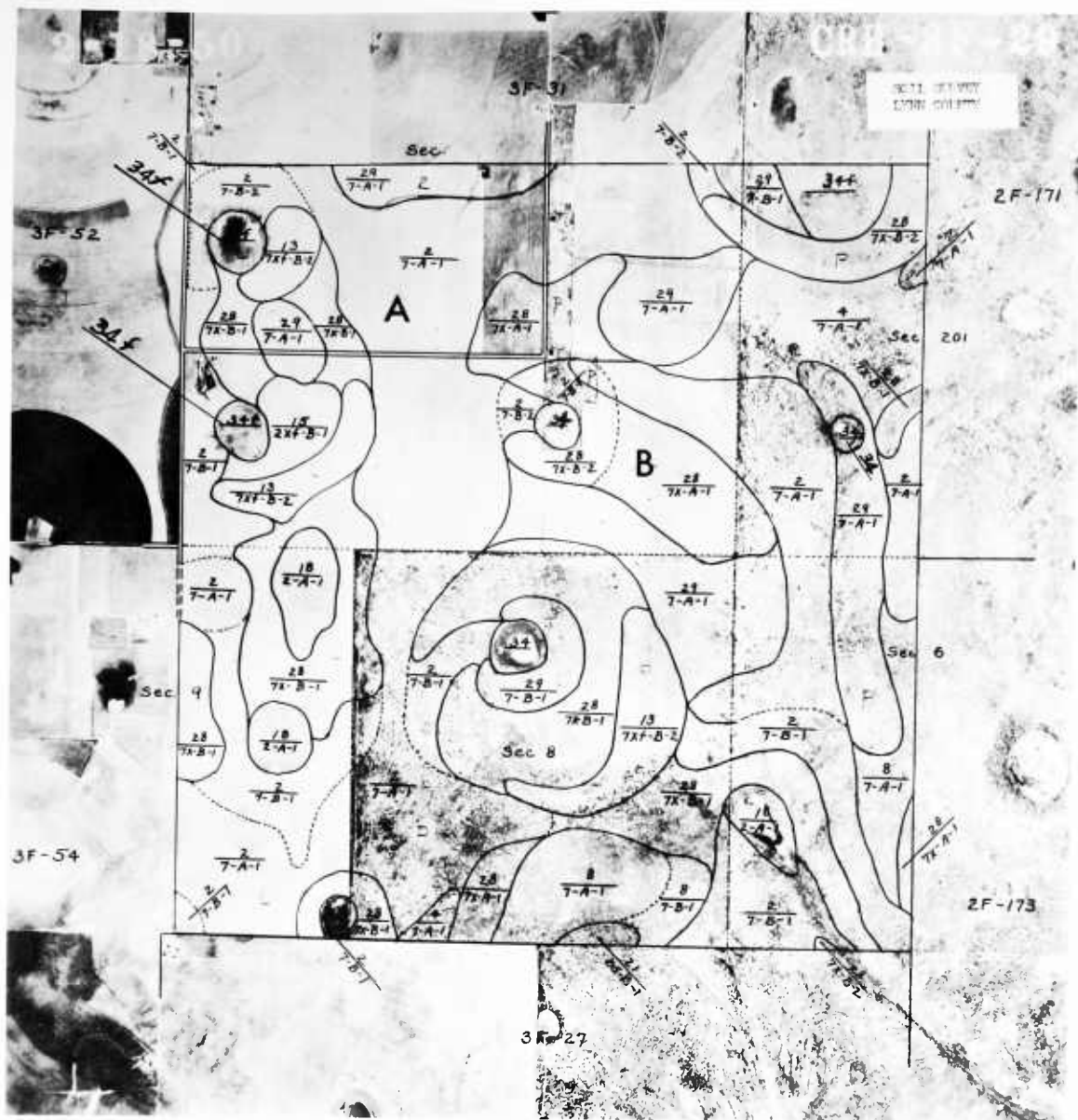
Figure 47.—Tone variations with gradual boundaries often are clues to differences in soil drainage, most commonly in humid areas. Sharp boundaries are due to vegetation or land use. The lightest tones in these photographs of sandy soils on the Atlantic Coastal Plain represent somewhat excessively drained Regosols; the intermediate ones well-drained and moderately well-drained Red-Yellow Podzolic soils; and the darkest, somewhat poorly or poorly drained Low-Humic Gley or Humic-Gley soils.



SCALE 1:20,000

SCS—DOP-1T-71, DOP-1T-72

Figure 48.—These photographs of an area in Nevada show the highly contrasting tones registered by sandy Regosols, the light tones, and by somewhat poorly drained Alluvial soils, the dark area in the lower part of the photographs.



SCALE 1:31,680

ASCS—CRH-3F-29

Figure 49.—Quite different soils may photograph in similar tones. Here a Reddish Chestnut soil in Texas in area A appears in light-gray tone like that of the Calcisol in area B. The darker tones of soil 34f, also a Calcisol, are as dark as those of soil 34, which is a Grumusol.



SCALE 1:20,000

NA—AWW-7-84; AWW-7-85

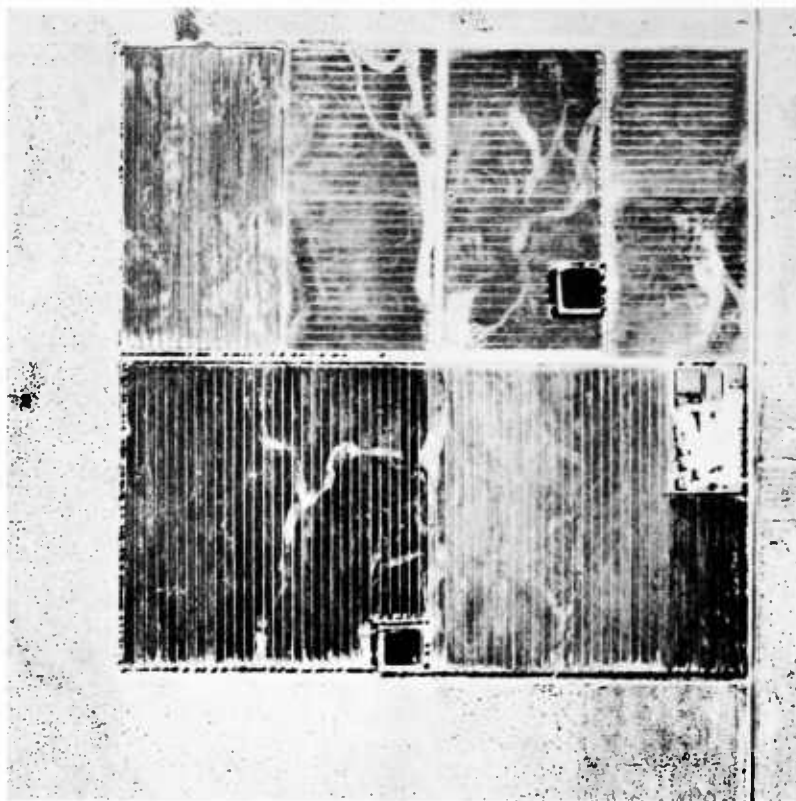
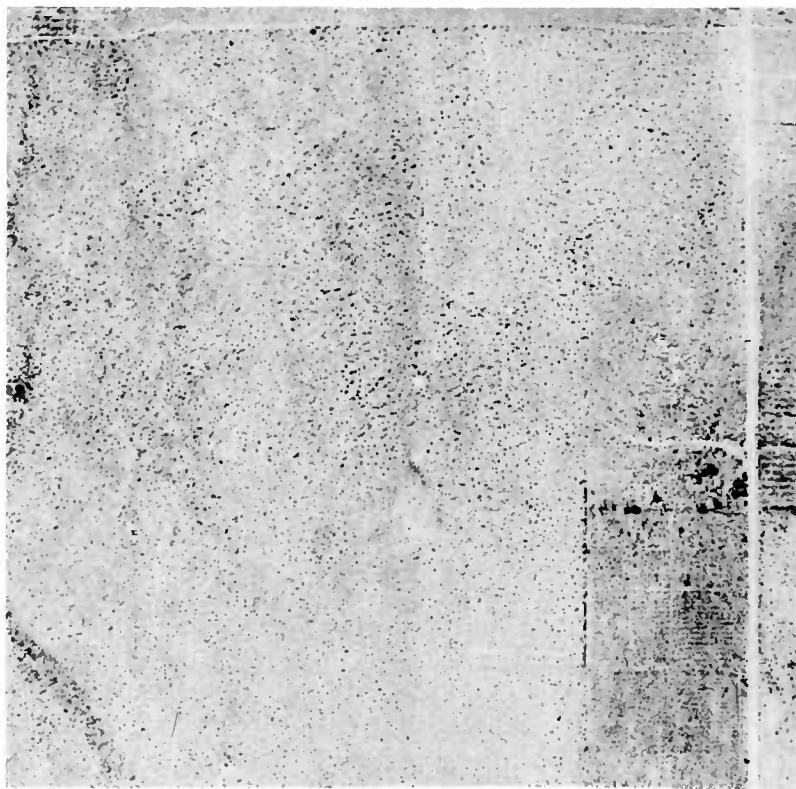
Figure 50.—These photographs of an area underlain by chalk in Texas illustrate the relationship of light and dark tones to differences in color among soils. Dark tones represent nearly level or gently sloping Grumusols, which have thick dark surface horizons. Light tones portray more strongly sloping and light-colored Lithosols formed in residuum from very light gray or white chalk. The topographic expression, though moderate, is easily noted under a stereoscope.



SCALE 1:31,680

USAD—TM-14-162

Figure 51.—In this photograph of an area in New Mexico the pattern suggests a rough, choppy, complex landscape with no agricultural potential except for range. Field examination, however, showed a succession of miniature escarpments 6 inches to 3 feet high on an alluvial fan; the escarpments are topped by ridges of sandy Regosols in eolian deposits 6 to 24 inches thick. Regosols are moderately fine-textured soils formed in alluvium.



SCALE 1:13,000

LEFT, USAF—4M741—4V—25, RIGHT: ASCS—AXL—44K—7

Figure 52.—These photographs of an area in the Mojave Desert, Calif., show vegetation that fails to reveal important differences in soil characteristics. The uniform cover in the left photograph consists chiefly of ereosotebush and bursage. The same 160-acre field is shown on the right after leveling and planting to alfalfa. The light streaks represent narrow beds of gravel or ebbles, which affect the efficiency of irrigation but have no apparent effect on native vegetation.

rolling or hilly uplands in the Southeast are related to the formation of Red-Yellow Podzolic soils. In the northern Great Plains tall grass was the native cover over Chernozems when they were forming.

Parent Material.—Parent material can be inferred from the aerial photograph after considering the landforms and, in some areas, the vegetation. But such inferences may be unreliable because no specific kind of parent material can be correlated exclusively with a specific kind of landform or vegetation. Rock structure, climate, and other factors affect the relationship.

In some areas, however, relationship can be found between topography shown on the photograph and parent material. In the Appalachian Highland, for example, rolling limestone valleys and ridges are distinct from steeply dissected shale plains; these in turn are unlike mountainous areas of crystalline rocks. In central United States, rolling areas of thick deposits may be separated from adjacent driftless plateaus that are more dissected.

Climate.—The climate of an area is reflected in the shape of landforms and in stream patterns, but the most reliable key to climate is vegetation. The effect of climate on vegetation can be seen by comparing vegetation across the United States; vegetative zones correspond to broad climatic belts.

The relationship of soils, climate, and vegetation in the western part of the Central Lowlands is also striking. Gray-Brown Podzolic soils occur in the humid, forested valleys; Brunizems are on the less humid grassland divides that intervene.

Age of Landforms.—Inferences concerning the age of landforms of an area, at best very general, are based mostly on deductions made after studying the physiographic expressions and acquiring some knowledge of the geology. Young soils are likely to occur on steep hillsides and flat flood plains. On strong slopes, horizon differentiation hardly keeps pace with geologic erosion. On alluvial plains, continued accretion of fresh materials keeps the soils young.

PLANNING FOR THE DETAILED SOIL SURVEY

Aerial photographs are used in both detailed and reconnaissance soil surveys. The principles of photo interpretation are the same for both although applications of them differ somewhat. More reliance is placed on clues offered by the photographs in reconnaissance than in detailed soil surveys. This is true of both determinations of kinds of soil and placement of soil boundaries. In detailed soil surveys, field examinations are made at frequent intervals and boundaries are observed throughout their entire course. In reconnaissance soil surveys, field examinations are widely spaced and parts of soil boundaries are projected.

Most soil surveys are detailed and procedures have been developed for the use of aerial photographs in such surveys. These procedures are outlined in this section. They include evaluations of existing aerial photographs, judgments of the need for procuring new ones, day-to-day operations, and determinations of the relationships of photographic features to elements of the local landscape.

PROCUREMENT OF AERIAL PHOTOGRAPHS

Plans for procuring aerial photographs should be made about 2 years before the start of a soil survey.

The SCS Cartographic Division prepares a report of existing aerial photography, which includes other agencies' plans to fly the survey area in the immediate future. On the basis of the report, and on knowledge of the physiographic changes since the last aerial survey, the SCS State Conservationist through his soil scientist decides whether a new aerial survey is needed.

If it is needed, arrangements to initiate flight operations must be made at least 1 year before the photographs are needed in the field. Aerial surveys are made by commercial aerial photographers under contract. About 6 weeks should be allowed to develop the specifications and schedule of advertisement, prepare flight maps, solicit bids, and award the contract.

If the State Conservationist decides that the existing aerial survey is adequate, photographs

are obtained through the Cartographic Division. Most soil surveys are made on photographs enlarged to scale 1 inch=1,320 feet (4 inches=1 mile). Where large-scale irrigation or land leveling developments are contemplated, more detailed soils information may be needed than can be shown at a scale of 1 inch=1,320 feet, and larger scale photographs are required. Contact prints, being of smaller scale, often are helpful in making a stereoscopic study of the area because a larger area can be viewed at one setting. Also, the smaller scale concentrates the detail, and broad associations of features can be studied.

Unless an older survey is specified the Cartographic Division furnishes photographs from the most recent adequate aerial survey. Photographs should be examined immediately to see that they are good quality prints and that all prints needed have been received. Images on the photographs should be sharp to permit study of small details. Prints should be of normal contrast with shadows and highlights printed so that details of the negatives reproduce to maximum advantage.

SELECTION OF PHOTOGRAPHS

Ordinarily, soil-survey data are recorded on alternate photographs since this reduces matching delineations of soils and other features from one photograph to the next. It also reduces costs of reproducing the completed soil-survey field sheets since only half as many sheets are required. But for areas of rough terrain, where the difference in ground elevation exceeds 750 feet on a large part of the survey area, soil-survey data are recorded on every photograph. Where there are large blocks of different terrain every photograph is used for the mountainous part and alternate photographs for the less rugged terrain.

COLLECTION OF REFERENCE MATERIAL

In addition to aerial photographs, existing maps and reports of the survey area should be studied. Photoindex, topographic, geologic, and forest-type maps, old soil maps and reports, and planning board maps and reports are helpful.

PROCEDURES FOR USING PHOTO INTERPRETATION IN MAKING SOIL SURVEYS

USE OF PHOTOINDEX SHEETS

Photoindex sheets are generally at a scale of 1:63,360 (1 inch=1 mile). Since each sheet covers a large area, they may show overall geologic and soils relationships not readily seen on individual photographs. Photoindex sheets are also useful as a base for the preparation of a preliminary soil-association map. Such a map is helpful in setting up the standard soil survey legend.

Photographs of representative sections of the areas should be selected from the index sheets. These should be studied stereoscopically to acquaint one with general topography, landforms, erosion, drainage patterns, land use, and general appearance of vegetation. Later, they should be checked in the field to determine the range and meaning of tone and to learn the local causes of differences in tone, such as wetness, soil texture, vegetation, bedrock, and outcrops.

MATCH LINES

Before the soil survey is started, match lines are drawn on every photograph selected for delineation of soils data. These lines are boundaries of the area to be mapped on the photograph. They can be drawn with or without the aid of a stereoscope. In using the stereoscopic method, a straight line is drawn midway through the overlap area parallel with the photograph edge. The straight line is then stereoscopically transferred to the adjoining photograph (fig. 53). In rough or mountainous terrain this line is usually transferred by marking its location on the high points, or ridges, and on the low points, or bottom drainage, and connecting these points by a series of straight lines. In areas of rough terrain, a straight match line on one photograph will be a very irregular one when transferred to the adjacent photograph.

Straight match lines can be transferred without using a stereoscope by sketching the line where it seems to curve over high spots and through low spots. On flat land the match lines may be transferred by connecting the same points of detail with a straight line.

In both methods, the process is continued

throughout the survey area by transferring the match lines to the next photograph in the flight line and to adjacent photographs in the adjoining flight lines.

Match lines may follow prominent ground features, such as roads, railroads, rivers, or land lines. If cultural and physical features are concentrated along the road, the match line should be drawn where it would be less difficult to match delineations of soils and other features. Match lines are usually drawn with green pencil.

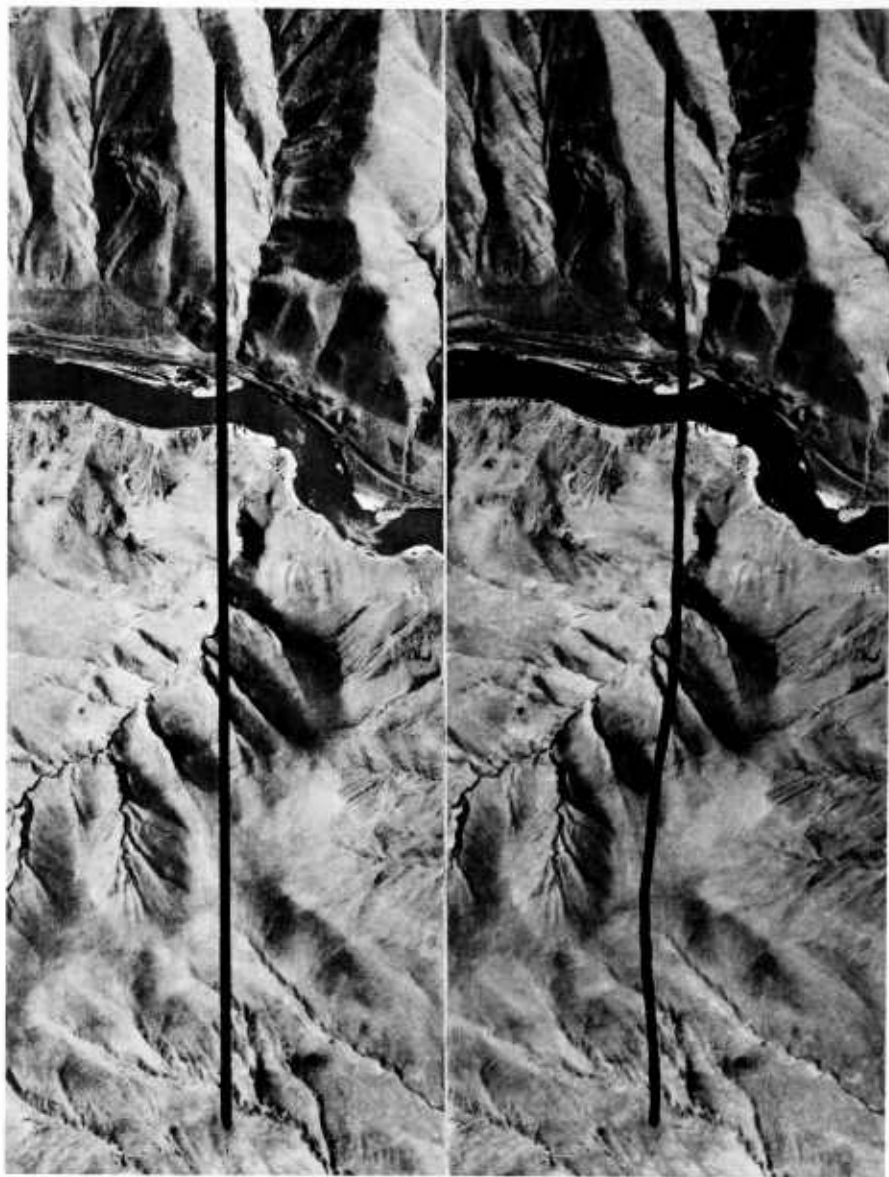
STEREOSCOPIC REVIEW

A careful stereoscopic review should be made each day before starting work. First, the area to be surveyed should be determined. If this is a farm or ranch its boundaries should be delineated on the photographs. With a stereoscope, the area is scanned to make a brief mental review of significant conditions such as type of farming, topography, geology, landforms, soils to be expected, drainage conditions; and farming practices.

PRELIMINARY DELINEATION OF FEATURES

Before field work begins all important features that can be accurately identified in the office should be delineated on the photographs. Some can be determined with more certainty than others, depending on one's familiarity with local conditions and skill with a stereoscope. Features easily identified should be delineated first. Then features that relate to and help identify obscure features should be studied. The following is an outline of steps for this preliminary stereoscopic delineation:

1. Major drains, smaller drains, intermittent streams, and drainage heads and ponds should be tentatively delineated before going to the field. This should be done in blue pencil so needed changes can be made after field checking.
2. If soil surveys have been made on adjacent photographs, all soil and mapped features should be transferred stereoscopically to the outside edge of the match lines. Many boundaries between kinds of soils, including slope and erosion phases, can be tentatively extended or closed. If



SCALE 1:20,000

SCS—DDS-192; DDS-1-93

Figure 53.—Transferred match line.

possible, lines should not be closed off directly on the match line. Careful selection of match lines minimizes the need for this.

3. Roads may be inked and classified on the basis of knowledge of the area and the latest county highway maps. According to some State policies, highways prominent and readily identified on a photograph need not be inked.

4. Whenever they can be identified, dwellings and other pertinent buildings outside of built-up areas may be inked on the photographs. In built-up areas, only public buildings important to farmers or farm programs such as court-houses and schools should be indicated

5. The following should be tentatively delineated in pencil:

- Bottom land and flood deposits

- Stream terraces

- Gravel and borrow pits

- Ridge lines

- Sinkholes and wet spots

- Swamp or marsh boundaries

- Other significant landforms such as escarpments and rock outcrops.

6. All slopes that are clearly seen and appear to correspond with the slope phases in the legend should be delineated, and the estimated slope groups given. In many soil survey areas, the definitions of slope phases vary among kinds of soil. Beginners may have difficulty delineating slope groups with reasonable accuracy. Regardless of the lack of success, this should be done and checked in the field each day, for this skill can be developed only through continual practice and field comparisons.

7. Gullied and severely eroded areas should be

delineated and an estimated-erosion symbol placed in the delineation.

8. Soil series or types that can be differentiated may be tentatively delineated and indicated by symbols.

9. Routes for traversing the area most efficiently should be planned. This should insure sufficient field checking and, at the same time, reduce the number of unnecessary traverses.

DETERMINATION OF GUIDES AND RELATIONSHIPS

Stereoscopic interpretations made in the office should be reviewed in the field and verified or revised as necessary. Areas not correctly identified in the office should be restudied. Valuable experience is gained by making notes on the relation of soil to the photographic features that are indicators of the particular soil. Accuracy in making estimates increases, and the soil scientist learns which delineations he can make with suitable accuracy.

For each slope group or major landform, slope can be established with an Abney level and areas delineated in the field. These delineated areas serve as references to compare with similar-appearing areas delineated with a stereoscope.

Soils tend to occur in systematic patterns. Assistance in determining local patterns may be obtained from the study of topographic and geological maps and reports. Block diagrams showing the relationship between local soil types and phases need to be prepared. (See figures 59 and 62.) These diagrams help to visualize the relationships between kinds of soil areas and factors that pertain to the development and occurrence of soils in the landscape.

CORRELATING AERIAL PHOTOGRAPHIC IMAGES WITH SOILS IN SPECIFIC AREAS

In many places soil scientists have learned how to recognize distinctive soil landscapes or soil associations on aerial photographs. Though within a given landscape the boundaries between soils of strongly contrasting texture, drainage, or depth can be readily recognized, this is not true of finer distinctions among these features. The soil scientist needs to be thoroughly familiar with soil landscapes on the ground before he attempts to interpret soils from the aerial photographs.

Up to now, no systematic key correlating aerial photographic images and soils has been issued. But soil scientists have used photographic tone, pattern and kinds of vegetation expressed in photographic tone, and physiography as interpreted from tone, detail, patterns, and shadows to make their own correlations.

The following extracts of local correlations are mainly from the humid East. With them as guides to things to look for in aerial photographs, each soil scientist should develop his own local key. Using such keys can significantly accelerate soil-survey field work.

CORRELATIONS IN THE NORTHEAST

Connecticut.—Landforms such as traprock ridges, drumlins, ground moraines, glaciofluvial or outwash terraces, kame and kettle topography, eskers, lacustrine terraces, flood plains, and bogs are features that can be identified with a stereoscope. Soil associations with well-defined features are associated with each of these landforms. Soil features such as drainage, texture, degrees of stoniness, and kind of vegetation can also be interpreted to a certain degree with a stereoscope.

Shallow to bedrock soils are common on traprock ridges in the Connecticut Valley of Connecticut. The principal indications of traprock ridges are steep western slopes that have dark tones due to shadows and linear crests that are jagged, irregular, and sharply outlined. The adjacent areas to the east have uniform decreasing slopes. There are more hemlock trees, recognizable by dark images, than on adjacent associated shallow soils. Presence of hemlock itself, however, does not indicate traprock ridges.

Shallow soils on granite, gneiss, and schist,

usually appear as large domelike rounded hills irregular in topographic features. The drainage pattern is dendritic; typical curved lines emerge from the base of the hills. Scattered light patches indicate exposed bedrock and a surrounding mantle of shallow soils. Darker tones are more difficult to interpret because of the nature of the topography, vegetation, and bedrock reflections. Extensive dark tones on either side of streams suggest soils with restricted drainage. Natural vegetation—mainly oak, maple, and beech and scattered white pine and hemlock—appears medium gray with some dark spots.

Drainage patterns of moraines, which have irregular slopes in contrast to the long, uniform, contoured slopes of drumlins, lack uniformity because of the irregular topography. There are many small individual drainage patterns that do not combine to form a well-defined drainage system. Individual streams are not long but are well defined. Generally they empty into peat bogs, swamps, and ponds in the low points of the landscape.

Light gray tones of moraines usually indicate shallow soils on steep valley walls or hillsides. Medium gray tones are confined to 3- to 8-percent slopes, which generally are moderately well drained. Darker tones on 2- to 3-percent slopes are evidence of poorly or very poorly drained soils. In general, all cultivated areas have the same tone. Oak, maple, and beech, the principal tree species of a mixed hardwood cover, appear in fairly uniform gray tones.

Drumlins, generally oriented in a northwest to southeast direction in Connecticut, are smooth, oval, cigar-shaped hills. A few, which are broad, flat surfaced, short sloped, and less elongated than typical, appear semicircular to semioval. Though defined drainage patterns are lacking, they do control the drainage in many adjacent till-covered areas. Those with broad tops or semioval shapes usually bear intermittent streams that flow southeast, that is, with the long axis.

Since many drumlins have soils with impervious subsurface layers that restrict vertical movement of water, lateral movement of water on the long slopes results in occasional seepage

spots and these are conspicuous by their darker tone. A uniform gray tone indicates moderate drainage and darker grays poor drainage. Clean-tilled land is usually lighter toned than old pastures and hayfields, but in both differences in soil drainage are reflected by tone.

Glaciofluvial and outwash terraces, generally nearly level to undulating, in places occur as a series of benches with intervening short terrace escarpments. Lack of surface drainage patterns show that the subsoil and substratum are permeable. Rapid permeability also accounts for the typical, but occasional, V-shaped short steep gullies. Light to bright overall tones are characteristic of terraces. The lightest tones indicate well-drained coarse-textured soils; darker tones indicate somewhat poorly drained or poorly drained finer textured soils.

Eskers, which are long narrow steep winding ridges consisting of sorted gravel and sand deposited by glacial-melt waters flowing in ice-walled tunnels or channels, appear superimposed upon surrounding landforms. Photographic tone as such is not diagnostic for eskers because gullies are few and the esker tones blend with surrounding landforms. When examined under the stereoscope, however, they stand out as ridges. Some show gravel pits. In many places they are idle or in forest in contrast to adjoining areas of outwash or till in cropland.

Kames and kettles are individual knobs or linked knobs with irregular shapes and haphazard distribution interspersed with random shallow to deep depressions and no definite drainage patterns. Coarse texture accounts for white-toned V-shaped gullies that occur on steep-sloped mounds. Tones range from white to light gray on kame crests and to darker shades toward the slope bases. Intermittent spattering of white to gray photographic tone, coupled with the topographic features, gives a three-dimensional effect on some single photographs. These topographic features are readily recognized under the stereoscope.

Though lacustrine deposits are distinct from the surrounding landforms, the topography may be so similar to adjoining areas of glacial till or outwash that differences are not discernible under the stereoscope.

On undulating topography, silts and clays generally lack well-defined drainage or gully patterns. Bright, dark gray, and random tones

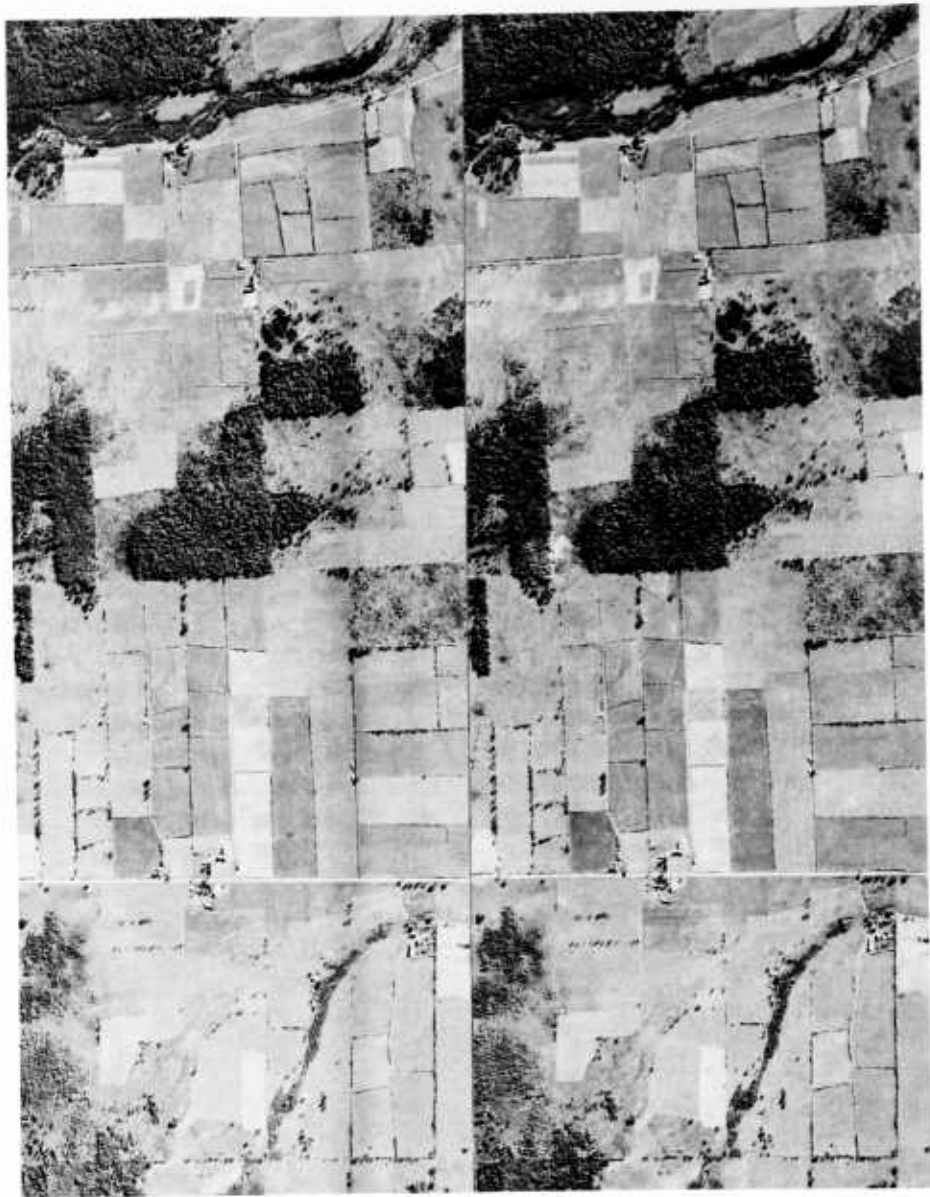
within a specific area are typical on these materials. Low mounds of sands are bright and are usually pock marked with black depressions. Clays, moderately well to poorly drained, have uniform light gray to darker gray tones.

Clay and sand over clay in terrace positions commonly have a fine dendritic drainage pattern. The valley walls are V-shaped and steep; interfluves are narrow and rolling. Photographic tones are fairly uniform except for shadows cast by the slopes. Gray tones are typical for the moderately well drained soils. The gray tone and drainage patterns are the principal indications of clay soils on dissected landscapes. In many places, undulating to rolling slopes can be delineated from hilly and steep areas under a stereoscope.

An overall level surface is the most significant feature of flood plains. Along mature rivers this uniform slope may be broken by irregularities which result from local stream cutting and deposition. Sandbars appear as raised areas adjacent to or parallel to rivers. Though uniform drainage systems do not develop on flood plains because of their low position, seasonal flooding, and deposition, streams flowing from the surrounding topography cut across flood plains in some places. Black streaks—curved and generally parallel—are typical of channel scars, oxbows, and abandoned channels. The black tone is accounted for by the fine-textured mineral soils and organic matter that accumulate in these depressed areas. Linear streaks of well-drained sands or loamy sands appear as nearly white. The gray tones represent level areas with a high water table.

Peat bogs usually occur as depressions; streams are very few. Vegetation changes abruptly at the border between the bog and surrounding terrain. Photographic tones are distinctly darker than surrounding areas.

In many places bogs are covered by low brush, sedges, and moss; these areas appear as a smooth gray tone. At higher elevations some bogs covered by spruce forest appear dark gray to nearly black in contrast to the lighter gray of adjacent uplands covered by hardwoods. Some of these bogs have a rim of spruce which diminish in height and give way to brush toward the center. Regardless of kind of vegetation, nearly all bogs are darker toned than adjoining better drained areas.



SCALE 1:20,000

NA—CXE-3B-147; CXE-3B-148

Figure 54.—These photographs represent the gently to moderately sloping landscape of ground moraines of Wisconsin glaciation in New York. Well-drained Gray-Brown Podzolic soils are on the gentle rises and Planosols and Low-Humic Gley soils on lower slopes and in depressions.

New York.—In New York, main soil associations can be recognized by tone although many associations may have similar patterns. In many places the soils can be picked out by photographic tone, shading, or vegetation.

Large areas of outwash photograph either in light or very light tones on level plains or in the spattered pattern of kame and kettle topography. Sharp slopes breaking to the bottom lands or valley sides usually can be recognized by slightly darker tones but are best identified under a stereoscope. Where frost-moved material covers the outwash, the slope to the valley sides is gentle and difficult to identify except under a stereoscope.

Where present in large blocks soils from lacustrine material usually have recognizable patterns. They have gently undulating to moderately steep topography.

Where the topography is nearly level, tonal value is the most important photographic feature for identifying individual soils that differ in drainage. Light gray tones are registered by Vergennes soils which have the best drainage, intermediate gray by Panton soils, and dark gray to black by Livingston and Covington soils, which have the poorest drainage. Limestone outcrops associated with these soils appear as light toned streaks or spots.

In areas that are dominantly till, the gently to moderately sloping landscape without abrupt slope breaks usually denotes deep, moderately well and somewhat poorly drained soils (fig. 54). Steeper slopes usually include well-drained soils. Darker toned depressions contain poorly and very poorly drained associates.

In the southern tier (Allegheny Plateau) Lordstown soils usually can be identified by step-like relief with short, steep breaks along a general east-west axis. The breaks are interspersed with nearly level to gentle slopes. Where this relief is absent the Lordstown soils may be mistaken for Bath, Mardin, or Volusia soils on photographs. Shallow soils do not give consistent tone values; field examination is necessary to differentiate them.

Shallow and moderately shallow Nassau and Macomber soils on folded rocks along the Hudson Valley are identified by the pattern of short broken slopes along a general north-northeast to south-southwest axis. Deeper Cossayuna and Dutchess soils on drumlins can be distin-

guished by their long uniform slopes. Poorly and very poorly drained soils of local alluvium in depressions and soils in glacial lacustrine materials appear in darker tones but are difficult to distinguish from each other without field checks.

In Rensselaer County the pattern of complexes of deep and shallow soils over folded bedrock, with occasional rock outcroppings, generally shows up well especially in areas that have been plowed or are in cultivation. On the newly plowed land, the outcrops and shallow areas are darker toned; in areas under cultivation, these same areas may be lighter toned than the surrounding land.

CORRELATIONS IN THE SOUTHEAST

Tennessee.—In Tennessee, most major soil associations in the Red-Yellow Podzolic soil region have slightly different tone patterns. A few, however, appear similar even though the soils of each are different.

The Dandridge-Whitesburg-Lindside soil association presents the most distinct pattern. The deeply entrenched drainways, high dissection, steep relief, and large amount of forest all show clearly on the photograph. Tones and other clues help identify the individual soils within the association. Ordinarily these clues suggest two or three soil series rather than clearly pointing out a specific one. After the soil scientist has identified the soil in the field, he usually can interpret area boundaries from the photograph. For example, Whitesburg soils on local alluvium are dark toned on the photograph because of higher moisture content and dense vegetation. On narrow strips of bottom land, however, Lindside and Melvin soils also photograph as dark areas.

In the Litz-Sequoia-Lindside soil association, also derived from shales, the landscape is dominantly rolling and hilly and streams are not so deeply entrenched. Individual fields are small; many areas are severely eroded and covered with second-growth pine forest. These clues suggest small subsistence farms and soils of low fertility and high susceptibility to erosion. Badly eroded areas within the association suggest either gullied land or severely eroded Litz soils. Where areas are nearly bare of vegetation, erosion can be detected on the photograph by light tones; where areas are covered by pine

forest, erosion can be detected by almost black tones. Most soils on local alluvium and narrow bottom land appear in dark tones. Once specifically identified with an auger, most areas can be delineated by differences in tone. Many soils on uplands and old colluvial slopes are similar in photographic tone and little photo interpretation of soils can be made.

In the Dewey-Decatur-Emory soil association, underlain by materials weathered from dolomitic limestone, fields are larger and more regular in outline; more land is in cultivation and crops; and only small areas are severely eroded. These features indicate that soils are higher in fertility. A poorly defined drainage pattern, modified by many sinks and depressions, can be fairly well detected. Small round depressions show as dark areas because alluvium high in organic matter covers the floors of the depressions. Numerous depressions indicate an irregular karst topography.

In many places studying photographs under a stereoscope is the quickest and most accurate means of locating sinkholes, especially in wooded areas. Mottled light and dark tones in this association indicate an uneven erosion pattern; the light spots have lost their original surface layer and the exposed dark red subsoil reflects a light tone on the photograph either because of bright color or sparse vegetation. (Almost all aerial photograph film is highly red sensitive.)

Most local alluvial areas contrast with upland soils by dark tone. Dewey and Decatur soils on the uplands cannot be separated by photo interpretation.

The Muskingum-Jefferson association is characterized by the narrow linear shape of its individual ridges and intervening valleys and the ridges are conspicuous on the photograph. Photo interpretation is of limited value in identifying soils in the intervening valleys; the valley floors are irregularly covered by alluvial and colluvial materials. Local alluvial spots are clearly shown by darker tone.

In East Tennessee, areas of Tellico soils, derived from the Holston formation, stand out in high ridges and are readily distinguished from soils derived from lower lying limestone and shale formations. Also, Lebew soils on the knobby or comby ridges of the Rome formation can be distinguished from lower lying soils on limestone, such as Dewey soils.

In the dissected area adjoining Caney Fork River in DeKalb and Warren Counties, the soil association comprises steep, forested Bodine soils capped by Mountview, Bodine, or Waynesboro soils in open land. Bodine and Mountview soils, which are moderately eroded, appear medium gray. Waynesboro soils, usually severely eroded and often gullied, appear in much lighter tones.

In areas of uniformly dissected landscapes, such as Bodine-Mountview-Lobelville association (fig. 55) or Memphis-Collins association, the soil scientist can make field checks at much wider intervals if he separates ridge tops and bottom lands under a stereoscope before going to the field.

Two landscapes in Tennessee that appear similar on photographs despite major difference in soils are the Highland Rim Plateau (open land Dickson and forested Guthrie soils) and the Inner Basin (open-land Hagerstown and Talbott and forested rockland areas).

Two that appear similar on aerial photographs but have quite different soils are the Highland Rim (open-land Mountview and forested Bodine and Baxter) and the Cumberland Plateau (open-land Hartsells and forested Muskingum).

Well-drained bottom-land soils such as Pope and Huntington appear in light tones; poorly drained Melvin and Atkins appear much darker. The poorly drained soils may also be covered with forest or brush—another clue to their identification. Moderately well drained Lindsay and Philo soils are less easily recognized; they may be either dark or light. Areas of sandy soils appear as very light streaks. The first bottoms and low terraces of large stream valleys are commonly separated by short steep escarpments which show plainly on the photograph. Boundaries between soils on terraces are less clear, however, than between those on bottom lands.

In nearly all landscapes, stony and rocky areas appear lighter than the surrounding areas. The strike or banding of the rock is very evident.

Coastal Plains of the Southeast.—Much of the lower Coastal Plain in the Southeast has slight relief. Tone, kind and pattern of vegetation, and pattern of cultural features, however, are useful guides on aerial photographs to soil conditions in this area.

Vegetation does not reveal specifically the



Figure 55.—These photographs of a dissected limestone plateau in Tennessee illustrate the significance of photo interpretation in dissected areas of uniform bedrock. Regosols are on steep slopes, Red-Yellow Podzolic soils on drainage divides and high terrace benches, and Alluvial soils on flood plains. The white streaks with fuzzy edges in the cleared area represent soil erosion.

kind of soil, but it often gives an indication of what to look for and where to look. For example, in the sandhill section of the Southeast, scrub oak with scattered longleaf pine indicates well-drained deep sand, and pond pines and gallberry indicate wet sand. In the coastal flatwoods section, stunted pine indicates Ground-Water Podzols with hardpans such as Leon and St. Johns soils. In contrast the associated Plummer soils, which have no pan, support much heavier forest. Soil boundaries can often be accurately located by outlining areas of different vegetation on the photographs. In Bladen soils, pure stands of hardwood indicate fine-textured types, whereas mixed stands of pine and hardwood indicate sandy loam types. In poorly drained areas of the middle Coastal Plain, sweetgum is often an indicator of Coxville soils. Black gum is often an indicator of coarse-textured poorly drained soils.

Water-loving vegetation shows dark to very dark gray in tone; its area is irregular. Trees or water-loving vegetation in dark tones appearing as narrow bands with irregular curves are clues to stream channels. Cypress indicates very poorly drained soils; it can readily be distinguished from pines.

In Florida, differences in patterns of vegetation can help the soil scientist separate poorly drained soils on acid sands from those on neutral sands even though the soils are identical in color and are similar in overall tone on the photograph. In many places cabbage palms indicate neutral to slightly acid soils or soils with carbonates at moderate depths since pine trees grow on acid soils. The vegetation alerts soil scientists of the need to examine given sites for possible differences in reaction.

In many areas in the Atlantic Coastal Plain in the Southeast, tone or pattern on the photograph may give a direct clue to soil differences (figs. 22, 32, 33, and 47). For example, cleared well-drained sandy soils appear lighter than cleared well-drained fine-textured soils. In wooded areas the vegetation shows up darker on fine-textured soils. Poorly drained soils show up as dark areas in both wooded and cleared areas. Well-drained clayey soils generally are represented by gray tones on the photograph.

Tones are somewhat misleading, however, since they are influenced by vegetation on the

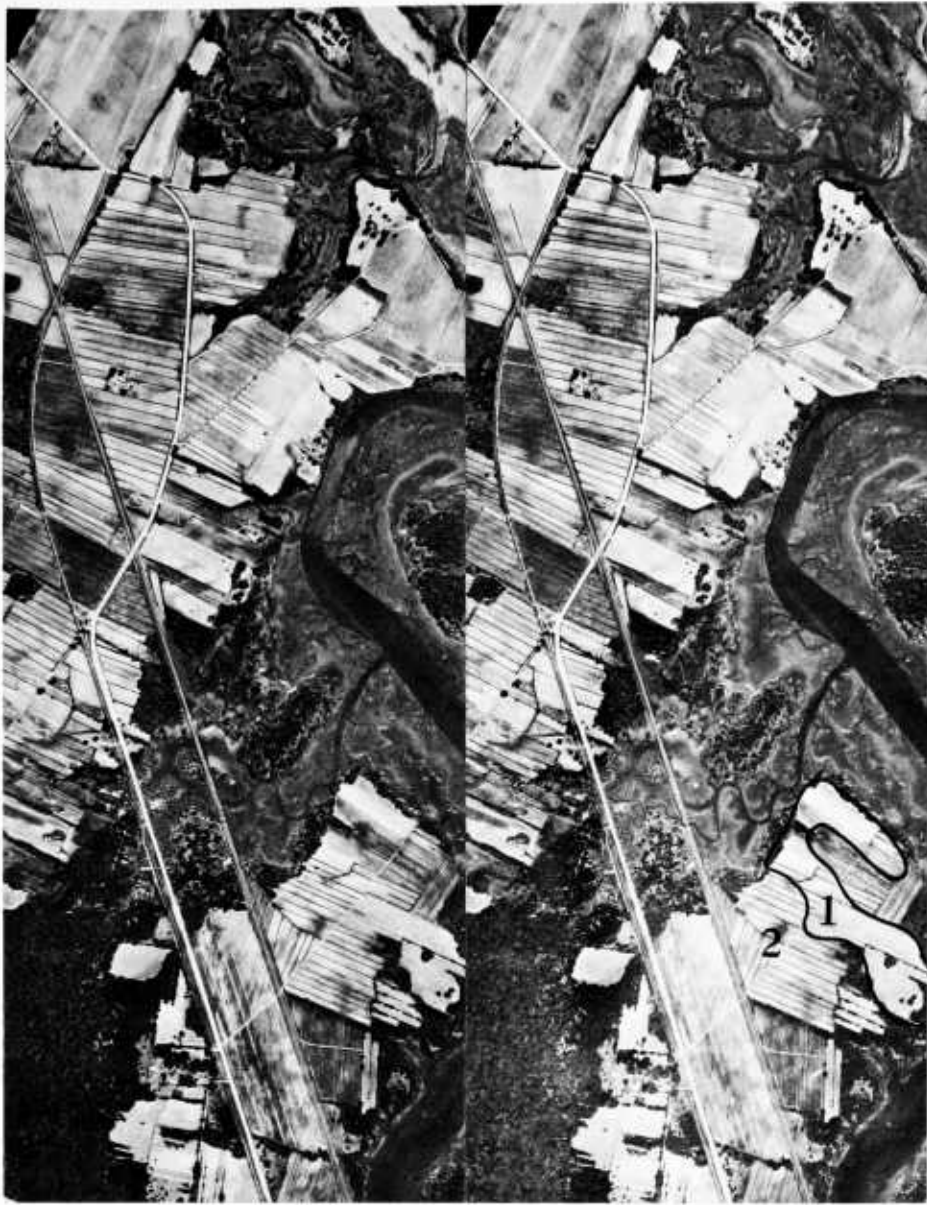
soil. Contrasting shades of light gray indicate coarse-textured somewhat excessively drained soils. Small irregularly shaped light-colored areas within darker areas may indicate severe sheet erosion. A disorderly arrangement of short lines in the direction of the slope represents gullies, which show up clearly under a stereoscope.

A boundary of gray tone against a dark gray tone implies a boundary between well drained and moderately well drained soils. As soil drainage becomes poorer, tones become darker. This suggests that there are two—and possibly three—soil series. In Florida, smooth dark gray tones often suggest Ona, Scranton, Sunniland, or Adamsville soils, whereas black or very dark gray are clues to Rutledge, Portsmouth, Plummer, Delray, Pompano, or Charlotte soils. The first group are moderately well drained and somewhat poorly drained soils, the second poorly drained and very poorly drained. Within the darker tone, areas of light gray sprinkled with black imply the presence of Leon, Pomello, or Immokalee soils, all of which are Ground-Water Podzols.

The boundary lines between better drained and more poorly drained soils on first bottoms can be recognized on aerial photographs because the more poorly drained soils commonly appear darker.

In Florida and Georgia, tone can give an accurate indication of major soil associations within an area. In many areas of Florida, tones give clues to areas having as few as two soil series. Within forested areas gray tones liberally sprinkled with spots of white indicate areas in which acid coarse-textured excessively drained soils predominate.

There is a danger, however, of misinterpreting this feature of a photograph. Coarse-textured excessively drained soils in some parts of Florida appear as dark gray or gray tones intermingled with specks of black that represent pines. This suggests soils that are influenced by limestone or phosphatic materials. In some areas dark-gray or gray tones on photographs represent clay soils. Smooth gray tones within the same area indicate a change in texture or the presence of soils with more restricted drainage. Increasing intensity of tone from gray to very dark gray strongly suggests somewhat



SCALE 1:20,000

ASCS—CDV-7M-174; CDV-7M-175

Figure 56.—Slight differences in tone and the pattern of drainage ditches often indicate differences in soil drainage. These photographs are of a truck-farming area in South Carolina. The light gray area (1) with scattered ditches irregular in length represents well-drained Red-Yellow Podzolic soils. The adjacent darker area (2) with many parallel ditches represents Low-Humic Gley soils.

poorly to very poorly drained mineral soils or soils with surface layers of high organic content (fig. 44).

Cultural and other features such as roads, ditches and canals, terraces, and field patterns may give useful clues to the kinds of soil to expect in some parts of the Coastal Plain (fig. 56).

In nearly level to gently sloping areas, fields are larger, field boundaries are more nearly straight, and secondary roads are straight in many places. Also, in contrast to more sloping areas that have smaller less regular fields and crooked secondary roads that are mainly in valleys or on ridge tops, terraces are lacking. Terraces, which are common on more sloping areas, appear as dark lines on the contour. The spacing of terraces is a clue to steepness of slope. Roads across better drained soils appear as light lines, those across lower more poorly drained areas as dark lines. None of these features by itself is necessarily diagnostic of a soil type, but the combination and patterns may enable the soil scientist familiar with the area to identify the soils.

Spacing of field ditches in truck-crop areas is a clue to the natural drainage and, to a lesser degree, to the subsoil texture of Humic Gley, Low-Humic Gley, and intergrades to Red-Yellow Podzolic soils on the first marine terrace of the Atlantic coast in Charleston County, S.C.

Ditches spaced 60 to 80 feet apart indicate poor to very poor drainage and a subsoil of plastic silty clay. Bladen and Bayboro are the principal soils having this close spacing. Somewhat wider spacing—80 to 120 feet—indicates poorly to somewhat poorly drained soils with subsoil textures ranging from sandy clay loam to sandy loam or loamy fine sand. Weston, Edisto, and Stono soils are the principal soils with these features. Wider spacing—more than 120 feet—and irregularly spaced ditches that are uneven in length indicate moderately well drained soils. These areas are better drained because they have slopes of 1 to 3 percent and are slightly higher than the surrounding soils. Eulonia and Charleston soils with subsoil textures ranging from sandy loam to sandy clay usually occupy these sites.

ACCURACY OF PHOTO INTERPRETATION IN SPECIFIC AREAS

Though photo interpretation is one of the most useful techniques in making soil surveys, too much or too little reliance on photo interpretation can result in inaccurate mapping. The objective is to use photo interpretation to maximum efficiency while keeping the mapping at or above acceptable standards of accuracy.

To obtain a better understanding of the accuracy that could be achieved through photo interpretation in specific areas, selected areas were interpreted and field checked by experienced soil scientists. The following are summaries of the procedures used and results obtained.

COASTAL PLAIN SAND HILLS OF SOUTH CAROLINA

A 640-acre area near Pontiac (Richland County), S.C., was outlined on aerial photographs. A soil scientist who had had 8 years' experience mapping soils in the area and who was thoroughly familiar with its geology and soil associations (fig. 57) and the vegetation that usually grows on the different soils made interpretations by using a stereoscope. He recorded his estimates of soil, slope, and erosion and placed soil boundary lines on the photograph in pencil. An inked tracing of these estimates was made on clear plastic as a permanent record (fig. 58). Then he and another soil scientist also familiar with these soils checked the estimates in the field.

His photo interpretation estimates were compared with the field mapping on the aerial photograph (fig. 59), by placing the inked overlay over the field sheet. The accuracy was determined by measuring the acreage on the overlay that did not correspond with the field mapping.

On 528 acres (82.5 percent), estimates by stereoscope were the same as the field mapping. All streams were accurately identified with the stereoscope. Of the 112 acres (17.5 percent) that were different, 38 acres were in error in designation of soil type or phase. One 12-acre area that was estimated to be Portsmouth sandy loam (53) on field examination was found to be Portsmouth loam (54). Identification of soil series and type was 94.1 percent correct. On

68 acres an error was made in estimating slope with the stereoscope. Two areas, totaling 44 acres, were a low B slope instead of the estimated A slope. Accuracy of estimating slope was 89.5 percent correct. On a 6-acre area class 2 erosion was not recognized.

The soil scientist using the stereoscope was not sure of the correct symbol to put in five delineations totaling 61 acres. He made first and second choices and placed a question mark by his second choice. These were recorded on the overlay before the field check. His first choice proved to be correct in three delineations totaling 36 acres. The second choice was correct on one 21-acre area. On one 4-acre area, the second choice was correct for soil type and erosion but the area was C slope instead of the estimated D slope.

The time required to map the 640 acres was as follows:

- $\frac{3}{4}$ hour in office making photo interpretation
- 5 hours in field checking the mapping done in the office
- $\frac{1}{4}$ hour inking time
- 6 hours—total time to map 640 acres (does not include travel time)

The block diagram in figure 57 shows the relationship of the major soils to the landscape and drainage. Clues used by the soil scientist in making his interpretations follow.

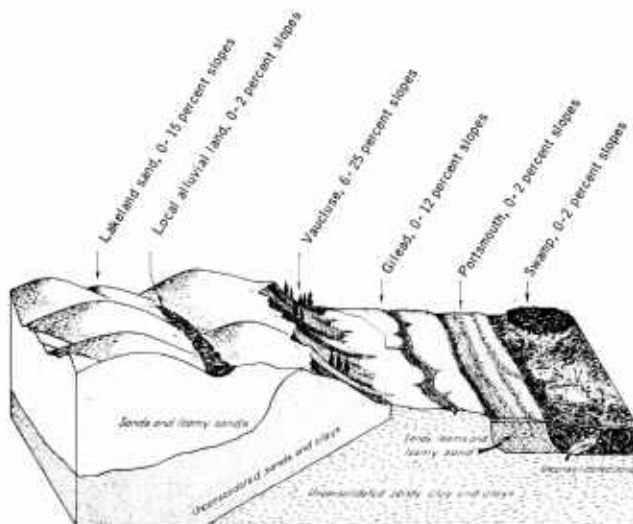


Figure 57.—Relationship of major soils to landscape in Coastal Plain sand hills of South Carolina.



SCALE 1:15,840

ASCS—ATA-3H-138

Figure 58.—Estimates of soil, slope, and erosion delineated by a soil scientist using photo interpretation. Hatching indicates areas for which estimates made in the office were changed in the field. The area is in the Coastal Plain sand hills, Richland County, S.C.

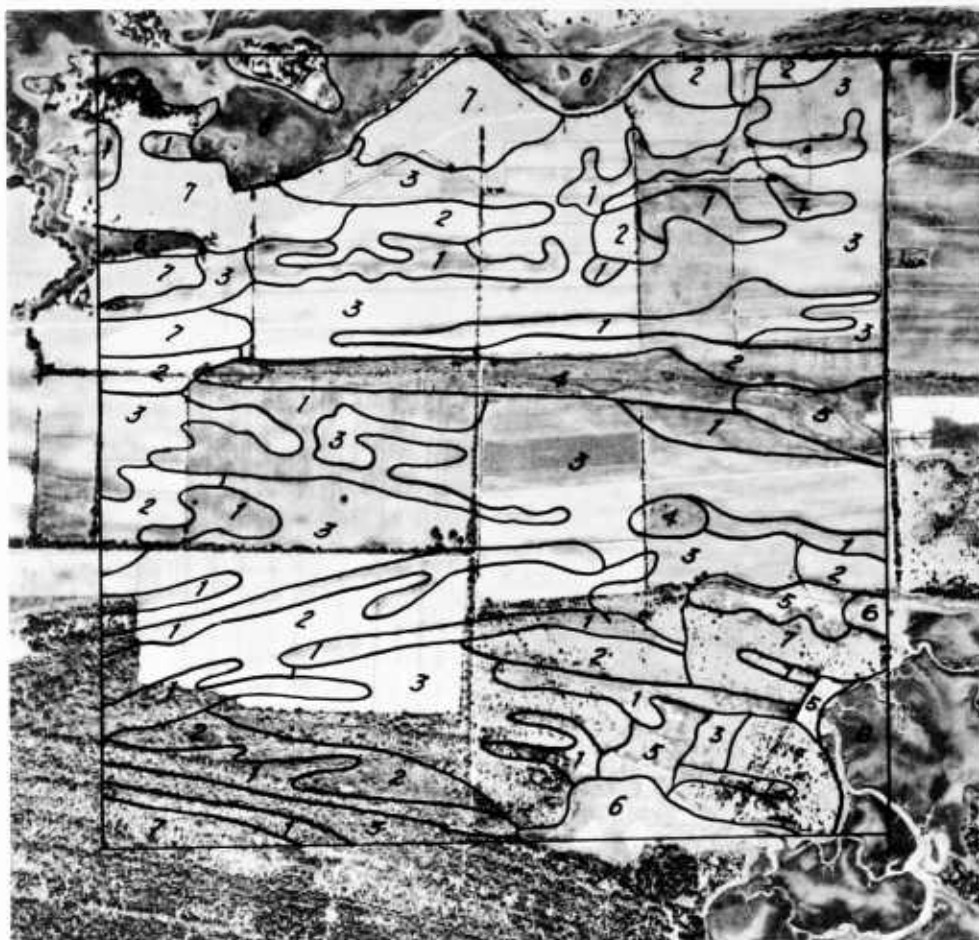
Lakeland sand (18) occurs as dunes or hills on the highest elevation of the soil association. The tone of the photograph is light gray in wooded areas and nearly white in cultivated fields. Cultivated areas reflect so much light that field roads, furrows, and other minor culture tend to be obliterated. The scrub oak of the wooded areas is sparse, and the light gray sand between trees reflects a large amount of light. Minor trails show up very light. Scattered pines show up as dark specks. Under the stereoscope, slopes contrast readily.

Vaocluse sandy loam (96) contrasts markedly under the stereoscope with the associated Lakeland sand by showing a sharp and sudden break in slope. It usually occurs on slopes two or more classes higher and displays some characteristics of an escarpment. Many times it oc-

curs in areas shaped like a horseshoe. The associated thick surface phase (97) generally occurs in broader areas and on somewhat gentler slopes. Tone of Vaocluse sandy loam, thick surface phase, is lighter than Vaocluse sandy loam.

Vegetation on both types is denser and tone is a darker gray than on Lakeland sand. Pine thickets on formerly cleared areas show up black on the photograph. Vaocluse sandy loam often occurs as a narrow band at the highest part of the slope break and on breaks around stream heads. Streams frequently originate at the foot of these breaks.

Gilead sandy loam (115) contrasts with Lakeland and Vaocluse by being at the base of slopes—often in stream heads—and on gentle slopes along the major streams. Few areas are above C slope (6–10 percent). Tone of the pho-



SCALE 1:15,840

ASCS—CDV-8F-112

Figure 60.—Delineations resulting from stereoscopic interpretations. The area is in the Atlantic Coastal Plain, Charleston County, S.C.

SOUTHEAST ATLANTIC COASTAL PLAIN OF SOUTH CAROLINA

Interpretations of the photograph of a 640-acre area on a first marine terrace in Charleston County, S.C., were made in the office by a soil scientist who had 12 years' experience mapping in this area. Delineations resulting from stereoscopic interpretations are shown in figure 60 and identified as follows: 1, Rutlege loamy fine sand; 2, Seabrook loamy fine sand; 3, Kiawah loamy fine sand; 4, Stono fine sandy loam; 5, Tidal marsh, high; 6, Tidal marsh; 7, Eustis fine sand.

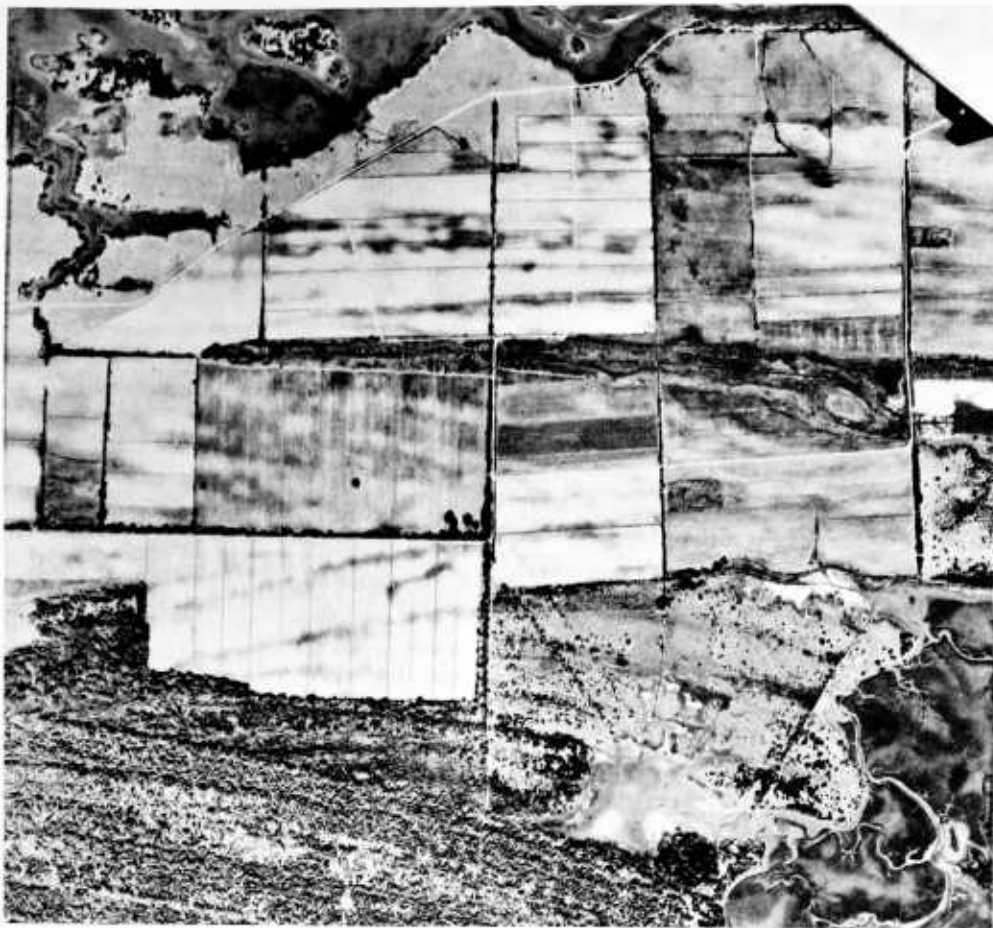
For comparison, a plain photograph of this area is shown in figure 61. A block diagram of the relationship of major soils to landscape and drainage is shown in figure 62.

Field checking of the mapping done in the office showed that about 95 percent of the inter-

pretation was correct. Interpretations in open areas were accurate where contrasting tones were apparent. A partially wooded area of about 24 acres on the southeast side of the mapped area was judged in the office to be better drained than field examination indicated. Scattered small trees and light gray tone of the photograph on a 12-acre area were interpreted to mean well-drained soils. Field examination showed that this area had been cleared and was being cultivated.

Two areas of 1.3 acres each in the east and northeast parts were better drained than indicated by stereoscopic examination. The lack of contrast in tone did not give the soil scientist the correct clue.

A 0.8-acre area on the northeast was interpreted as part of a 10-acre poorly drained area. Field examination showed that it was poorly drained but was an area of high phase tidal



SCALE 1:15,840

ASCS—CDV-8F-113

Figure 61.—Plain photograph for comparison with figure 60.

marsh separated by a farm road from an adjoining area of tidal marsh.

The soils interpretation was based on two factors: (1) *Landform*—parallel bands of old beach ridges and sloughs. (2) *Tone*—white, whitish gray, and dark gray tones indicating good, imperfect, and poor natural soil drainage, respectively.

Landform.—The ridge-slough landform originated as parallel lines of beach dune sands modified by wind and water with time and shoreline recession. The landform in varying stages of development can be traced from the present shoreline beach sand dunes onto tree-covered steep-sided dunes and sloughs and across the broad ridge and slough areas for a distance of about 5 miles. The landform is more extensive and visible on the first (Pamlico) marine terrace than on the second (Talbot) terrace.

A difference in elevation of about 4 to 8 feet

between the ridges and sloughs shows on the photograph (fig. 60), but it cannot be readily seen under the stereoscope because the change is gradual. This difference in elevation makes the difference in the drainage class. All the area has A slope (0–2 percent) and class 1 erosion (none to slight). In the entire area of nearly level sand, the water table is high; in low areas it is at the surface where undrained; in higher areas at 4 to 6 feet below. The water table and drainage class affect the amount of vegetation cover that grows and accumulates in the surface soil.

Tone.—Ridge areas grow less vegetation and have less organic matter in the surface soil and therefore show up as white or chalky colored. Low areas having the most organic matter show up dark. Areas intermediate in elevation have an intermediate amount of organic matter and show up as grayish white. The chalky white-

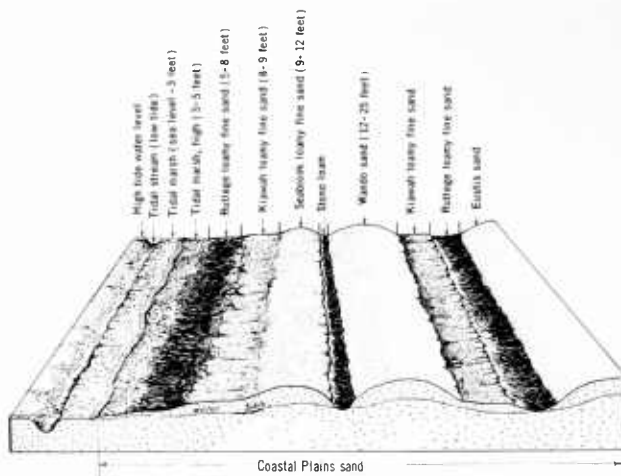


Figure 62.—Relationship of major soils to land-scape and drainage in Pamlico Terrace, Coastal Plain of South Carolina. Numbers in parentheses give feet above sea level.

toned ridges are the Eustis soil series, intermediate areas are Seabrook and Kiawah series, and the dark-toned, low areas are the Rutlege series. The problem was to separate Seabrook from Kiawah. The clue was that Seabrook has more white than gray-white tone and that Kiawah has more gray-white than white. In wooded areas the higher well-drained to excessively well drained areas are in pine with about 75 percent crown cover plus some live oak and hickory. Gray areas show up indicating reflection of light from the ground. The pines show up dark. Poorly drained areas in woods are dark indicating a dense stand of pine, black gum, and low-growing shrubs. Intermediately drained areas are gray to dark gray indicating some ground reflection of light with a crown

cover between 75 to 100 percent of mostly pine and a few oaks.

On the second marine terrace the sand soils associated with the ridge-slough landform are the Lakeland, Ona, Plummer, St. Johns, and Rutlege series.

The time required to map the 640 acres follows:

- ½ hour in the office making photo interpretation
- 3½ hours in field checking the mapping done in the office
- ½ hour inking time
- 4½ hours—total time to map 640 acres (does not include travel time)

In both of these test areas the high proportion of agreement between photo interpretation and field examination resulted from several factors—the long experience that soil scientists had had in the areas, their intimate knowledge of the soils and of their relationships to landforms, the relatively simple patterns of the soils, and the noninterference of foliage in the interpretations of soils of forested areas. If any of these factors had been lacking, the photo interpretation might have been considerably less accurate.

Even with an intimate knowledge of the soils one would need to field check constantly and continually revise photographic guides because of the close relationships of soils and variations from photograph to photograph and place to place. Areas of such closely related soils as Kiawah and Seabrook are always suspect until examined in the field. Clues change from place to place and may not apply from one photograph to another even if appearances are the same.

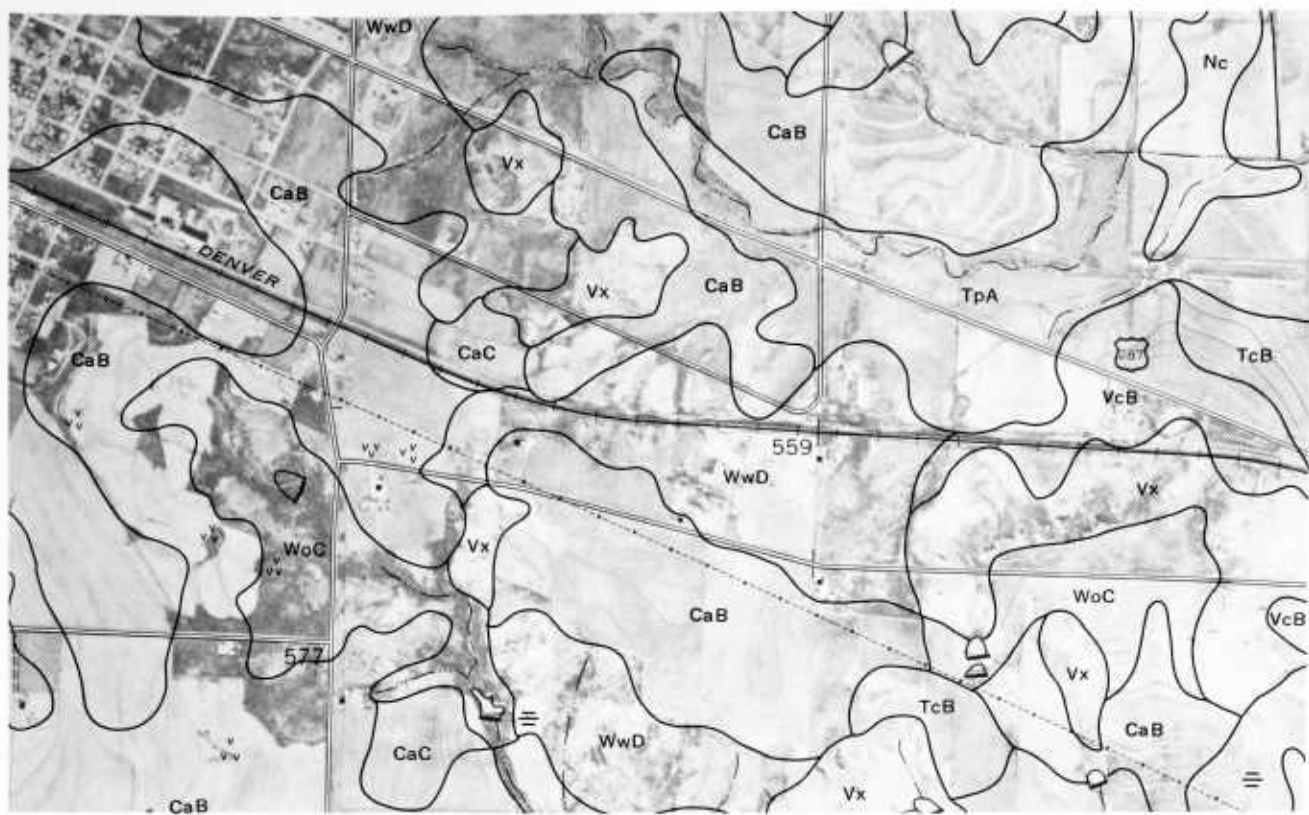


Figure 63.—Section of a soil map compiled on a controlled mosaic base.

SOIL MAPS FOR PUBLISHED SOIL SURVEYS

Maps systematically compiled from soil-survey data delineated on aerial photographs make up the detailed soil map that is part of every published soil survey. Most of them cover a full county.

Usually the soil-survey data are superimposed on a controlled aerial mosaic base (fig. 63). This base produces uniformity of scale, provides a close match of images between adjoining map sheets, and makes possible the economical production of data on a base that is generally understood and useful.

The published map sheets are 11 x 17 inches in size and usually 1:20,000 in scale. Some are at scale of 1:31,680 or 1:15,840, depending on the complexity of soil delineations and on the intended use of the maps.

Some aerial photographs selected for the mosaic are from the same film used to print the photographs on which soil data were originally plotted. When a more recent aerial survey has been flown, it is used if the photographs have good quality and a satisfactory scale.

The SCS Cartographic Division may begin compiling the mosaic while the soil mapping is being completed in the field.

CONTROL FOR THE MOSAIC

A radial-control network is established for each project. This network provides a pattern of correctly located image points that are identified on the photographs. These provide a basis for rectifying and mounting the individual aerial photographs into a continuous map image.

First, a base grid is constructed at the scale selected for map compilation. The grid, usually constructed on the State rectangular coordinate system, forms a system of spaced lines of reference from which any ground position within the area may be plotted if the coordinates of that position are known. The positions of all geodetic control stations that can be identified and marked on the aerial photographs are then plotted on the base.

Because geodetic control stations are too widely spaced to provide a basis for rectifying and mounting aerial photographs, a system of radial-line triangulation is used to provide accurate locations for additional image points. Since for all practical purposes image displacements caused by relief are radial from the center of

the photograph, the true location of an object falls on a line drawn from the center of the photograph through the object. Therefore, the center point of the photograph is a triangulation station from which angles to various objects in the photograph area may be determined accurately.

To provide the triangulation pattern, nine image points are marked on each photograph: the center point, two "conjugate" center points that are transferred from adjacent photographs within the line of flight, two "wing" points on images in the sidelap areas opposite the center point, and four wing points that are transferred from adjacent photographs (fig. 64). Wing points are transferred to adjacent lines of flight much as the center points are transferred from photograph to photograph within a line of flight. Where images of geodetic control stations fall in the sidelap area, they may serve as wing points.

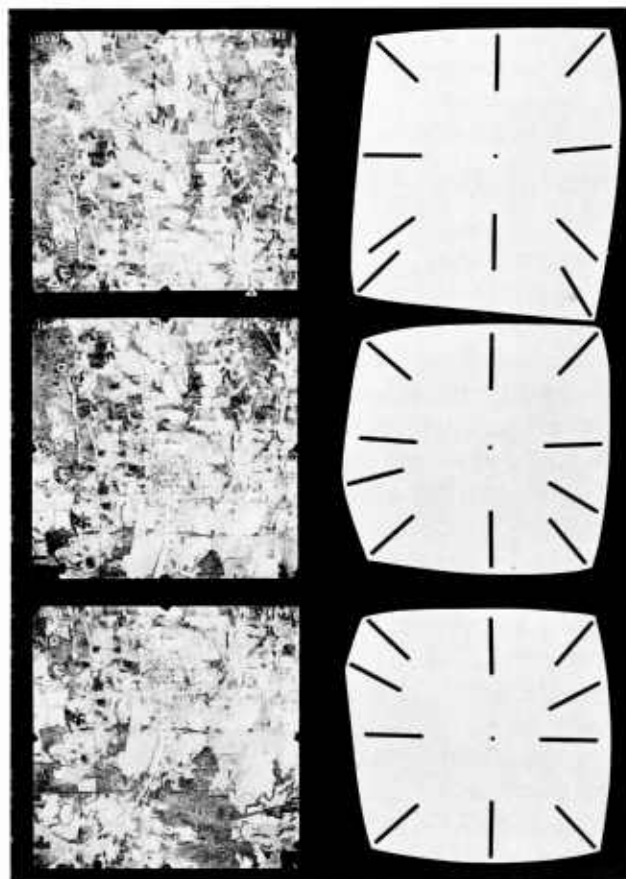


Figure 64.—Typical pattern of center and wing points circled on aerial photographs and corresponding slotted templates.

Where they do not, they are additional points that must be transferred to adjacent photographs within the line of flight. Contact prints are nearly always used to provide radial-line triangulation.

SCS uses the slotted-templet method of assembly to establish the radial-control net. A high-quality cardboard, such as three-ply railroad board or four-ply bristol board in sheets about the size of the aerial photographs, is used for the templets. A templet of the triangulation pattern of each photograph is made by punching a small hole in the center and by punching long, narrow radial slots that accurately reproduce the radial angles established on the photograph (fig. 64). Studs are "anchored" directly on the geodetic control stations plotted on the base, and the templet assembly is jointed by "floating" studs: one stud for each center hole and one for each intersection or radial lines through common wing points. The assembly is expanded or contracted until it fits the anchored studs. Then the locations of all the floating studs, fixed in position, are marked on the base (fig. 65). All radial-control positions are then transferred to 1/4-inch tempered hardboard sheets on which the mosaic will be compiled.

RECTIFIED PHOTOGRAPHS

On contact prints used to establish the radial-control network, a small dot of black ink is placed on the image points picked for the triangulation pattern; all other notations are removed from the prints. Then a copy negative of each contact print is made. A strip of thin, stable transparent plastic is placed over each flight line pictured on the hardboard control base, and a "strip" templet of each flight line is made by carefully circling on the plastic all control points common to the flight line. The copy negative, which has dotted image points that are displaced, is placed in a rectifying enlarging printer; the strip templet, which has corresponding points that are positioned correctly, is placed on the easel. The dotted points on the negative are projected, ratioed, and rectified until they fit the corresponding points on the strip templet. Then, the templet is removed; photographic paper is placed on the easel; and the rectified image of the copy negative is printed. Great care is taken to expose and develop photographs that will match the tone, contrast, and density of adjoining photographs.

MOSAIC ASSEMBLY AND REPRODUCTION

Because cut lines are less evident along features that have abrupt changes of tone, whenever possible match lines are selected where they can be made along prominent features such as roads, trails, streams, certain landforms, or boundaries of fields, forests, or bodies of water. Since only features that have about the same ground elevation may be precisely matched to adjoining photographs, in areas of moderate to severe relief, cut lines tend to follow a generalized contour line.

Some paper backing is removed along the cut and the remaining paper is sanded to provide a smoothly tapered joint with adjacent photographs. The segment is then positioned on the hardboard base, dotted points are matched to corresponding control points on the base, and photographic detail is matched to detail of adjacent photographs. The photographs are mounted with gum arabic adhesive (fig. 66).

When all photographs are mounted, a transparent dye solution is applied to darken any segment that has a photographic density lighter than that of adjoining photographs. Also, opaque paints in gray tones are applied to correct minor mismatches of prominent features. Finally, corners of individual map sheets are plotted on the mosaic, and each map sheet area is copied through a halftone screen on dimensionally stable film. The halftone negatives are used to print the mosaic images on bases for manuscript compilation and to make press plates for reproducing the photographic background of the map.

To prepare a base—called a greencote—for soil map compilation, dimensionally stable, clear plastic sheets are coated with a white pigment paint developed for scribing.

A green, water-soluble sensitizer is applied over this coating. The sheet is then exposed in contact with the halftone negative to produce a "manuscript base". The greencote reduces the passage of actinic light except through lines where the paint has been removed by scribing. The scribed greencote, therefore, serves as a negative for reproducing the manuscript.

MANUSCRIPT COMPILATION

The map manuscript is compiled by scribing on greencotes the main drainage, roads, soil

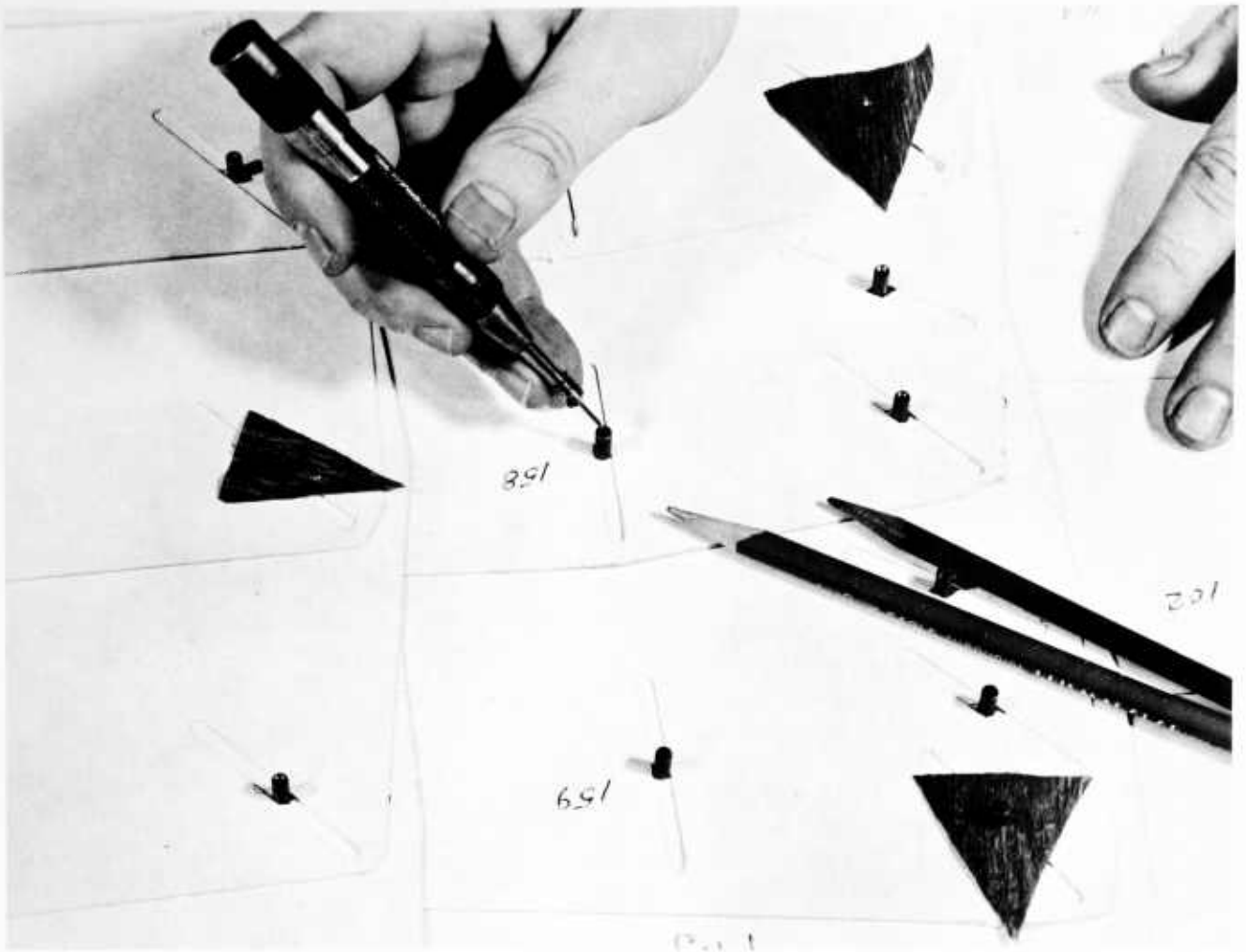


Figure 65.—Portion of a slotted-templet assembly. To mark the locations of studs on the base, a needle is passed through holes drilled through the studs.

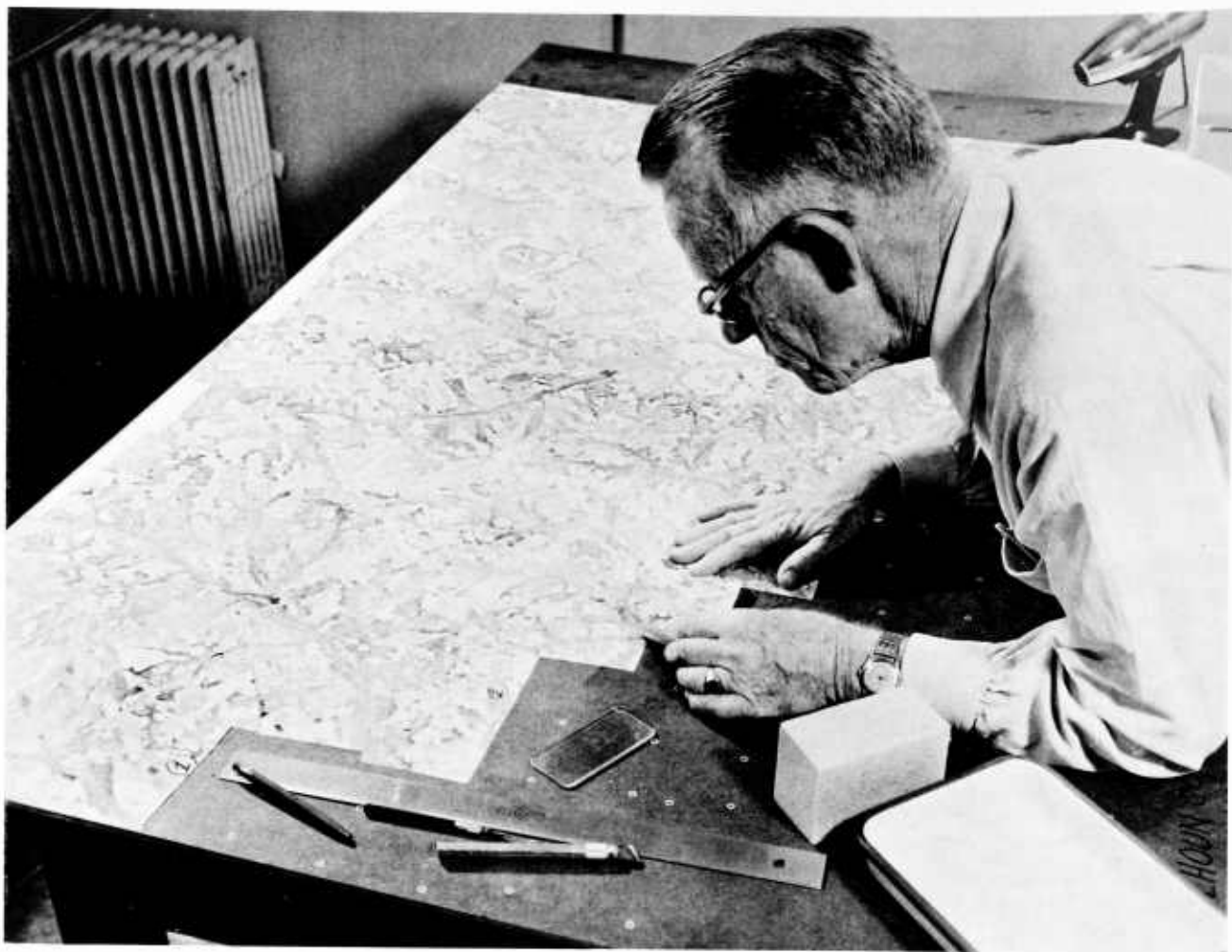


Figure 66.—Mounting aerial photographs to form a controlled mosaic. Note the control points plotted on the hardboard base.

boundaries, soil symbols, and other data shown on field sheets. Main drainage and roads are first traced with a stylus (scribed) as they appear on the mosaic. The greencote is then placed under an overhead reflecting projector, which projects the field sheets to the greencote. The gray-tone image of the field sheet is enlarged or reduced to fit the green-tone image and the scribed drainage and roads on the greencote. The map compiler then scribes soil boundaries and other data that appear on the field sheet. Succeeding field sheets are thus projected until compilation on the greencote is completed.

After soil survey data are scribed on greencotes, identifying soil symbols are scribed in the soil areas (fig. 67). These symbols are taken from a working conversion legend prepared from the correlation and final soil legend. The scribed soil boundaries separating soils that are combined is opaqued out.

When the greencote manuscript is completed, the soil map is edited. Manuscript editors use the original field sheets and the correlation legend to check the accuracy of the soil-survey transfer, adjustment of soil boundaries to the mosaic image, and conversion of field soil symbols to the final map symbols.

COLOR-SEPARATION SCRIBING

Since on final map sheets soils data are printed in red and culture and drainage features in black these features must be separately scribed in negative (left-reading) form. To prepare a base for this scribing, the greencote manuscript is contact printed to a plastic "yellowcote." A yellowcote is similar to a greencote but is coated with yellow pigment paint and sensitized with blue watercote. Since all scribing on the greencote is positive (right-reading), the manuscript is contact-printed emulsion-to-emulsion on the yellowcote to reproduce a left-reading image. Two yellowcotes are printed from each manuscript. Only culture and drainage features to be printed in black are scribed on one yellowcote. Soil boundaries, erosion symbols, and other symbols to be printed in red, such as es-

carpments, depressions, and rock outcrops, are scribed on the other. Each scribed yellowcote is contact-printed on film to produce a right-reading film positive. Lettering to be printed on the final map sheet is added to these positives.

SCRIBING TOOLS

The scribing tools used are standard throughout the mapping industry. They are ground and adjusted to cut sharp lines of uniform weight and spacing. A tool designed to scribe highways is used to cut a double-line road that will have the specified width and line weight. A rigid scriber is used to scribe soil boundaries and perennial drainage, and a dotting instrument is used to make dots in the symbol that distinguishes intermittent drainage.

MAP LETTERING

To determine the proper position of place names and conventional signs, a lettering guide is first laid out on paper reproductions of the greencote. The size, style and weight of type, and the position of names and signs are shown on this guide. Soil symbols, names, conventional signs, and soil legends are printed on cellophane, the back of which is coated with wax to form a pressure-sensitive adhesive. Next, lettering is cut from the cellophane letterpress sheets and applied to the film positives reproduced from the yellowcotes. Names of roads, drainage, and cultural features are applied to the black plate positive; alphabetical soil symbols are added to the red plate positive after this positive has been placed over and registered with the first one. In this manner the two plates are properly registered, and overprinting of red and black features such as lettering or conventional signs is avoided.

FINAL EDIT

Each completed film positive is contact printed on film to produce a negative, and a composite color proof is made from these negatives. A final edit of the proof is made, and the negatives are corrected before press plates are made.



Figure 67.—Scribing soil symbols on greencote manuscript.

PHOTO INTERPRETATION IN WATERSHED-PROTECTION AND FLOOD PREVENTION PROGRAMS

Photo interpretation and related techniques, many of them similar to those used in making soil surveys, are also used to find facts about watersheds. Enough necessary information for watershed planning can be determined by photo interpretation to produce a significant saving in time and cost. A good knowledge of the physical and cultural features of the area being studied increases the accuracy as well as reduces the time required.

Photographs also form the basis for watershed measurements and are used to record information and to make mosaics and maps necessary for planning and working with local watershed sponsoring organizations.

Aerial photographs that have a slightly "flat" finish allow slight tone differences to be distinguished in lighter areas of photographs. These differences may be significant to the soil scientist or geologist. Though 1:20,000 is usually a good scale, the physical and cultural characteristics of the watershed could require a different scale. A 60-percent overlap within the flight line and 30-percent sidelap between flight lines give adequate stereoscopic coverage. The most recent aerial survey should be used; a single storm after a survey is flown could cause significant changes in stream channels and erosion conditions.

A folding pocket stereoscope of 2 $\times$ -power magnification is adequate for studying the pictures, but a stand stereoscope of 2 $\times$ - or 4 $\times$ -power is often preferred because the pictures can be moved more easily under it. A pricker or similar instrument is needed for pricking point locations. Also, for close study, a good quality reading-glass magnifier is essential.

Either colored pencils or inks may be used for delineating physical and cultural features. Ink may be better if the pictures will be used several years later or will receive rough field use.

A good color legend for delineation is: Drainage, blue; match lines, green; watershed lines, black; cultural features, red; erosion condition, orange.

All delineation should be made under the stereoscope and should be neat and accurate.

All features should be marked clearly.

To avoid duplication there should be a set of match lines on the photographs. Unless the terrain is unusually rough and steep, straight lines can be used for all four match lines.

The interpreter usually is given a county highway or topographic map on which a rough watershed boundary is drawn. But any general map of the county is adequate. The interpreter also has an index map of aerial photographs to be used. A "point of beginning" is set at the lowest level of the watershed before interpretative work is begun. This may be any point on a stream, but normally it is the point where the stream enters a larger stream or lake.

The interpreter locates this point on the photograph by noting on the map features that are near it and finding their images. Under the stereoscope he orients the stereoscopic pair showing the point of beginning and on both photographs pricks and circles this point with a pencil. Starting at the point, under the stereoscope he marks the ridge, or the dividing line from which the ground slopes toward the stream, between match lines on one of the photographs. The procedure is repeated on the succeeding stereoscopic pairs. The completed watershed boundary is a continuous line within which all land drains into one stream.

Next, stream or drainage lines within the watershed are drawn under the stereoscope. Generally stream channels appear as irregular striations and are easily seen. The interpreter overdraws these lines in blue. To keep photographs from becoming cluttered and to show only those drainage lines necessary for further study, the shortest length of stream to be overdrawn is specified before any lines are drawn.

Through stereoscopic study of aerial photographs, the photo interpreter can locate areas that contribute sediment to the stream. Sheet erosion, a major source of sediment, can be marked for field study. If gullies, which appear as irregular striated lines usually sloping toward a stream or drainageway, are in groups the entire area can be marked as a silt-contributing area. For single gullies the gully line is overdrawn.

Streambank erosion, which appears as jagged deep vertical cuts, is delineated by overdrawing the line or outlining the area of cutting. Other sediment-producing areas that must be marked are stream beds clogged with alluvial material; sand or silt bars in streams, which appear as elongated elliptical areas that have a slight mounding or raised surface; and alluvial fans at the mouths of streams or gullies, which appear as triangular areas with the peak or apex of the triangle pointed upstream.

To prepare flood-routing data, planners must know the configuration of the flood plain of a stream. The photo interpreter can assist the planner in this work by delineating the limits of flood plains in the watershed.

Some field work is necessary to locate the highest known water mark along a stream channel. Levels are run to these high-water marks and elevations are transferred by leveling to the opposite bank of the stream. This is repeated throughout each stream for which flood-routing data are required. Each point is marked on a photograph.

In the office the photo interpreter studies the photographs stereoscopically and, using the field-located points, delineates an approximate contour line. It is approximate—not a true contour—because the previous-high-water locations include the hydraulic gradient of the stream.

To help locate economical damsites, the photo interpreter studies the aerial photographs stereoscopically and selects sites where valley walls converge and the valley above is wide and flat. He marks these sites on a photograph for checking in the field. Often he marks the water line as well as the watershed line above each site.

He makes preliminary contour maps of the most desirable sites selected by the field check to determine the approximate storage capacity of each. Field crews may locate elevations along the center line of the proposed dam and upstream along the stream channel to a point higher than any elevation at the center line on the damsite. Points of elevation at intervals of about 10 feet are located on aerial photographs covering each damsite. The photo interpreter views the photographs stereoscopically and draws the approximate contour lines connecting these points. A preliminary estimate of reser-

voir storage capacity can then be computed by measuring the area of each applicable contour interval.

Land use patterns delineated to help planners estimate runoff should be marked on a separate set of aerial photographs to avoid congestion. If the photo interpreter is familiar with the area under study, he can easily identify almost all land uses. But he must be aware that climatic area affects the interpretations of land use. Land use patterns in arid areas are different from those in humid areas. Even within a climatic area, the tone of the photographic image varies depending on whether the ground surface is wet, moist, or dry.

BASE MAPS FOR WATERSHED PLANNING

All features delineated on aerial photographs are transferred to a base map, which for many areas is an uncontrolled mosaic. One advantage of a mosaic is the ease with which information from individual aerial photographs can be assembled and integrated for the whole watershed. The overall picture a mosaic provides is also often helpful when working with local people.

If a line map is used as the base map, the features on the photographs can be projected onto it with a vertical reflecting projector. A tracing may also be made from the photographs. Appropriate symbols and patterns identify the various features.

If a mosaic is used, it is compiled from a set of contact prints or from reduced-scale prints made by copying the watershed planning party's aerial photographs. Published maps are used to maintain overall scale and alignment. Prints are trimmed as necessary and then taped or pasted together to make the mosaic. Important names, physical and cultural features, and the watershed divide are usually added to the mosaic. Drainage may be delineated in white ink on the aerial photographs before they are copied for mosaicking.

In some areas for which a mosaic is compiled as a base map, a planimetric map of the watershed may also be prepared. Unless the mosaic was compiled from prints made after the drainage had been delineated on individual photographs, drainage is stereoscoped and then delineated on a manuscript overlay of acetate or

other plastic placed on the mosaic. Roads and other features taken from the photographs and information from U.S. Geological Survey quadrangles and county maps are also compiled on the manuscript overlay. Map features, including lettering, are cut on scribecoat placed in contact with the manuscript on a light table. A contact film positive made directly from the scribecoat yields diazo reproductions in the original scale. Other sizes can also be made.

TOPOGRAPHIC MAPS OF STRUCTURE SITES

Topographic maps of sites finally chosen for structures are prepared to make the preliminary design for the structure and a storage-data table. These can be made by stereoplotter or conventional survey methods.

For stereoplotting, aerial photographs are studied to select identifiable image points that are suitable for vertical control. They are analyzed stereoscopically to select suitable terminal points for taking measurements to scale the plotter models (areas covered by two overlapping photographs).

Setting up a stereoscopic model in the plotter requires a minimum of horizontal and vertical ground control. A base line, measured on the ground between two clearly identifiable points on the photographs, is required on about every third or fourth model to control horizontal scale. It should be long enough to measure 3 inches or more on the contact photograph and to fall entirely within the model. In addition, four vertical control points, one near each corner, are required for each model. They should have a middle tone on the photograph and be within a flat area about 15 or more feet in radius on the ground.

These control points must be positively identified in the field, positively identified and marked on the photographs, and easily seen in the stereoscopic model. Depending on the accuracy required, differential leveling or trigonometric leveling is used to determine the elevation of the four vertical control points.

The plotter operator should be a member of the field survey party. If this is not possible, the chief of the field survey party should become thoroughly familiar with the operation of the plotter and should know exactly what type of control points to select.

SCS uses Kelsh plotters to produce topographic maps that have fairly large scales and cover areas of 100 acres or more.

The Kelsh plotter provides a maximum of 5× enlargement and forms a single stereoscopic model. This model is produced by two precise projectors that project aerial pictures onto a tracing table. Each projector is provided with a contact glass positive made photographically from original aerial negatives. Each has a colored filter—one blue, the other red. The operator wears glasses with one blue and one red lens.

Once the stereoscopic model is alined with the control points, the operator sets what appears to be a floating dot of light on the elevation to be traced. This light comes through a pinhole in the center of the platen of the tracing table, which is a white disk about 3 inches in diameter. The operator keeps the dot on the ground as he moves the tracing table and an attached pencil traces the contour from below as shown in figure 68.

The Kelsh plotter is economical for preparing topographic maps. For example, from aerial



Figure 68.—Tracing contours with a Kelsh plotter.

photographs at a scale of 1:9,600, 4-foot contours can be plotted using a mapping scale of 1 inch=160 feet; at a scale of 1:4,800, 2-foot contours can be plotted using a mapping scale of 1 inch=80 feet.

Field time for obtaining the ground control points varies widely. When trigonometric leveling is used on the average site, it should be

possible to obtain the four ground control points and the measured distance for scale control in 1 day's time. In rough or brushy country, reconnaissance mapping can be plotted from control elevations obtained by barometric readings from precise altimeters. The accuracy of any topographic map can be no better than the field control on which it is based.

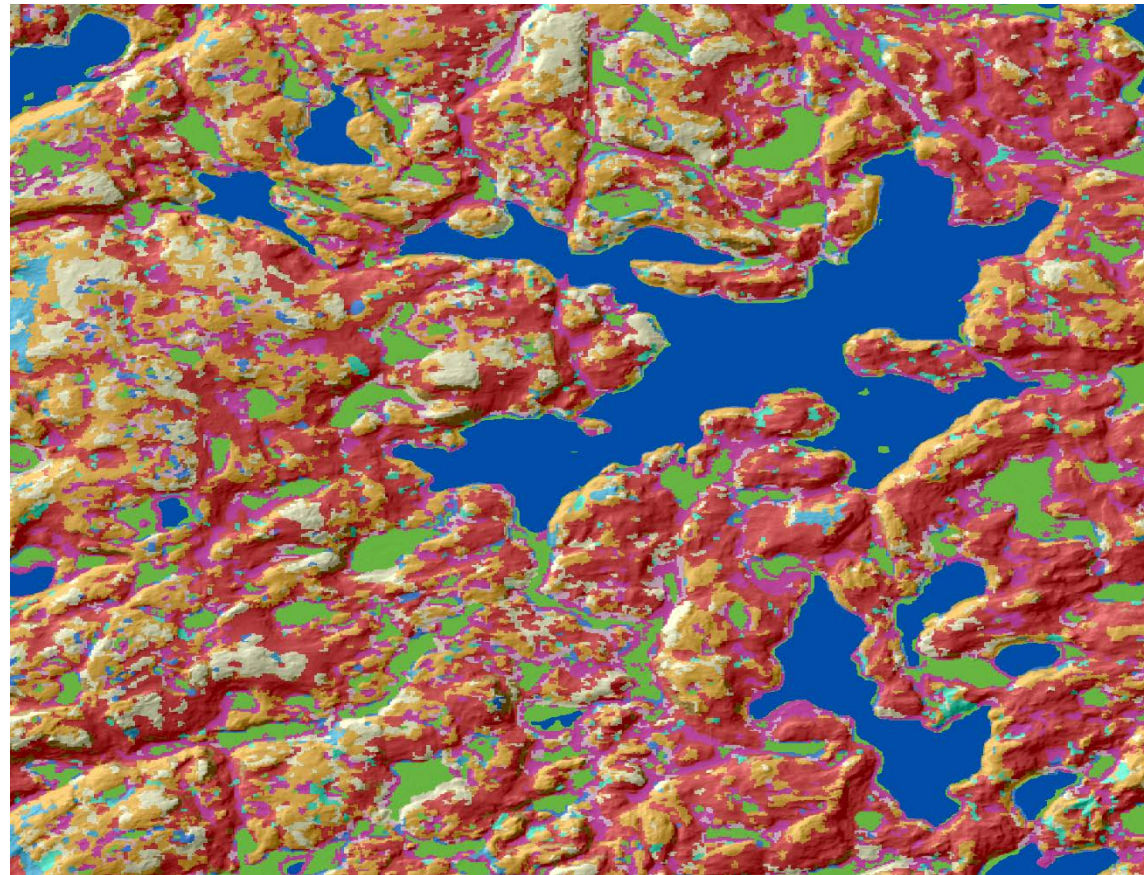
BIBLIOGRAPHY

- American Society of Photogrammetry. 1952. Manual of photogrammetry. 2nd ed.
- American Society of Photogrammetry. 1960. Manual of photographic interpretation. American Society of Photogrammetry, Washington, D.C. 868 pp.
- Heller, R. C., G. E. Doverspike and R. C. Aldrich. 1964. Identification of tree species on large-scale panchromatic and color aerial photographs. U.S. Dept. Agr., Agr. Hbk. 261, 17 pp.
- Lobeck, A. K. 1939. Geomorphology; an introduction to the study of landscapes. McGraw-Hill, New York. 731 pp.
- Lueder, Donald R. 1959. Aerial photographic interpretation; principles and applications. McGraw-Hill, New York. 462 pp.
- Marschner, F. J. 1958. Land use and its patterns in the United States. U.S. Dept. Agr., Agr. Hbk. 153, 277 pp. [Out of print; may be available in library.]
- Purdue University of Civil Engineering and Engineering Mechanics. 1953. Airphoto interpretation of soils and rocks for engineering purposes. Purdue Univ., Lafayette, Ind. 206 pp.
- Ray, Richard G. 1960. Aerial photographs in geologic interpretation and mapping. U.S. Geol. Survey Prof. Paper 373, 230 pp.
- Soil Survey Staff. 1951. Soil survey manual. U.S. Dept. Agr., Agr. Hbk. 18, 503 pp.
- Spurr, Stephen H. 1960. Photogrammetry and photo-interpretation; with a section on application to forestry. Ronald Press, New York. 472 pp.
- Thornbury, William D. 1954. Principles of geomorphology. Wiley, New York. 618 pp.
- U.S. Department of Agriculture. 1958. Land, year-book of agriculture 1958. 605 pp.
- U.S. Geological Survey, Topographical Division. 1961. Color-separation scribing. Geol. Survey Topog. Instr. Ch. 4B1, 4B2, and 4B3, 31 pp.
- U.S. Geological Survey, Topographical Division. 1961. ER-55 plotter procedures. Geol. Survey Topog. Instr. Ch. 3F6, 49 pp.
- U.S. Geological Survey, Topographical Division. 1960. Kelsh plotter procedures. Geol. Survey Topog. Instr. Ch. 3F5, 29 pp.
- U.S. Geological Survey, Topographical Division. 1960. Multiplex plotter procedures. Geol. Survey Topog. Instr. Ch. 3F4, 45 pp.
- U.S. Geological Survey, Topographical Division. 1961. Photogrammetric rectification. Geol. Survey Topog. Instr. Ch. 3C3, 42 pp.
- U.S. Geological Survey, Topographical Division. 1960. Planimetric map compilation with trimetrogon photographs. Geol. Survey Topog. Instr. Ch. 3G1, 28 pp.
- U.S. War Department. 1942. Interpretation of aerial photographs. TM 5-246. [Out of print; may be available in library.]

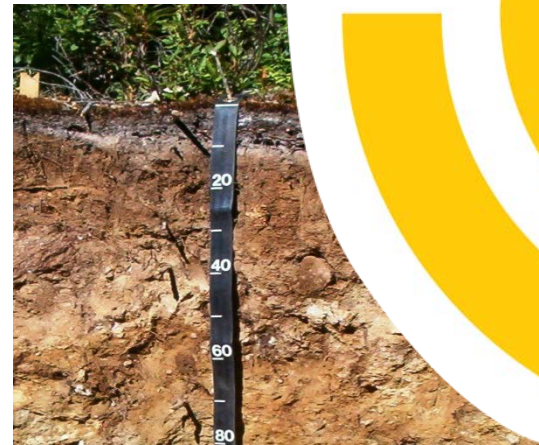
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United States Department of Agriculture



Soil Science Division
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Digital Soil Mapping Primer

Tom D'Avello | Suzann Kienast-Brown

2.22.2018

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Principles and Concepts

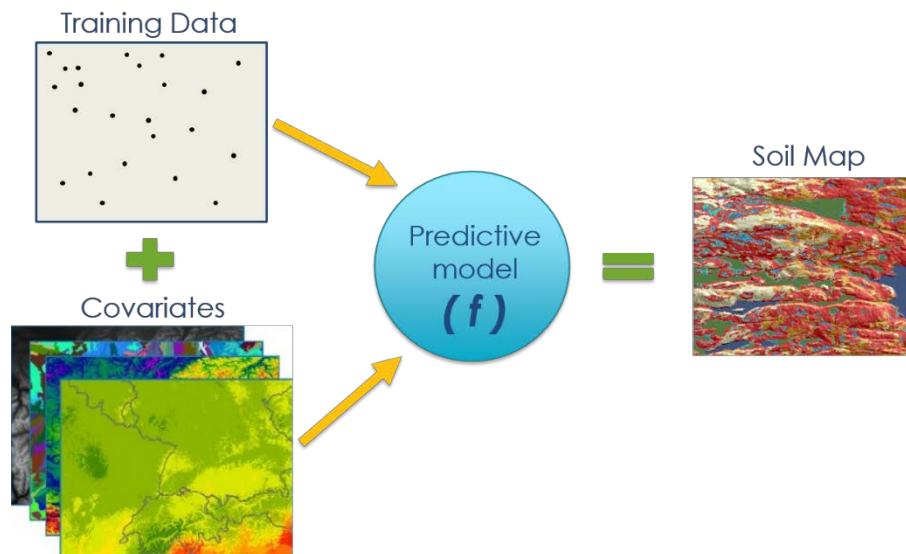
- Overview
- Why digital soil mapping?
- Soil-landscape models
- Environmental covariates
- Training data
- Prediction of soil classes or properties
- Validation and uncertainty



Overview

Digital Soil Mapping

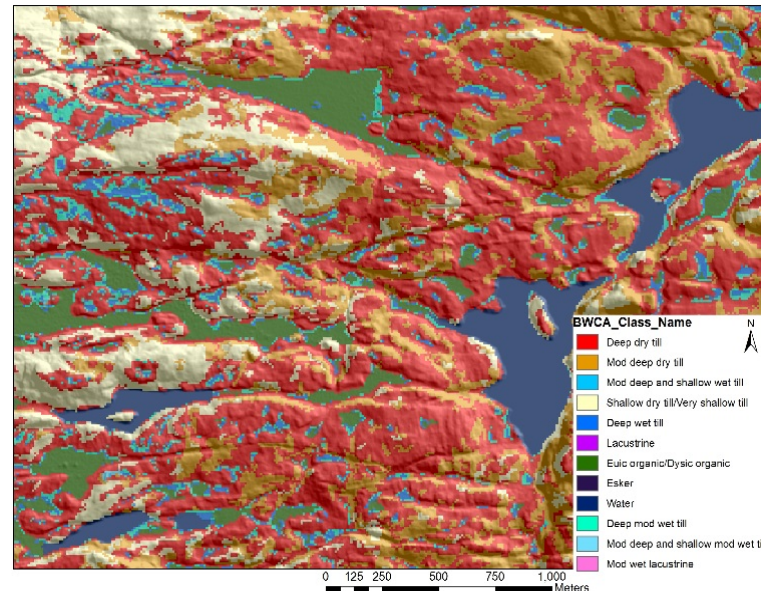
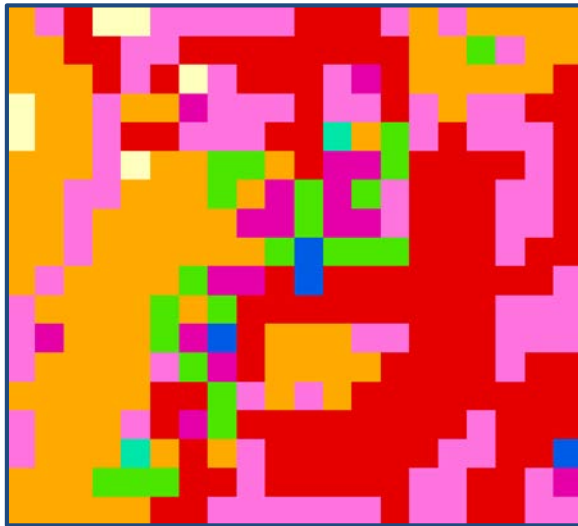
- The generation of geographically referenced soil databases based on quantitative relationships between spatially explicit environmental data and measurements made in the field and laboratory (McBratney et al., 2003)
- The spatial prediction of soil classes or properties from point data using a statistical algorithm



Overview

Digital Soil Map

- Raster composed of 2-dimensional cells (pixels) organized into a grid
- Each pixel has a specific geographic location and contains soil data



Overview

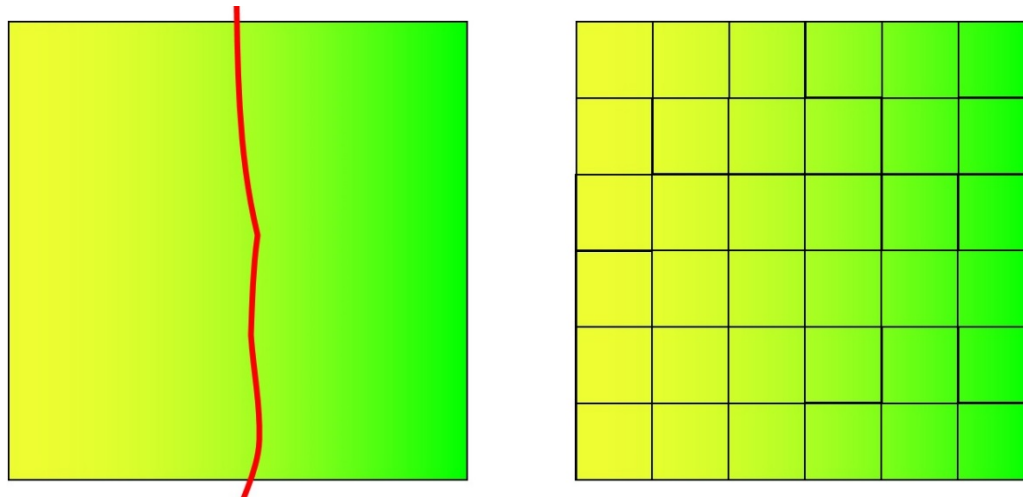


Conventional soil mapping

- “Where is the boundary between two soils?”
- Focus on the marginal areas

Digital soil mapping

- Central concept is well defined
- Variation expressed across the landscape



Why?

Digital soil mapping

- Illustrate spatial distribution of soil classes or properties
- Can document the uncertainty of the prediction
- Documentation of tacit knowledge
- Reproducible and consistent
- Can be used for
 - Initial soil maps
 - Update or refine existing soil maps
 - Generate specific interpretations
 - Assess risk
- Rapid inventory, re-inventory, and project-based management of lands in a changing environment
 - *FLEXIBLE*



Soil-Landscape Models

Factors of Soil Formation (Jenny 1941)

$$S = f (Cl, O, R, P, T)$$

- Soils are a function of 5 environmental factors
 - Climate
 - Organisms
 - Relief
 - Parent Material
 - Time
- Conceptual model (tacit knowledge)



Soil-Landscape Models

SCORPAN (McBratney et al., 2003)

$$S = f(S, C, O, R, P, A, N) + \varepsilon$$

- Soil, at a specific point in **space** and time
 - Soil classes, S_c
 - Soil attributes, S_a
- Empirical **quantitative** function of environmental covariates
 - Soil (class, or directly or remotely sensed property)
 - Climate
 - Organisms
 - Relief
 - Parent Material
 - Age
 - **N = Spatial Position**
- Plus an estimation of **error or uncertainty**



Soil-Landscape Models

SCORPAN facilitates

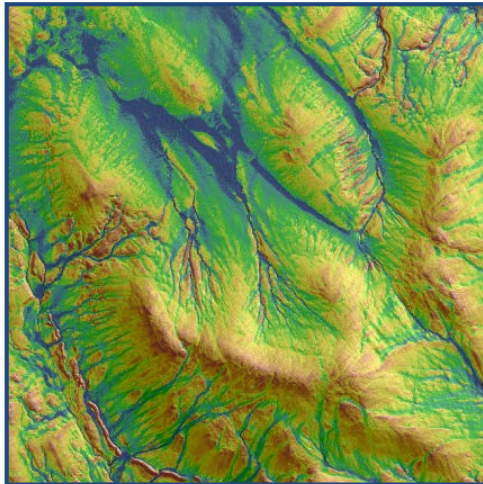
- *Quantification* of the relationships between environmental covariates and soil classes or properties in a *spatial context*
- *Estimation of error or uncertainty* of the spatial prediction of soil classes or properties



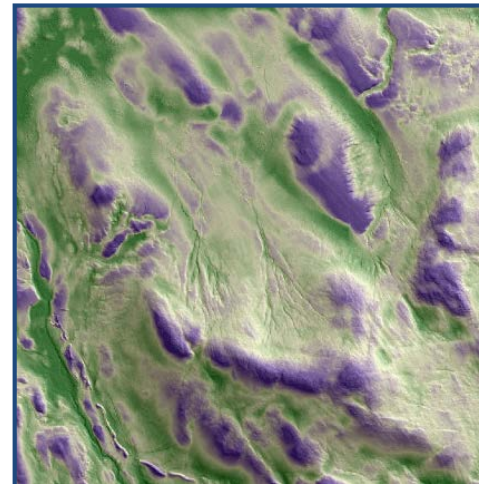
Environmental Covariates

Choosing covariates

- What factors influence soil formation?
 - **Link to pedological knowledge**
- What data do I have? Want? Need?
- Data should represent the multiple SCORPAN covariates that influence soil development in your project area



Multi-path smoothed wetness index



Relative Position



Environmental Covariates

$$S = f(S, C, O, R, P, A, N)$$

- Soil
 - Legacy soils data, field measurements
- Climate
 - Temp, precip, ET, solar radiation, etc.
- Organisms
 - Land cover, NDVI, spectral data and derivatives
- Relief
 - Elevation derivatives
- Parent material
 - Geology, spectral data and derivatives
- Age
 - Landform models
- Spatial position
 - Inherent in georeferenced data layers



Elevation and spectral data/derivatives

Environmental Covariates

Choosing covariates

- Consider resolution (spatial, spectral, temporal, radiometric) and what is required to meet the project needs
 - Target soil feature
- Compare needs to the range of data available
- **Elevation and spectral derivatives are a powerful combination for predicting soil classes or properties in most areas**
 - Project needs and physical features of the area may require only one of these data sources



Sampling for Training Data

Digital soil mapping is dependent upon the relationship between

- Predictor variables (covariates)
- Target soil feature (soil class or property)

True for all modeling methods

Samples of covariates representing the distribution of the target soil feature are required

- *Training data*
 - “Trains” the model to predict similar occurrences



Sampling for Training Data

Prediction is successful when

- Precise, observed locations of typical soil members are available

Directed (purposive) field samples

- Knowledge-based classification approaches
- Should not be used exclusively

Random or stratified sampling

- More robust
- Less prone to bias
- Sampling design appropriate for modeling objectives



Sampling for Training Data

DIGITAL SOIL MAPPING = FIELD WORK

Soil scientist
engaged in
digital soil
mapping



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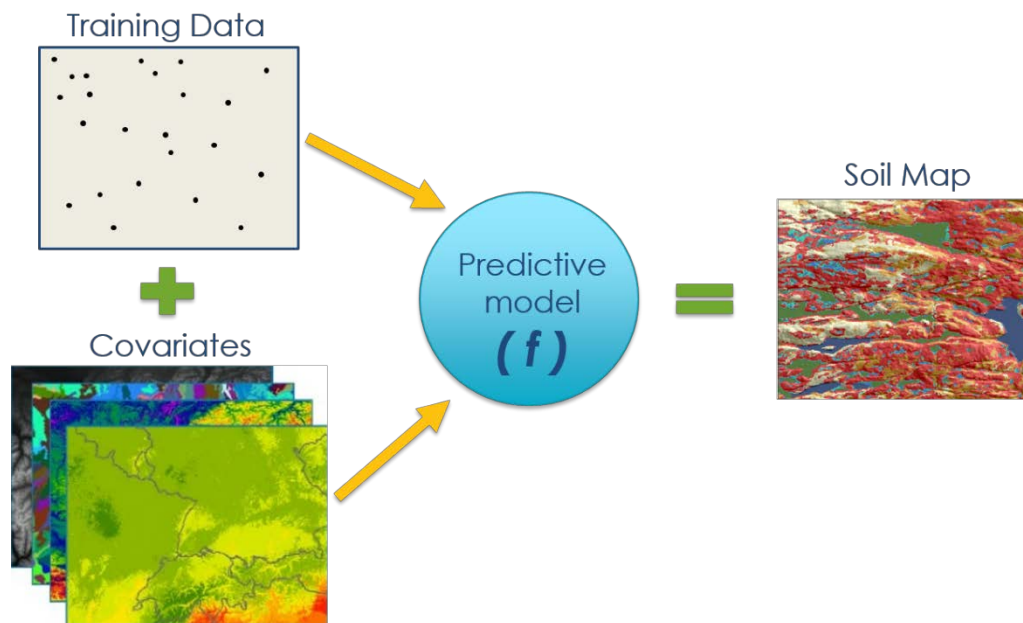


Predict Soil Classes or Properties

Optimal set of SCORPAN covariates chosen

Training data collected

Apply a model to the data and predict soil classes or properties



Predicting Soil Classes



Classification is the process of predicting discrete classes

- Sorting pixels into finite number of classes based on data values and distribution in feature space
- If a pixel satisfies class criteria, then it's assigned to that class



Classification



Unsupervised

- Algorithm identifies clusters in the data
 - Non-informational clusters
- Analyst must interpret resulting clusters
 - Informational classes
- No training data required
- Exploratory
- K-means, ISODATA

Supervised

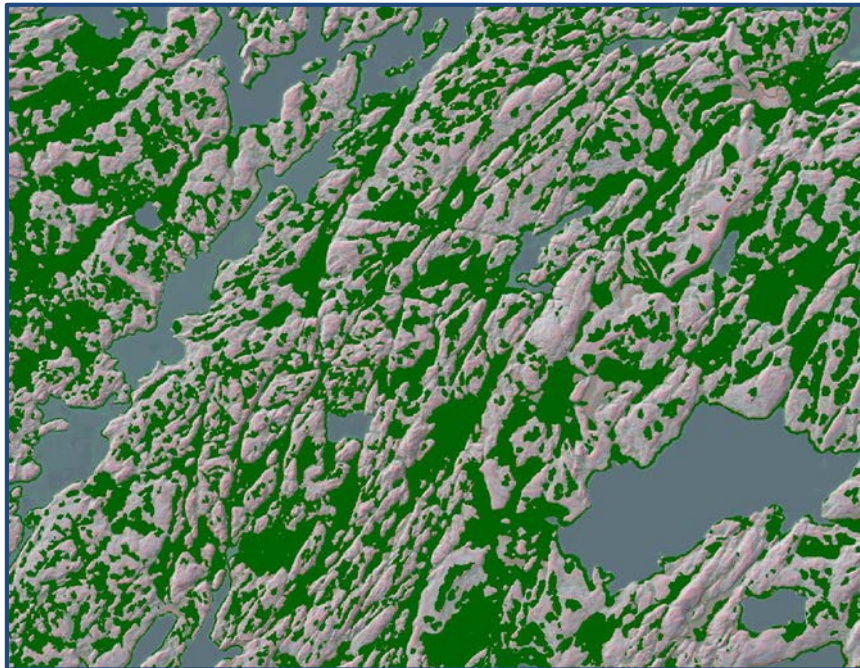
- Analyst selects training sites
- Algorithm creates decision boundaries from class statistics to cluster data
- Training data required
- Beyond exploratory
- Knowledge-based classification (ArcSIE), fuzzy classification, predictive modeling (random forests, neural networks)



Unsupervised Classification

ISODATA

- Shows natural clustering in the data and how potential classes may be distributed across the landscape
- Covariates include both terrain and spectral data derivatives



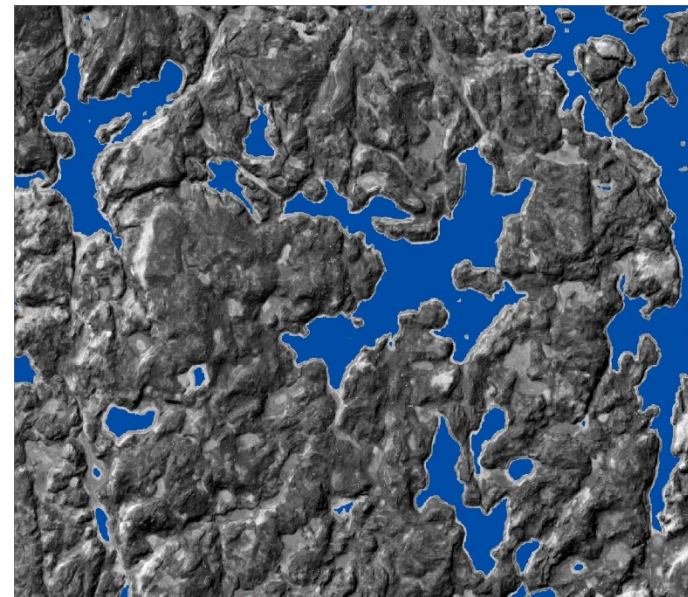
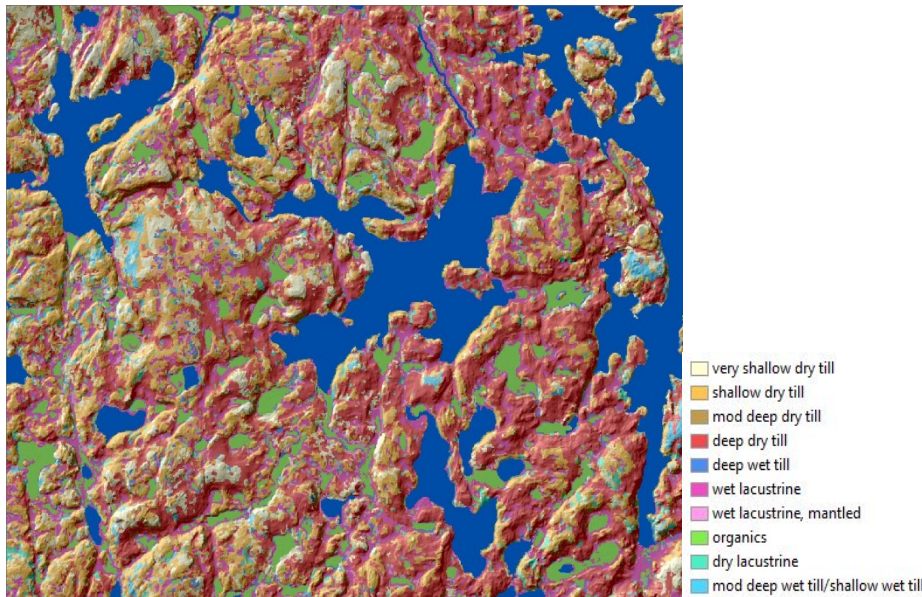
Boundary Water Canoe Area Wilderness, MN



Supervised Classification

Predictive modeling (machine learning)

- Classes and probability surface for one class from random forests (tree-based)
- Covariates include both terrain and spectral derivatives



Boundary Water Canoe Area Wilderness, MN



Predicting Soil Properties

Regression and interpolation methods
predict continuous soil properties

Regression

- Estimates the relationship between the dependent (soil observations) and independent variables (covariates)
- Linear regression, logistic regression, random forests

Interpolation

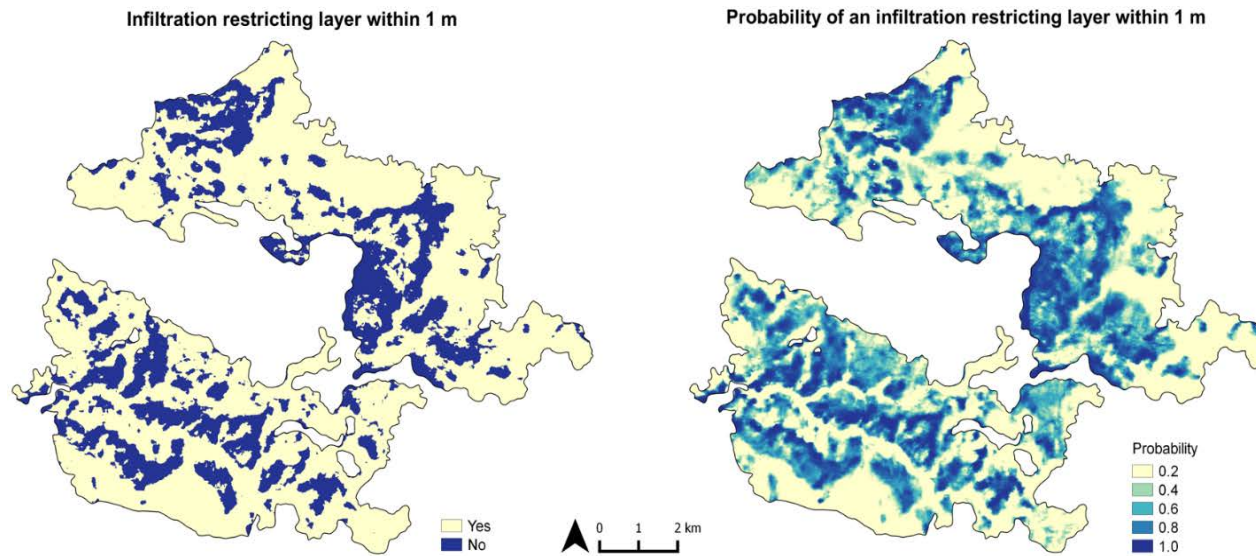
- Models spatial patterns based on values at known locations and the assumption that locations that are closer to one another are more similar than those that are further apart
- Geostatistics (kriging)



Regression

Predictive modeling (machine learning)

- Properties and associated probability surface from generalized linear model (regression)



Beef Basin area, UT

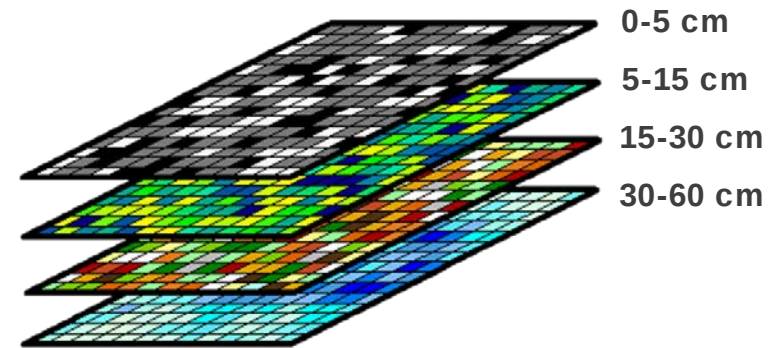


Predicting Soil Properties

Raster stack

- Continuous raster soil properties
- Key soil property layers at fixed depths
 - 0-5cm, 5-15cm, 15-30cm, 30-60cm, 60-100cm and 100-200cm
 - Target soil properties
 - Total profile depth (cm)
 - Plant exploitable soil depth (cm)
 - Organic carbon (g/kg)
 - pH (x10)
 - Sand (g/kg)
 - Silt (g/kg)
 - Clay (g/kg)
 - Gravel ($\text{m}^3 \text{m}^{-3}$)
 - ECEC (cmolc/kg)
 - Bulk density of fine earth (<2mm) fraction (excluding gravel) (Mg/m^3)
 - Bulk density of whole soil (includes gravel) (Mg/m^3)
 - Available water holding capacity (mm)
- Prediction uncertainty

Concept
soil property



Predicting Soil Properties

Continuous soil property raster stack

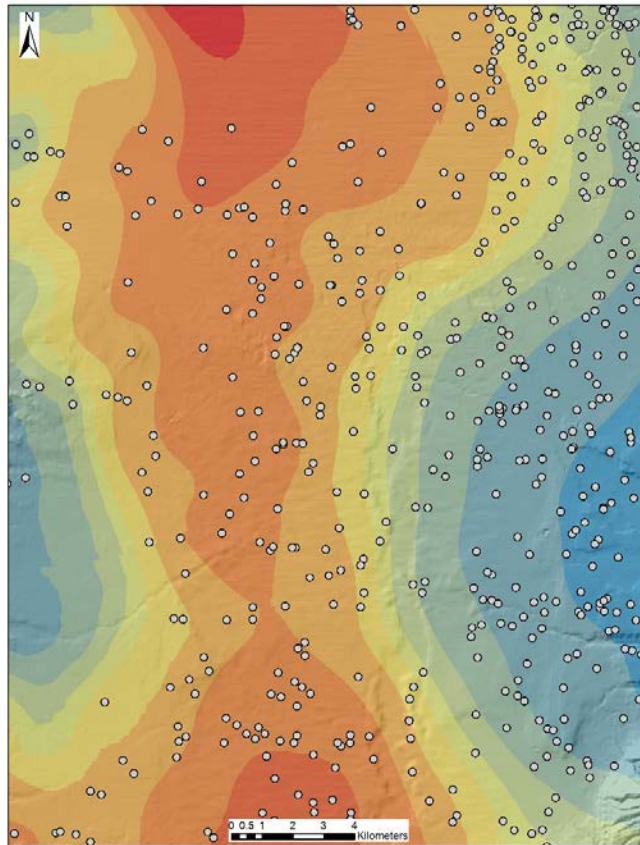
- Interpretations for management and use
 - The data stack becomes the database
 - Add slope, climate, etc. layers needed for calculating interpretations
- Class data – taxonomic or technical



Interpolation

Geostatistics

- Ordinary kriging applied to predict soil K concentrations



Salt Lake Valley, UT



Validation and Uncertainty

All soil mapping methods rely on models

- Conventional soil mapping
 - Qualitative
 - Relies on conceptual model (CLOPPT)
- Digital soil mapping
 - Quantitative
 - Relies on quantitative model (SCORPAN)

All models approximate reality and are subject to error and uncertainty



Validation and Uncertainty

Quantitative nature of digital soil mapping

- Lends itself to quantitative assessments of accuracy and uncertainty

Communication of accuracy and uncertainty associated with soil spatial predictions is imperative

Integral part of delivering modeled products given their use in resource management decision making and risk assessment



Accuracy



Predicted values on a map will deviate from true values to some extent

Accuracy

- Difference between predicted value at a location and measured value at same location
- High prediction accuracy
 - Small difference between predicted and observed values

Accuracy measures quantify prediction quality using a validation data set



Accuracy



Soil classes

- User's, producer's, overall accuracy
 - Confusion matrix
- Kappa, Tau index (weighted Tau), Brier score

Soil properties

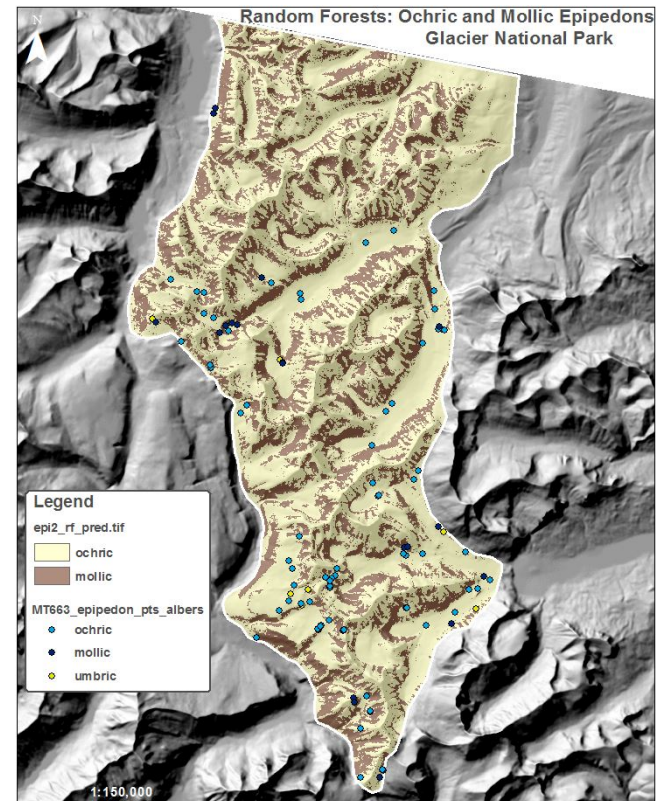
- MSE, RMSE, standard error, modified R^2



Uncertainty

Sources

- Positional accuracy of pedon location
- Covariate accuracy (e.g., vertical uncertainty of DEM)
- Soil class or property measurement (e.g., taxonomic classification or lab measurement)
- Model structure (e.g., using linear model for curvilinear data)



Uncertainty



Soil classes

- Memberships or probabilities
- Class confusion measures (confusion index, distance files, entropy)

Soil properties

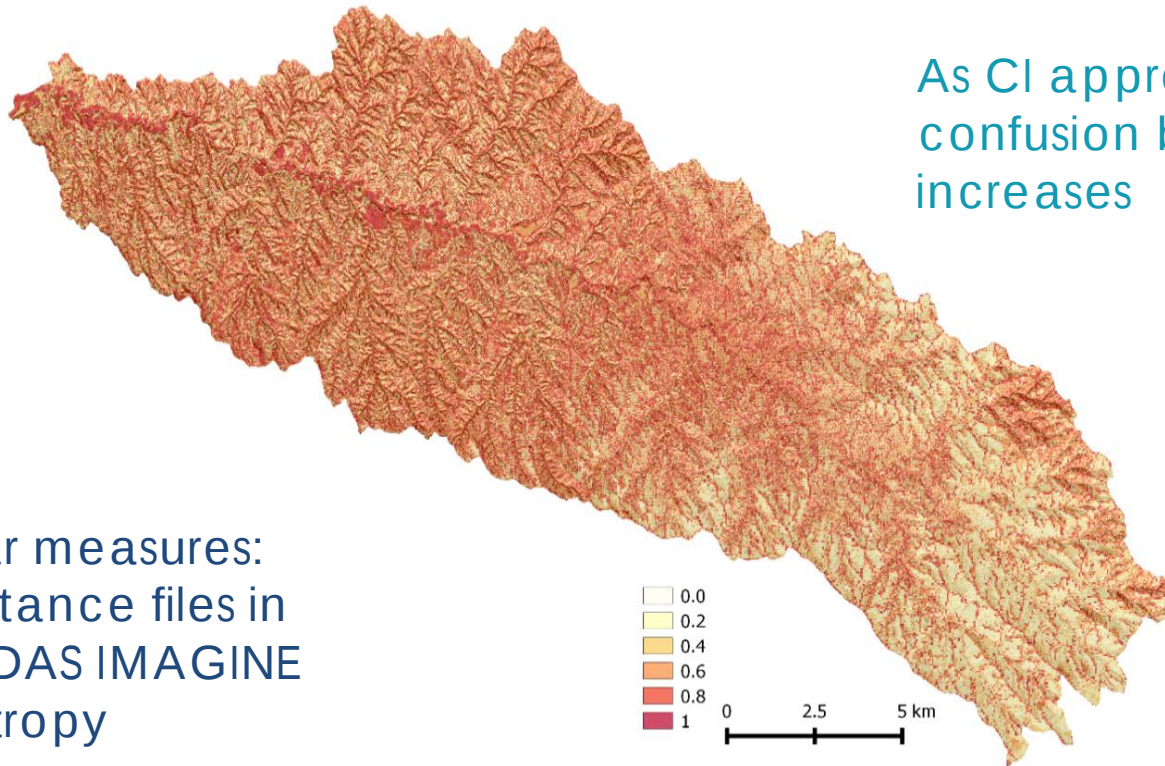
- Prediction intervals

Uncertainty measures can be generated during the modeling process or calculated from results, and represented spatially



Uncertainty

Soil classes – confusion index



*Powder River Basin, WY
Brungard et al., 2015*

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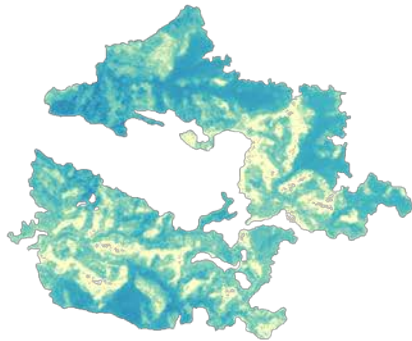


Uncertainty

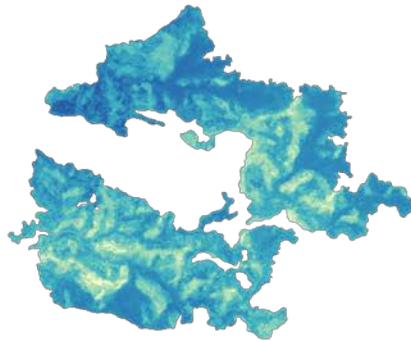
Soil properties – prediction interval

- Often shown as lower, mean, upper prediction interval (similar to low, RV, high)
- Prediction interval width shows spatial variability of uncertainty

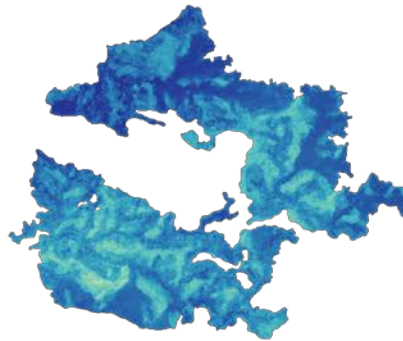
Lower 90% Prediction Interval



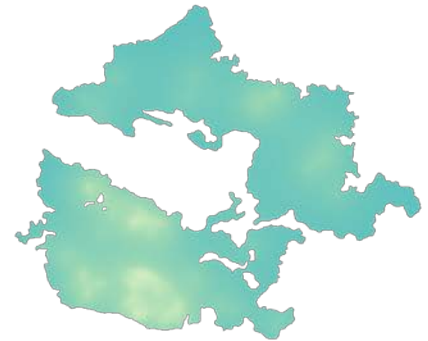
Mean



Upper 90% Prediction Interval

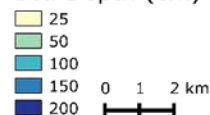


Prediction Interval Width



Beef Basin area, UT

Soil Depth (cm)



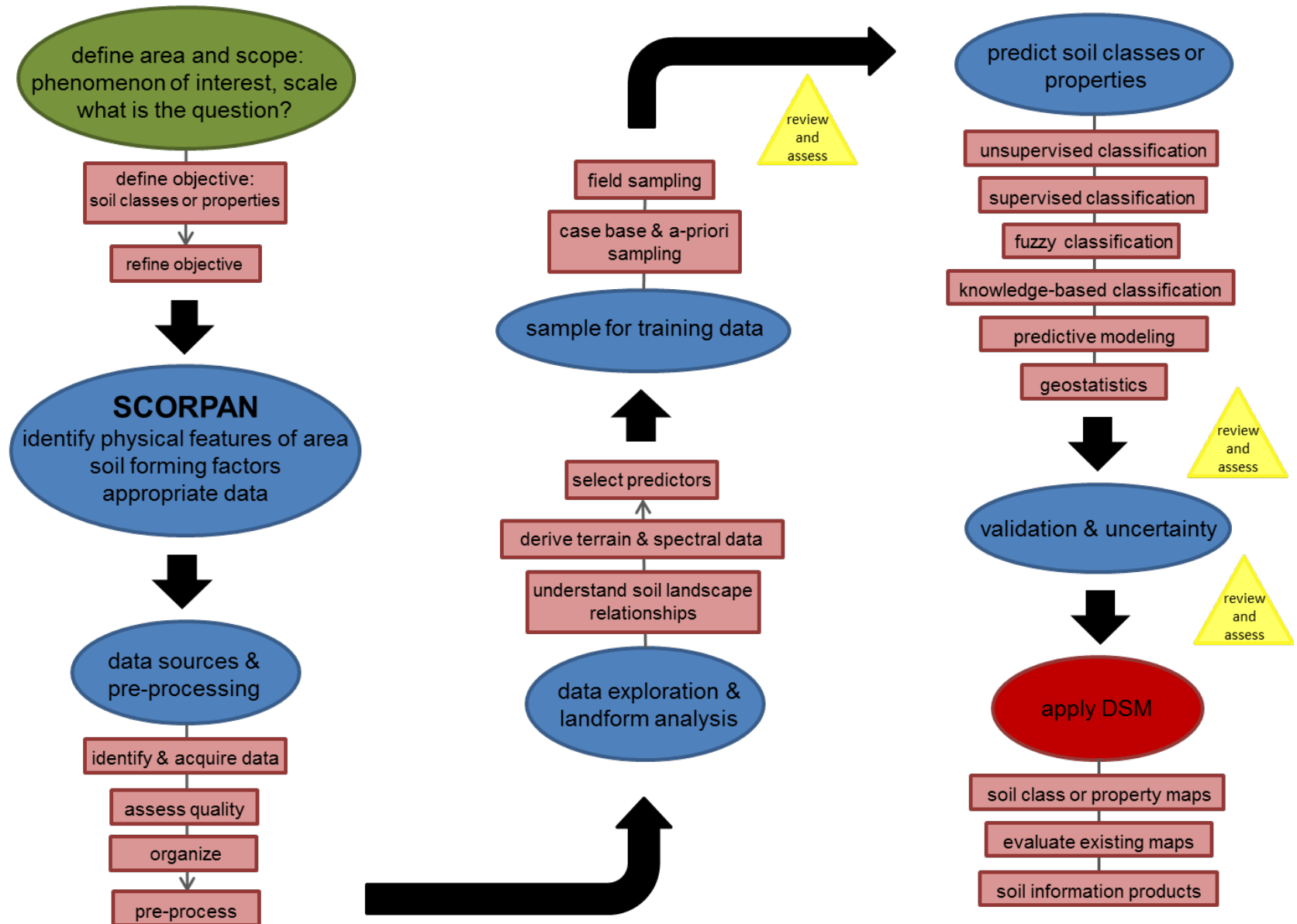
0 1 2 km

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Digital Soil Mapping: Stages and Processes

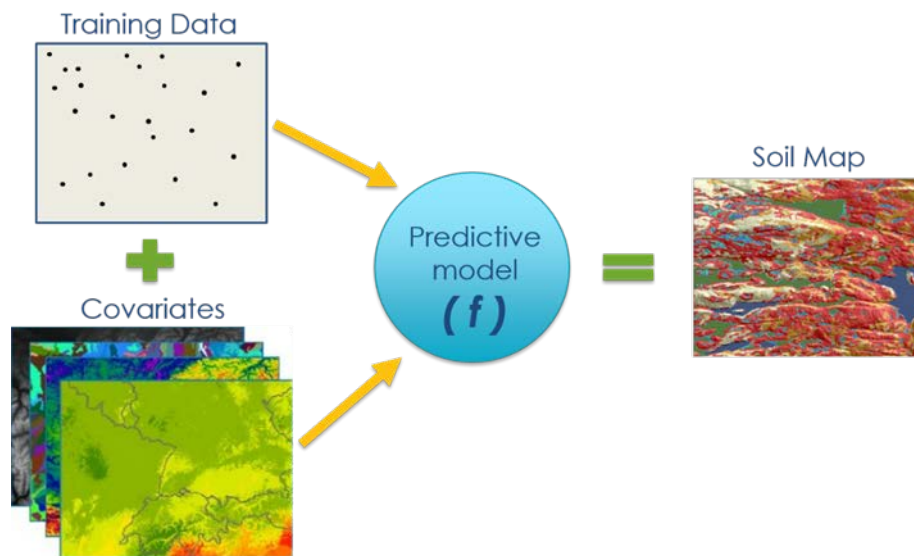


Digital Soil Mapping



Summary

- Predicting soil classes or properties from field observations and environmental covariates using a statistical algorithm
- Spatial representation of classes or properties
- Includes estimates of accuracy and uncertainty
- Consistency and reproducibility
- Flexible product to meet variety of user needs



Digital Soil Mapping

Focus

- Fundamental pedology
 - **Knowledge** of the soil resource as a natural body
 - Existing and newly acquired
 - **Field component**
- Latest technological resources
 - Applied adaptively throughout process and in **combination** with soil knowledge



Digital Soil Mapping Training



Foundational Prerequisites Taken in the Following Order:

1. Spatial Analyst Workshop (NRCS-NEDC-000271)
2. Statistics for Soil Survey Part 1 (NRCS-NEDC-000400)
3. Intro to Digital Soil Mapping (NRCS-NEDC-000272)

Digital Soil Mapping with ArcSIE (NRCS-NEDC-000273)

- Prerequisites
 - All 3 foundational prerequisites

Statistics For Soil Survey Part 2 (NRCS-NEDC-000332)

- Prerequisites
 - Statistics for Soil Survey Part 1

Remote Sensing for Soil Survey Applications (NRCS-NEDC-000244)

- Prerequisites
 - All 3 foundational prerequisites
- Intro to Digital Remote Sensing (available on-line from Michigan State University)

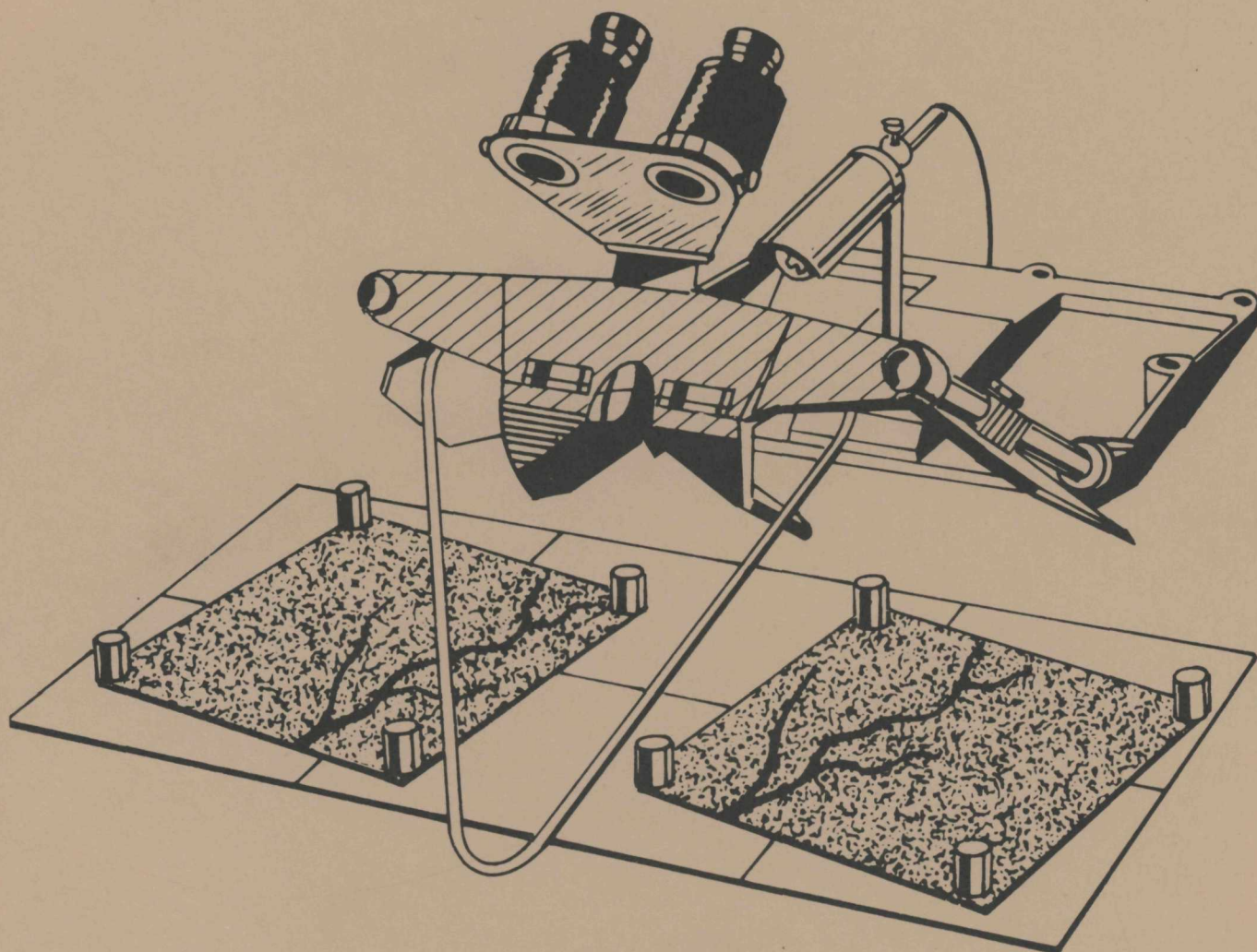
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Forester's Guide to Aerial Photo Interpretation



Agriculture Handbook No. 308
U.S. Department of Agriculture
Forest Service

FORESTER'S GUIDE TO AERIAL PHOTO INTERPRETATION

Thomas Eugene Avery

Tree height, crown diameter, crown closure	25
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U.S. Department of Agriculture
Forest Service

Agriculture Handbook 308
Slightly revised November 1978

This handbook is a revised and enlarged version of Occasional Paper 156, issued by the Southern Forest Experiment Station, New Orleans, La., in January 1957.

Dr. Thomas Eugene Avery, who prepared the original guide while employed by the Forest Service, is now an independent forest consultant and writer residing in Sedona, Ariz.

FORESTER'S GUIDE TO AERIAL PHOTO INTERPRETATION

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FORESTER'S GUIDE TO AERIAL PHOTO INTERPRETATION

This handbook was written as a practical reference on techniques of aerial photo interpretation in forest inventory. It is for the forester with a casual knowledge of the subject. While oblique photographs are occasionally useful for interpretation, this manual emphasizes stereoscopic interpretation of vertical aerial photographs available from various agencies of the U.S. Department of Agriculture (USDA). Figure 1 (foldout, inside back cover) is an example of a vertical aerial photograph.

With training, the forester can use aerial photographs to locate property boundaries and trails, determine bearings and distances, identify classes

of vegetation, and measure areas. Experience will enable him to improve the efficiency of forest inventories by distributing field samples on the basis of photo stratifications. In some instances, he may even be able to estimate timber volumes directly from the photographs.

While photo interpretation may make the forester's job easier, there are limitations. Accurate measurements of such items as tree diameter, form class, and stem defect are possible only on the ground. Aerial photographs are best used to complement, assist, or reduce field work rather than take its place.

TYPES OF AERIAL PHOTOGRAPHS

Oblique photographs are taken with the axis of the aerial camera at various angles between the horizon and the ground. *High* obliques show the horizon on the photograph; *low* obliques do not. An oblique photograph covers a larger area compared with a vertical photograph from the same altitude, but its usefulness is limited to fairly level terrain where the view is not obstructed by ridges. For this reason, and because obliques do not readily lend themselves to stereoscopic viewing, they are seldom used by foresters in the United States.

Vertical photographs are taken with the aerial camera pointed straight down at the ground, or as nearly so as feasible. Overlapping exposures in each flight line permit an interpreter to study vertical photographs three dimensionally with a stereoscope. Because such prints have become so useful for mapping and interpretation, the term "aerial photo" is normally assumed to denote a vertical photograph and will be thus applied in this handbook.

Mosaics are composite pictures assembled from as many individual, vertical photographs as may be required to cover a specified area; they are usually constructed to provide a pictorial representation and a planimetric approximation of a fairly extensive ground area. The principal kinds of mosaics, in order of ascending scale reliability are: (1) index or uncontrolled mosaics, (2) semi-

controlled mosaics, (3) controlled mosaics, and (4) orthophotomosaics.

The *index mosaic* is simply an assembly of untrimmed contact prints that are pasted up in overlap and sidelap positions so that image detail is matched and the original flight-line position of each exposure is reconstructed. The entire layup is usually rephotographed at a smaller scale for use as a pictorial reference to individual prints. An *uncontrolled mosaic* is assembled in a similar fashion (i.e., without ground control) except that each frame is first trimmed down to its "effective" or non-overlapping area. Then, each trimmed portion is matched together like the segments of a jigsaw puzzle.

A *semi-controlled mosaic* differs from the uncontrolled type in that it is assembled with the aid of limited ground control points. It is thus intermediate in scale reliability, depending somewhat on the local relief of the area depicted.

A *controlled mosaic* is one that is directly tied to an extensive network of ground control points, and it is usually assembled from prints that are both rectified and ratioed. As a result, the mosaic will approximate planimetric map accuracy in regions of flat to gently rolling terrain. However, distortions due to relief are *not* eliminated in controlled mosaics, and *some* images will be displaced from their true plan positions.

OBTAINING AERIAL PHOTOGRAPHY

An *orthophotograph* is a reproduction, prepared from ordinary perspective photographs, in which image displacements caused by tilt and relief have been entirely removed. When these unique photographs are assembled into an *orthophotomosaic*, the result is a picture-map with both scale and planimetric detail of high reliability. When such mosaics are overprinted onto standard mapping quadrangles, they are referred to as orthophotoquads.

Users of this guide will ordinarily rely on prints of existent photography flown for public agencies. Thus there is no need here to discuss specifications for new aerial photography. Details of flight planning and photographic contracts are covered in the *Manual of Photogrammetry* and the *Manual of Photographic Interpretation* (1, 2).¹

Sources of cartographic information.—The National Cartographic Information Center (NCIC), established in 1974 by the U.S. Geological Survey, Department of Interior, provides a national information service to make cartographic data of the United States more easily accessible to the public and to various Federal, State, and local agencies. At present, more than 30 Federal agencies collect and prepare cartographic data. Existing data includes more than 1.5 million maps and charts, 25 million aerial and space photographs, and 1.5 million geodetic control points.

Much of this information is available by contacting NCIC at the following address:

**National Cartographic Information Center
U.S. Geological Survey
507 National Center Rm. 1C101
Reston, VA 22092**

NCIC does not obtain cartographic data from present holders; rather it collects and organizes descriptive information about the data, such as location, availability, and ordering instructions. Existing government and private data centers will continue to hold and distribute cartographic data, and some will provide local users with direct access to NCIC information through their existing public service facilities.

Sources of aerial photography.—A large proportion of the existing aerial photography of interest to foresters is held by Federal agencies within the Department of Agriculture. Principal among these are the Agricultural Stabilization and Conservation Service (ASCS), the Forest Service (FS) and the Soil Conservation Service (SCS).

The ASCS has the responsibility of contracting for aerial photography for all three agencies. It

also has the responsibility for providing reproductions from all ASCS and FS photography and from SCS photography that is 2 or more years old. A central laboratory for ordering this photography is provided by ASCS:

**Aerial Photography Field Office
ASCS/USDA
P. O. Box 30010
Salt Lake City, Utah 84125**

Films, season, and date of photography.—Two types of black-and-white aerial film are in common use: panchromatic and infrared. Infrared is usually modified by a minus-blue filter to reduce contrast and improve image resolution. Panchromatic photography offers better resolution and lighter shadows but exhibits little tonal contrast among forest types. Modified infrared photography presents a maximum of contrast between conifers and deciduous hardwoods, but wet sites and shadows register in black, thus restricting interpretation.

In Western United States, where coniferous trees predominate, panchromatic film is more likely to be used. Conversely, foresters managing eastern hardwoods often prefer infrared photography because forest type separation is more definite. In figure 2, dark-toned pines (A) are readily differentiated from the light-colored upland hardwoods (B) on the infrared stereogram, but there is little tonal contrast on the panchromatic exposures. Also the farm pond at (C) is obvious on the infrared prints, but may be completely overlooked on the panchromatic photographs.

If measurements are needed for deciduous species, both kinds of photography should be taken during the growing season. Infrared is likely to be used specifically for forestry purposes and usually meets this requirement. On panchromatic photographs taken in winter, conifers can be distinguished from hardwoods, but interpretation of hardwood stand-sizes is difficult.

If there is a choice between photography of different dates, you should select the most recent. Also, if there is more than one source, you should choose which photograph shows the most information or use the photographs in conjunction. In regions characterized by rapid tree growth and frequent cuttings, the value of photos more than 5 years old is questionable.

With minor exceptions, ASCS and SCS photography is taken with black-and-white panchromatic film. A large percentage of the more recent FS photography is taken on color film, with most of the remainder taken on color infrared, black-and-white infrared, or panchromatic.

Photo scales and enlargements.—In earlier years, the negative scale of ASCS and SCS photography was commonly set at 1:20,000 (1,667

¹ Italic numbers in parentheses refer to Literature Cited, page 40.

feet per inch), while much of FS photography was set at a scale 1:15,840 (1,320 feet per inch). The FS has established a standard scale program of 1:24,000 for resource photography and 1:80,000 for high altitude photography.

Since about 1972, the negative scale of most ASCS photography has been set at 1:40,000 (3,333 feet per inch). Much of the FS photography acquired prior to the adoption of a standard scale was at a scale of 1:15,840 (1,320 feet per inch). Resource photography now used is at a scale of 1:24,000 (2,000 feet per inch). Scales of SCS photography are mostly in the range of 1:38,000 (3,167 feet per inch) or 1:58,000 (4,333 feet per inch).

The standard 9- by 9-inch contact prints can be enlarged, of course. Enlargements up to 38 by 38 inches are available, with commensurate increases in scale and image size. For example, a common product used by ASCS is an enlargement rectified to a scale of 1:7,920 (660 feet per inch) on sheets that measure 24 by 24 inches.

Unless sophisticated equipment is available, it is difficult to study enlargements stereoscopically. Therefore, contact prints are recommended for general use by foresters who must rely on simple pocket stereoscopes.

Paper surface, weight, and contrast.—Black-and-white prints ordered from ASCS are made on a medium-weight, semi-mat, resin-coated base material; as a result, the prints are both stable and water-resistant. Reproductions are also available in the form of positive film transparencies; as a rule, these provide greater sharpness and clarity of detail than ordinary prints.

When a specific degree of contrast is required, this should be indicated when ordering. If possible, the order should be accompanied by a sample print that illustrates the desired amount of density and contrast.

Coverage available.—USDA aerial photography covers more than 80 percent of the United States, including portions of Alaska and Hawaii. Coverage is updated periodically according to pro-

gram needs; this results in new photography every 5 to 10 years for many areas.

The ASCS annually publishes "status maps" which are available free upon request. These maps show the most recent coverage available for a given area, the scale of photography, focal length of the camera lens, and number of photo index sheets required to cover a project area.

Ordering photography from ASCS.—Photo index sheets or index mosaics, showing the relative positions of all individual photographs within a given county (fig. 3a), can be examined at local offices of the Agricultural Stabilization and Conservation Service or the Soil Conservation Service. The number of index sheets per county varies from one to six or more. It is possible to visit an ASCS office, select desired photos from an index, and order them on the spot.

Forest Service indexes are usually available for inspection in local supervisor's offices or on ranger districts. Instead of conventional photographic indexes, the Forest Service now uses "spot indexes," i.e., maps showing the locations of photo centers (fig. 3b).

If you are interested in aerial photography of a distant county, you may wish to purchase an index of that county and make your selection. Again, your own county ASCS office will help you order the index and will provide assistance in selecting the photos that will best suit your needs. Prints are identified by a county symbol (or by a special state and county code), and by film roll and exposure number (fig. 1). Other items to specify are date of photography, scale, and type of reproduction (print size, weight, finish, contrast, etc.).

Special order blanks and current price lists may be obtained through local ASCS offices. Orders must be accompanied by advance payment, and 3 to 4 weeks should be allowed for delivery.

If you do not have access to the appropriate index sheet, an alternative is to outline the area of interest on a reliable map. This map can then be sent to the Aerial Photography Field Office in Salt Lake City with your inquiry.

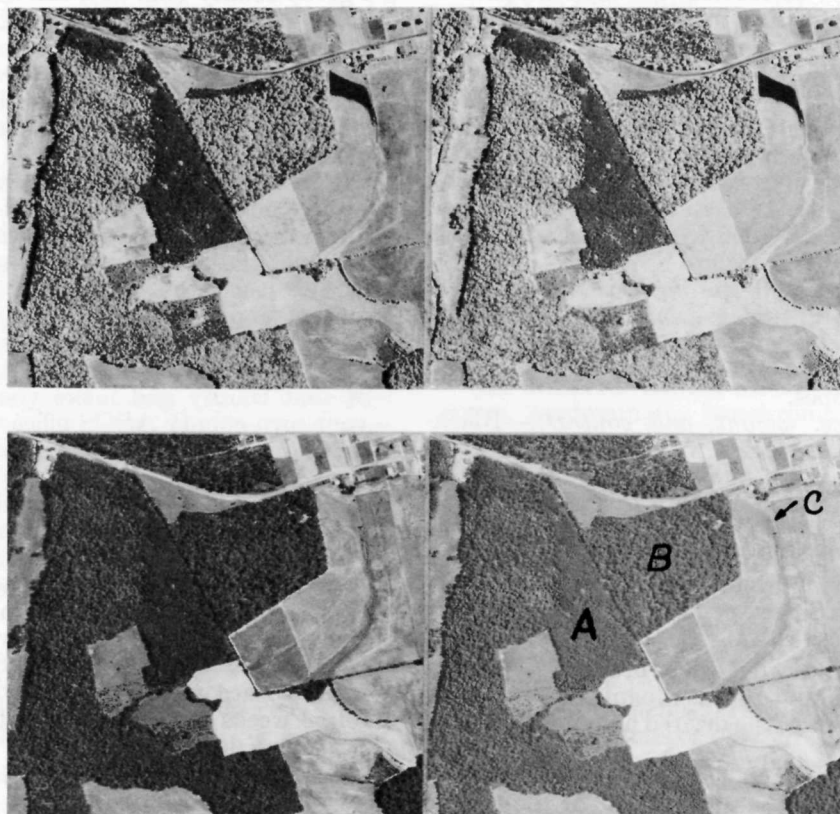


Figure 2.—Modified infrared (above) and panchromatic photography made in the North Carolina Piedmont during June. Exposures were made simultaneously with a dual aerial camera system. Scale is 1,320 feet per inch. Prints may be viewed three-dimensionally with a lens stereoscope.

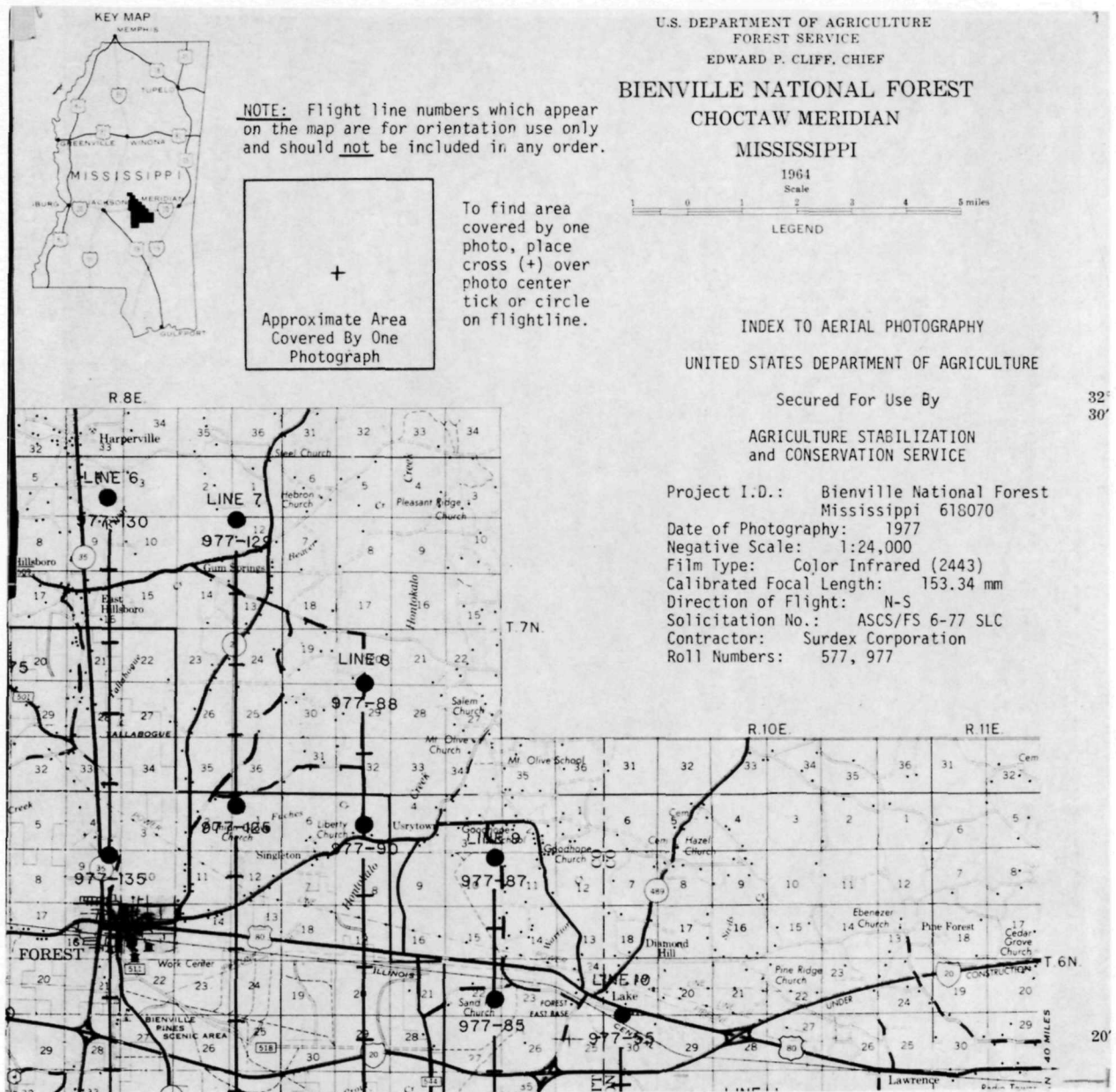


Figure 3b.—The "spot index" showing plotted positions of flight lines and photo centers, used by the Forest Service.

PREPARING PHOTOGRAPHS FOR STEREO-VIEWING

Equipment Needed

Equipment considered essential by one interpreter may be of limited use to another; nevertheless, the forester who anticipates a continued use of aerial photographs will probably find the following list closely approximates his minimum needs.

Lens stereoscope, folding pocket type.
Parallax bar or parallax wedge for measuring object heights.

Engineer's scale, graduated to 0.02 inch.
Tree crown-density scale.
Tree crown-diameter scale.
Dot grids for acreage determination.
China-marking pencils for writing on photographs.
Carbon tetrachloride and cotton for cleaning photographs.
Drafting instruments, triangles, and drafting tape.
Needles for point-pricking.
Tracing table.
Magnetic or spring-clipboard for holding stereo-pairs.
Proportional dividers.

If purchased with discretion, the items can be obtained for less than \$250. For a price list of photo interpretation aids available from the Forest Service, write to the Engineering Staff, Forest Service, U.S. Department of Agriculture, P.O. Box 2417, Washington, D.C. 20013.

Many foresters will already own drafting instruments, dot grids, and pocket stereoscopes. A satisfactory tracing table can be improvised by installing a uniform light source under a glass surface. Fluorescent tubes are better than incandescent bulbs because they produce less heat. A sheet of frosted cellulose acetate between two pieces of ordinary single-weight glass serves well when special frosted glass is not available.

If the forester uses aerial photographs regularly and becomes adept in interpretation and mapping, he may wish to acquire more expensive equipment, such as a mirror stereoscope, vertical sketchmaster, reflecting projector, or radial plotting devices. The *Manual of Photogrammetry* (1) contains information on such equipment.

Preparing the Photographs

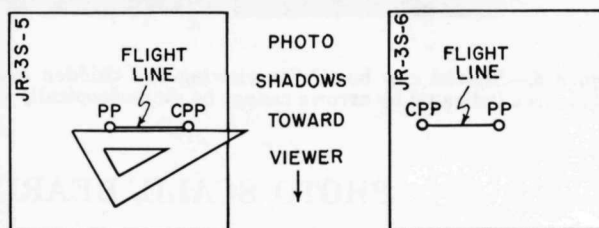
Photographic flights are planned so that prints will overlap about 60 percent in the line of flight and about 30 percent between flight strips. For effective stereo-viewing, prints must be trimmed to the nominal 9- by 9-inch size, preserving the four fiducial marks at the midpoint of each of the edges (fig. 1). Then:

1. *Locate the principal point (PP) or center of each photograph.* Aline opposite sets of fiducial marks with a straightedge or triangle. Draw a cross at the center with a wedge-pointed pencil, and make a fine needle hole at the intersection.
2. *Locate the conjugate principal points (CPP's) on each photograph*—the points that correspond to PP's of adjacent photographs. Adjust the stereoscope until distance between centers of lenses corresponds with interpupillary distance (usually about 2.5 inches). Arrange the first two photographs of a given flight line so that corresponding gross features overlap. Shadows should be toward the observer; if they fall away from the viewer there is a tendency to see relief in reverse. Clip down one photograph. Move adjacent photograph in direction of line of flight until corresponding images on each print are about 2.2 inches apart. Place lens stereoscope over prints *parallel to line of flight* so that the left-hand lens is over the left photograph and the right-hand lens is over the same image on the right photograph. The area around the PP will be seen as a three-dimensional image. The movable photograph should then be fastened down. While viewing this area through the stereoscope, place a needle in the same area on the adjacent photograph until it appears to fall precisely in the hole pricked for the PP. This locates the CPP (fig. 1), though a monocular check should

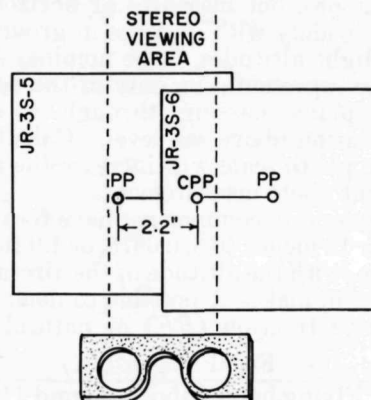
be made before the point is permanently marked. Repeat for all photographs; each will then have one PP and two CPP's except that prints falling at the ends of the flight lines will have only one CPP. Ink a 0.2-inch diameter circle around each PP and CPP (fig. 1).

3. *Locate the flight lines on each print by alining the PP's and CPP's.* Connect the edges of the alined circles with a fine ink line (fig. 1). Because of lateral shifting of the photographic plane in flight, a straight line will rarely pass through the PP and both CPP's on a given print.
4. *Determine the photo base length for each stereo-overlap* by averaging the distance between the PP and CPP on one print and the corresponding distance on the overlapping print. Measure to the nearest 0.02 inch and record on the back of each overlap. There will be two average base lengths for each print, i.e., one for each set of overlapping flight lines.

Alining prints for stereoscopic study.—A print is selected and clipped down with shadows toward the viewer. The adjacent print is placed with its CPP 2.2 inches from the corresponding PP on the first print. With flight lines superimposed, the second print is positioned and clipped down. The stereoscope is placed with its long axis parallel to the flight line and with the lenses over corresponding images. In this way an overlapping strip 2.2 inches wide and 9 inches long can be viewed by moving the stereoscope up and down the overlap area (fig. 4).



A. PRELIMINARY PHOTO ORIENTATION



B. FINAL PHOTO ALIGNMENT

Figure 4.—Method of alining 9- by 9-inch contact prints for viewing with a lens stereoscope. Compare this diagram with figure 1.

While the photos are still clipped down, the prints can be flipped into reverse position with the opposite photo on top. This presents another area of the overlap for stereo-viewing. To study the

narrow strip between, the edge of one print must be curled upward or downward and the stereoscope moved parallel to the flight line until the "hidden area" comes into view (fig. 5).

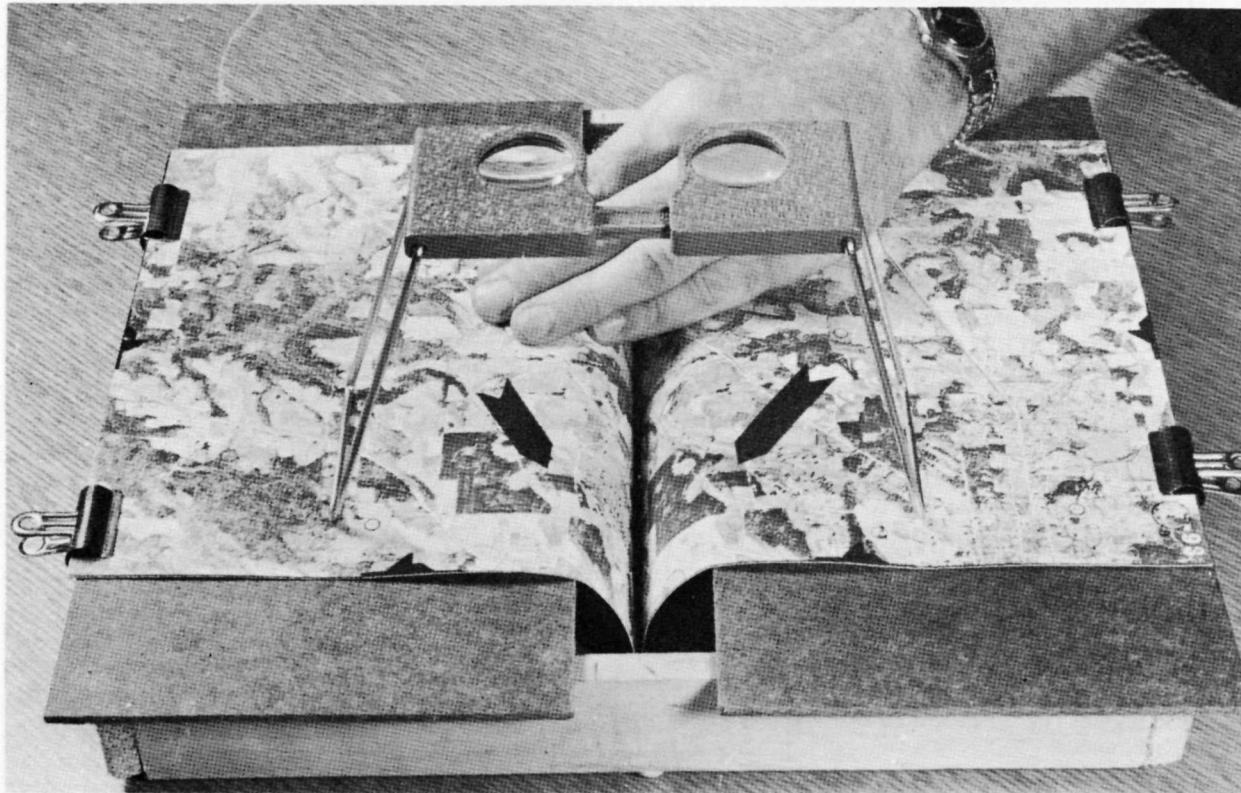


Figure 5.—Slotted clip board for viewing the "hidden area" of overlapping contact prints with a lens stereoscope. The area indicated by arrows cannot be stereoscopically studied when prints are lapped as in figures 1 and 4.

PHOTO SCALE, BEARINGS, AND DISTANCES

The vertical aerial photograph presents a true record of angles, but measures of horizontal distances vary widely with changes in ground elevations and flight altitudes. The nominal scale (as 1:20,000) is representative only of the datum, an imaginary plane passing through a specified ground elevation above sea level. Calculation of the average photo scale will increase the accuracy of subsequent photo measurements.

Aerial cameras in common use have focal lengths of 6, 8.25, or 12 inches (0.5, 0.6875, or 1.0 ft.). This information, with the altitude of the aircraft above ground datum, makes it possible to determine the representative fraction (*RF*) or natural scale:

$$RF = \frac{\text{Focal length (ft.)}}{\text{Flying height above ground (ft.)}}$$

The height of the aircraft is rarely known to the interpreter, however, and photo scale is more often calculated by this proportion:

$$RF = \frac{\left[\begin{array}{l} \text{Photographic distance} \\ \text{between two points (ft.)} \end{array} \right]}{\left[\begin{array}{l} \text{Ground or map distance} \\ \text{between same points (ft.)} \end{array} \right]}$$

Determining scale from ground measurements.—Select two points on opposite sides of the print so that a line connecting them passes near the PP. If the points are approximately equidistant from the PP, the effect of photographic tilt will be minimized. (Tilt results when the camera axis deviates from the vertical at the instant of exposure. It is often present, but generally not enough to be readily noticed.) Points must be easily identifiable on the ground so that the distance between them can be precisely measured. Gas and power line rights-of-way, highways, and railroads offer clearings where ground distances can be quickly chained. It is not necessary to calculate the scale of every photograph in a flight

strip. In hilly terrain, every third or fifth print may be used; in flat topography, every tenth or twentieth. Scales of intervening photographs can be obtained by interpolation.

Office checks of photo scale.—Scale determination from ground measurements is laborious and expensive; hence other methods should be used wherever possible. If a U.S. Geological Survey quadrangle sheet is available, the map distance can be measured and used in the formula, provided the same distance can be identified for photo measurement (fig. 6).

Another alternative is presented in areas of flat terrain where General Land Office subdivisions of sections, quarter-sections, and forties are visible on the photographs. Since the lengths of these

subdivisions will be known, they can also be used as ground distances. A given section may rarely be exactly 5,280 feet on a side, but determining scale by this method is more accurate than accepting the nominal scale.

Compass bearings and distances.—Although flight lines usually run north-south or east-west, few photographs are oriented exactly with the cardinal directions. For this reason, a reference line must be located before bearings can be determined. The method described is used by field teams on the U.S. Forest Survey:

1. Select a straight-line feature such as a highway, section line, or field edge and determine its bearing. Draw this reference line on the photograph, extend it as necessary, and record the bearing (fig. 7).



Figure 6.—Determination of photo scale from a U.S. Geological Survey map. Map scale is 1:24,000 or 2,000 feet per inch. Map distance between X and Y is 2.00 inches, or 4,000 feet on the ground. Photo distance is 4.80 inches. Thus the photo scale is $4.80 \div 4,000 \times 12$, or 1:10,000. (Courtesy of Abrams Aerial Survey Corporation.)

2. Pick a point of beginning (PB) from which the line of approach to a field location will be run. This should be some feature visible on both photograph and ground, such as a fence corner, barn, road intersection, or stream fork. Draw a line on the photograph from the PB to the location, and extend until it intersects the reference line. Measure the angle between the two lines with a protractor and determine the bearing of the line of approach.
3. Measure the distance between the PB and the field location to the nearest 0.01 inch and convert to feet or chains at the calculated photo scale. At a scale of 1:20,000, a measure of 0.01 inch equals 16.67 feet or about 25 links. In figure 7, the distance from PB to the center of the circular field plot is 1.15 inches, or about 29 chains. Common scale conversions are given in table 1.

TABLE 1.—Scale conversions for vertical aerial photographs ¹

Representative fraction (scale)	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Square miles per square inch
(1)	(2)	(3)	(4)	(5)	(6)
1:7,920	660.00	10.00	8.00	10.00	0.0156
1:8,000	666.67	10.10	7.92	10.20	.0159
1:8,400	700.00	10.61	7.54	11.25	.0176
1:9,000	750.00	11.36	7.04	12.91	.0202
1:9,600	800.00	12.12	6.60	14.69	.0230
1:10,000	833.33	12.63	6.34	15.94	.0249
1:10,800	900.00	13.64	5.87	18.60	.0291
1:12,000	1,000.00	15.15	5.28	22.96	.0359
1:13,200	1,100.00	16.67	4.80	27.78	.0434
1:14,400	1,200.00	18.18	4.40	33.06	.0517
1:15,000	1,250.00	18.94	4.22	35.87	.0560
1:15,600	1,300.00	19.70	4.06	38.80	.0606
1:15,840	1,320.00	20.00	4.00	40.00	.0625
1:16,000	1,333.33	20.20	3.96	40.81	.0638
1:16,800	1,400.00	21.21	3.77	45.00	.0703
1:18,000	1,500.00	22.73	3.52	51.65	.0807
1:19,200	1,600.00	24.24	3.30	58.77	.0918
1:20,000	1,666.67	25.25	3.17	63.77	.0996
1:20,400	1,700.00	25.76	3.11	66.34	.1037
1:21,120	1,760.00	26.67	3.00	71.11	.1111
1:21,600	1,800.00	27.27	2.93	74.38	.1162
1:22,800	1,900.00	28.79	2.78	82.87	.1295
1:24,000	2,000.00	30.30	2.64	91.83	.1435
1:25,000	2,083.33	31.57	2.53	99.64	.1557
1:31,680	2,640.00	40.00	2.00	160.00	.2500
Method of calculation	RFD 12	RFD 792	63,360 RFD	(RFD) ² 6,272,640	Acres/sq. in. 640

¹ Conversions for scales not shown can be made from the relationships listed at the bottom of each column. With the scale of 1:7,920 as an example (column 1, line 1), the number of feet per inch is computed by dividing the representative fraction denominator (RFD) by 12 (number of inches per foot). Thus, $7,920 \div 12 = 660$ feet per inch (column 2). By dividing the RFD by 792 (inches per chain), the number of chains per inch is derived (column 3). Other calculations can be made similarly. Under column 4, the figure 63,360 represents the number of inches in one mile; in column 5, the figure 6,272,640 is the number of square inches in one acre; and in column 6, the number 640 is acres per square mile.

IDENTIFYING FOREST TYPES AND TREE SPECIES

Forest types and tree species can often be delineated with greater accuracy and lower cost on aerial photographs than by ground methods. The degree to which species groups can be recognized depends on the quality, scale, and season of photography; the type of film used; and the interpreter's training. A general knowledge of forest associations and plant ecology is helpful, but field

experience in the specific area to be mapped is far more valuable.

A generalized map of forest regions in the United States is shown in figure 8. The tree species listed provide the first step in identification, i.e., the elimination of those cover types not likely to occur in a given locality. The second step, heavily dependent on a knowledge of local

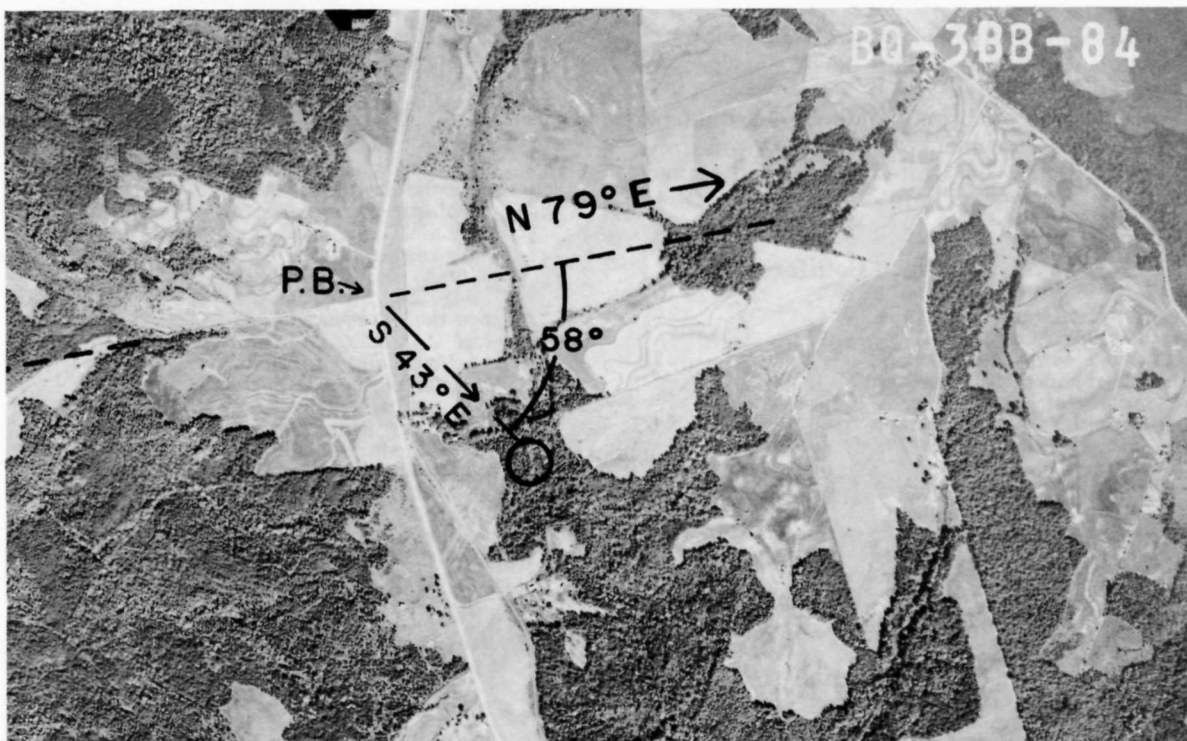


Figure 7.—Determination of compass bearing and distance to a field plot on a USDA contact print. Scale is 1,667 feet per inch.

vegetation, is to establish which forest types may be encountered in the area to be mapped.

Recognition of an individual species, often feasible only on large-scale photography, is normally the culmination of intensive study. Obviously the forest interpreter must be familiar with branching patterns and crown shapes of all important species in his region. Mature conifers in sparsely stocked stands can often be recognized on 1:20,000 USDA photography by the configuration of their crown shadows falling on level ground (fig. 9). Studying oblique photographs of trees has been helpful to many foresters.

Recognition of species on vertical photographs also requires a familiarity with tree crowns as seen in overhead views (fig. 10). While overhead crown characteristics are not always apparent on 1:12,000 to 1:20,000 photographs, they can be highly useful on large-scale stereograms. Photo scales as large as 50 feet per inch have been utilized for tree species identifications in Canada (16, 20).

Aside from shadows, crown shapes, and branching patterns, the features to consider in identifying tree species are photographic texture (smoothness or coarseness of images), tonal contrast, relative sizes of tree images at a given photo scale, and topographic location or site. Most of these are rather weak clues when observed singly, yet together they may be the final link in identification by elimination.

For some parts of the United States and Canada,

vegetation keys are available aids in tree species recognition. Keys are useful for training new interpreters and for reference by more experienced personnel. Depending on the method of presenting diagnostic features, photo interpretation keys may be grouped into two general classes: *selective* keys and *elimination* keys. Selective keys are usually illustrations and descriptions of trees in a specific region, e.g., pines of Florida. They are organized for comparative use; the interpreter merely selects the key example that most nearly coincides with the forest stand he must identify. By contrast, elimination keys require the user to follow a step-by-step procedure, working from the general to the specific. One of the more common forms of elimination keys is the dichotomous type. Here the interpreter must continually select one of two contrasting alternatives until he progressively eliminates all but the item being sought.

A sample elimination key for identifying northern conifers is reproduced here. It may be used to identify tree species pictured in the large-scale stereograms in figure 11. In original form, this Canadian key had additional descriptive materials and illustrations such as those shown in figures 9 and 10 (16).

Vegetation keys are most easily constructed for northern and western forests where conifers predominate, because there are relatively few species to be considered and crown patterns are rather distinctive for each important group. By con-

trast, few if any, reliable keys are available for the highly variable hardwood forests of Southern and Eastern United States.

While the scope of this handbook does not permit a detailed treatment of all important forest types throughout the United States and Canada, examples are given in figures 12 through 18.

Key to the Northern Conifers ²

1. Crowns small, or if large then definitely cone-shaped.
2. Crown broadly conical, usually rounded tip, branches not prominent ----- cedar
2. Crowns have a pointed top, or coarse branching, or both.
 - crowns narrow, often cylindrical, trees frequently grow in swamps ----- swamp type
 - crowns conical, deciduous, very light-toned in fall, usually associated with black spruce ----- black spruce
 - crowns narrowly conical, very symmetrical, top ----- tamarack

- pointed, branches less prominent than in white spruce ----- balsam fir
- crowns narrowly conical, top often appears obtuse on photograph (except northern white spruce), branches more prominent than in balsam fir ----- white spruce, black spruce (except swamp type)
- crowns irregular, with pointed top, has thinner foliage and smoother texture than spruce and balsam fir ----- jack pine
- 1. Crowns large and spreading, not narrowly conical, top often not well defined.
- 3. Crowns very dense, irregular or broadly conical.
 - 4. Individual branches very prominent, crown usually irregular ----- white pine
 - 4. Individual branches rarely very prominent, crown usually conical ----- eastern hemlock
- 3. Crowns open, oval (circular in plain view) ----- red pine

MAPPING FROM AERIAL PHOTOGRAPHS

Type maps are no longer considered essential by all foresters, but at times their cost may be justified. A general ownership map showing principal roads, streams, forest types, and condition classes may be desired for management planning and illustrative purposes. Also, in making a photo-controlled ground cruise where precise forest-area estimates are required, it may be necessary to measure stand areas on controlled maps of known scale rather than directly on contact prints. This is particularly important where topography causes wide variation in photo scales.

The wise interpreter will delineate only those types that he can consistently recognize. For maximum accuracy, type lines should be drawn under the stereoscope. As lines made with a china-marking pencil are easily removed with carbon tetrachloride or benzene, this method is recommended for preliminary work. Water-soluble ink is also suitable. Permanent markings can be made with drawing ink after types have been verified by ground reconnaissance.

Uncontrolled maps.—Where area measurement is not critical, simple uncontrolled type maps can be prepared at photo scale by direct tracing. Tract boundaries are drawn within the "effective area"³

² Reproduced by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry (16).

³ If 9- by 9-inch photographs with 60-percent endlap and 30-percent sidelap are assumed, alternate photographs will have effective areas of about 7.2 by 6.3 inches.

of alternate prints in each flight strip. Photographs are interpreted under the stereoscope, and all types and planimetric data are outlined. The detail is then traced onto frosted acetate or vellum, from one annotated print at a time. If boundaries are accurately drawn on interpreted prints to include all of the tract without duplication, the traced data from adjoining prints should match up without difficulty. To assure standardization in type recognition, it is desirable to have one man perform all interpretation work.

Uncontrolled maps are no more accurate for area measurement than the photographs from which they were prepared, but they may suffice for management plans and illustrations. Where flat terrain predominates, average photo scales vary only slightly and tracings may approach the accuracy of controlled maps.

Controlled maps.—Base maps of uniform scale may be required for photo-controlled ground cruises, as precise measures of forest area by type and stand size are essential for accurate volume estimates. In flat terrain, average photo scale can be determined and acreages measured directly on contact prints, but in steep topography variations in photo scale require the transfer of forest types to base maps for accurate area measurement. The most common way of adjusting variable photo scales to controlled maps is by constructing "radial line plots" or by preparing plat sheets from field notes of the General Land Office. As construction of a radial line plot is complex and has been ade-

PRINCIPAL TREES OF THE FOREST REGIONS

NOTE.—The order indicates the relative importance or abundance of the trees

ROCKY MOUNTAIN FOREST

Northern Portion (Northern Idaho and Western Montana):

Lodgepole pine
Douglas-fir
Western larch
Engelmann spruce
Ponderosa pine
Western white pine
Western redcedar
Grand and alpine firs
Western and mountain hemlocks
Whitebark pine
Balsam poplar

Eastern Oregon, Central Idaho, and Eastern Washington:

Ponderosa pine
Douglas-fir
Lodgepole pine
Western larch
Engelmann spruce
Western redcedar
Western hemlock
White, grand, and alpine firs
Western white pine
Oaks and junipers (in Oregon)

Central Montana, Wyoming, and South Dakota:

Lodgepole pine
Douglas-fir
Ponderosa pine
Engelmann spruce
Alpine fir
Limbber pine
Aspen and cottonwoods
Rocky Mountain juniper
White spruce

Central Portion (Colorado, Utah, and Nevada):

Lodgepole pine
Engelmann and blue spruces
Alpine and white firs
Douglas-fir
Ponderosa pine
Aspen and cottonwoods
Pinyons
Rocky Mountain and Utah junipers
Bristlecone and limbber pines
Mountain-mahogany

Southern Portion (New Mexico and Arizona):

Ponderosa pine
Douglas-fir
White, alpine, and corkbark firs
Engelmann and blue spruces
Pinyons
One-seed, alligator, and Rocky Mountain junipers
Aspen and cottonwoods
Limbber, Mexican white, and Arizona pines
Oaks, walnut, sycamore, alder, boxelder
Arizona cypress

PACIFIC COAST FOREST

Northern Portion (Western Washington and Western Oregon):

Douglas-fir
Western hemlock
Grand, noble, and Pacific silver firs
Western redcedar
Sitka and Engelmann spruces
Western white pine
Port Orford cedar and Alaska cedar
Western and alpine larches
Lodgepole pine
Mountain hemlock
Oaks, ashes, maples, birches, alders, cottonwoods, madrone

Southern Portion (California):

Ponderosa and Jeffrey pines
Sugar pine
Redwood and giant sequoia
White, red, grand, and Shasta red firs
California incense-cedar
Douglas-fir
Lodgepole pine
Knobcone and Digger pines
Bigcone-spruce
Monterey and Gowen cypresses
Sierra and California junipers
Singleleaf pinyon
Oaks, buckeye, California-laurel, alder, madrone

SOUTHERN FOREST

Pine Lands:

Shortleaf, loblolly, longleaf, slash, and sand pines
Southern red, black, post, laurel, cherrybark, and willow oaks
Sweetgum
Winged, American, and cedar elms
Black, red, sand, and pignut hickories
Eastern and southern redcedars
Basswoods

Alluvial Bottoms and Swamps:

Sweetgum and tupelos
Water, laurel, live, overcup, Texas, and swamp white oaks
Southern cypress
Pecan, water and swamp hickories
Beech
River birch
Ashes

Alluvial Bottoms and Swamps:

Red and silver maples
Cottonwoods and willows
Sycamore
Hackberry
Honeylocust
Holly
Redbay and sweetbay
Southern magnolia
Pond and spruce pines
Atlantic white-cedar

CENTRAL HARDWOOD FOREST

Northern Portion:

White, black, northern red, scarlet, bur, chestnut, and chinquapin oaks
Shagbark, mockernut, pignut, and bitternut hickories
White, blue, green, and red ashes
American, rock, and slippery elms
Red, sugar, and silver maples
Beech
Pitch, shortleaf, and Virginia pines
Yellow-poplar
Sycamore
Chestnut
Black walnut
Cottonwoods
Hackberry
Black cherry
Basswoods
Ohio buckeye
Eastern redcedar

Southern Portion:

White, post, southern red, blackjack, Shumard, chestnut, swamp chestnut, and pin oaks
Sweetgum and tupelos
Mockernut, pignut, southern shagbark, and shellbark hickories
Shortleaf and Virginia ("scrub") pines
White, blue, and red ashes
Yellow-poplar
Black locust
Elms
Sycamore
Black walnut
Silver and red maples
Beech
Dogwood
Persimmon
Cottonwoods and willows
Eastern redcedar
Osage-orange

Texas Portion:

Post, southern red, and blackjack oaks
Eastern redcedar, Ashe juniper

FLORIDA AND TEXAS FOREST—TROPICAL

Mangrove, false mangrove
Royal and thatch palms; palmettos
Florida yew
Wild figs
Seagrasses ("pigeon plum")
Blolly
Bahama lysiloma ("wild tamarind")
Wild-dilly
Gumbo-limbo
Poison-tree
Inkwood
Button-mangrove
False-mastic ("wild olive")
Fishpoison-tree ("Jamaica dogwood")

NORTHERN FOREST

Northern Portion:

Red, black, and white spruces
Balsam fir
Eastern white, red ("Norway"), jack, and pitch pines
Hemlock
Sugar and red maples
Beech
Northern red, white, black, and scarlet oaks
Yellow, paper, sweet, and gray birches
Quaking and bigtooth aspens
Basswoods
Black cherry
American, rock, and slippery elms
White and black ashes
Shagbark and pignut hickories
Butternut
Northern white-cedar
Tamarack

Southern Portion (Appalachian Region):

White, northern red, chestnut, black, and scarlet oaks
Chestnut
Hemlock
Eastern white, shortleaf, pitch, and Virginia ("scrub") pines
Sweet, yellow, and river birches
Basswood
Sugar and red maples
Beech
Red spruce
Fraser fir
Yellow-poplar
Cucumber magnolia
Black walnut and butternut
Black cherry
Pignut, mockernut, and red hickories
Black locust
Tupelos ("blackgums")
Buckeye

ALASKA FOREST

Coast Forest:

Western hemlock (important)
Sitka spruce (important)
Western redcedar
Alaska cedar
Mountain hemlock
Lodgepole pine
Black cottonwood
Red and Sitka alders
Willows

Interior Forest:

White (important) and black spruces
Alaska paper (important) and Kenai birches
Black cottonwood
Balsam poplar
Aspen
Willows
Tamarack

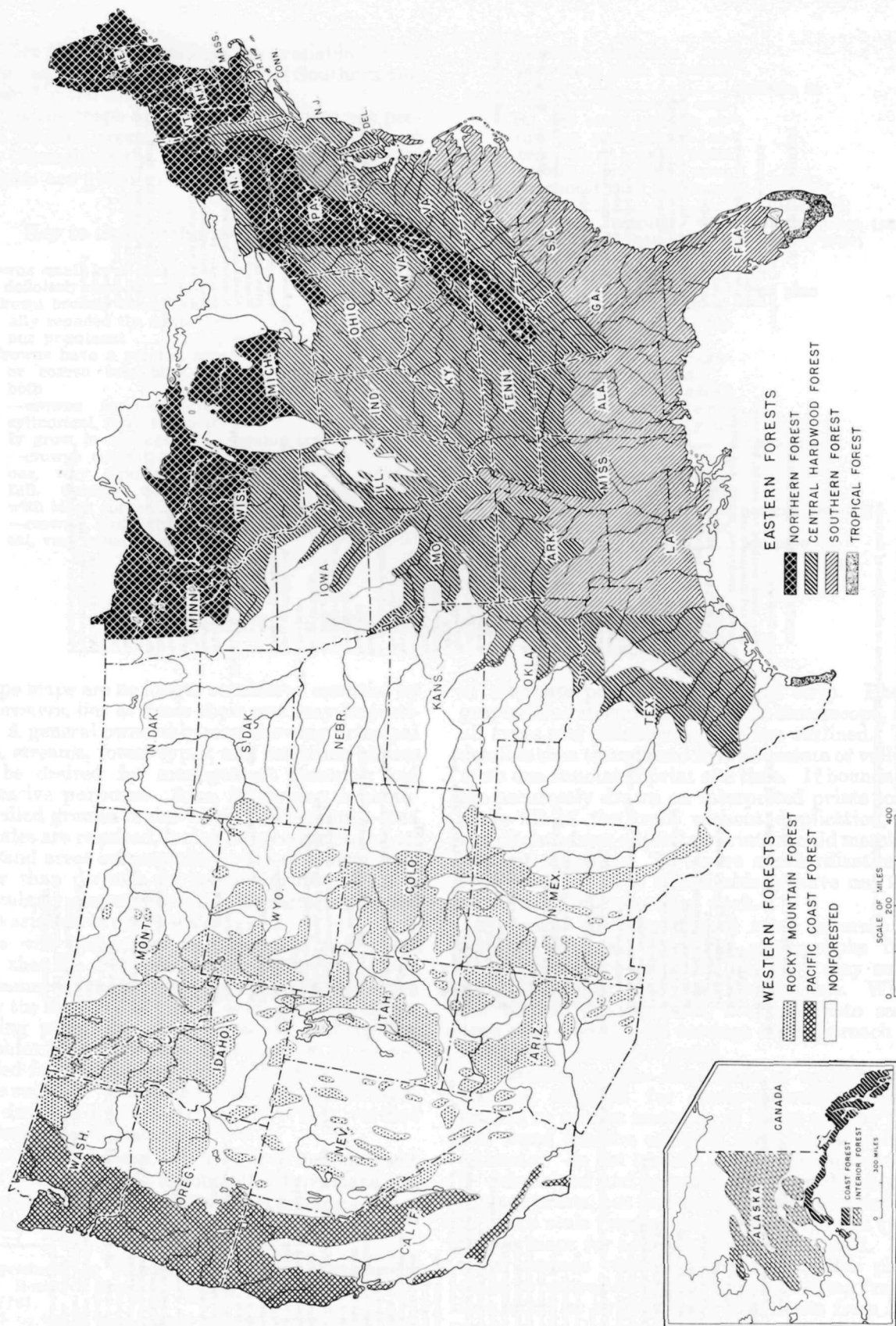


Figure 8.—Forest regions of the United States.

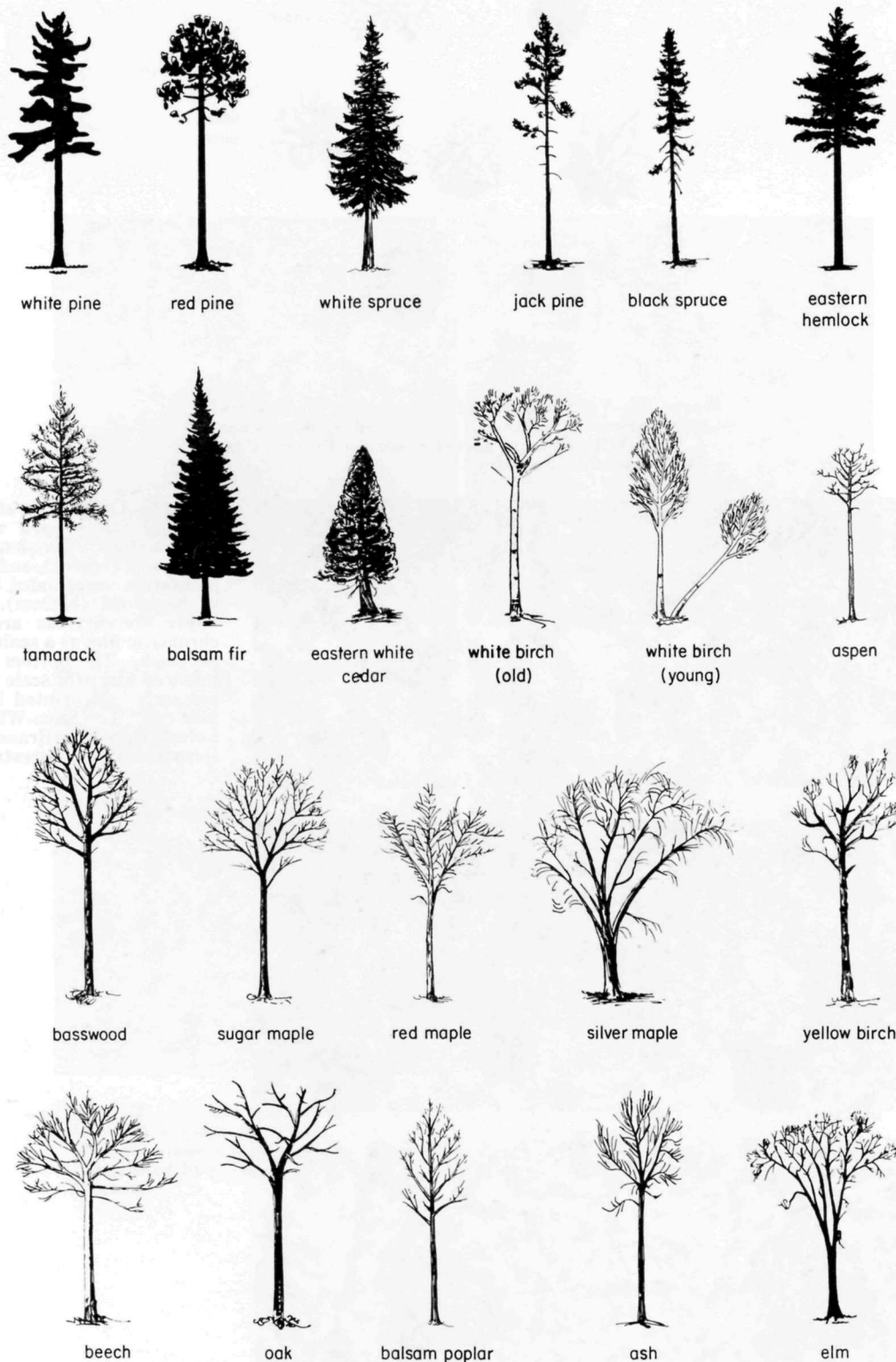


Figure 9.—Silhouettes of forest trees. When tree shadows fall on level ground, they often permit identification of individual species. (Reprinted by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry.)

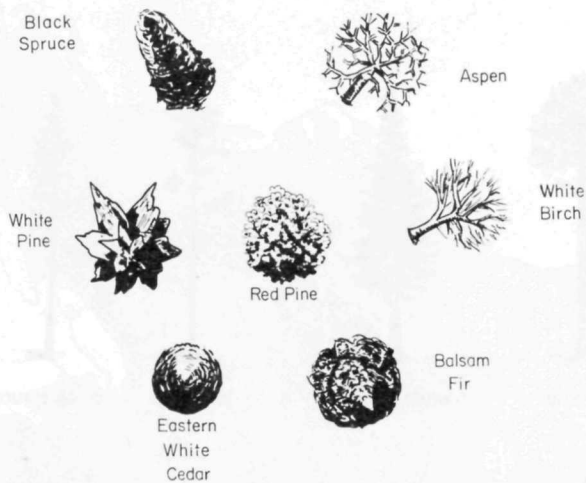


Figure 10.—Vertical views of tree crowns. Compare with stereograms in figure 11. (Reprinted by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry.)

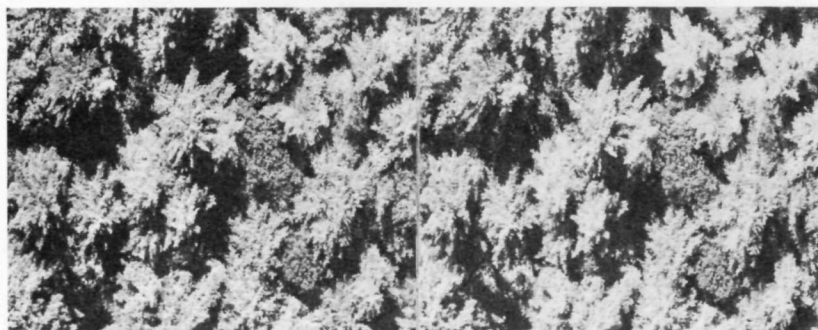
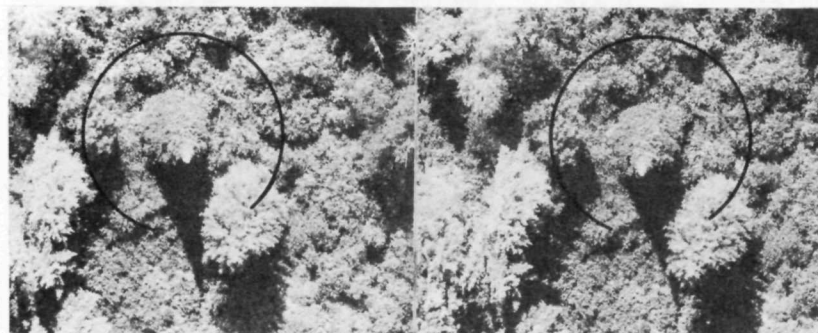


Figure 11.—Large-scale stereograms showing star-shaped white pine crowns (top), cone-shaped balsam fir crowns (center), and a red pine plantation surrounded by a stand of basswood (bottom). The two upper stereograms are on panchromatic film at a scale of 50 feet per inch. The bottom pair is on infrared film at a scale of 330 feet per inch. (Reprinted by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry.)



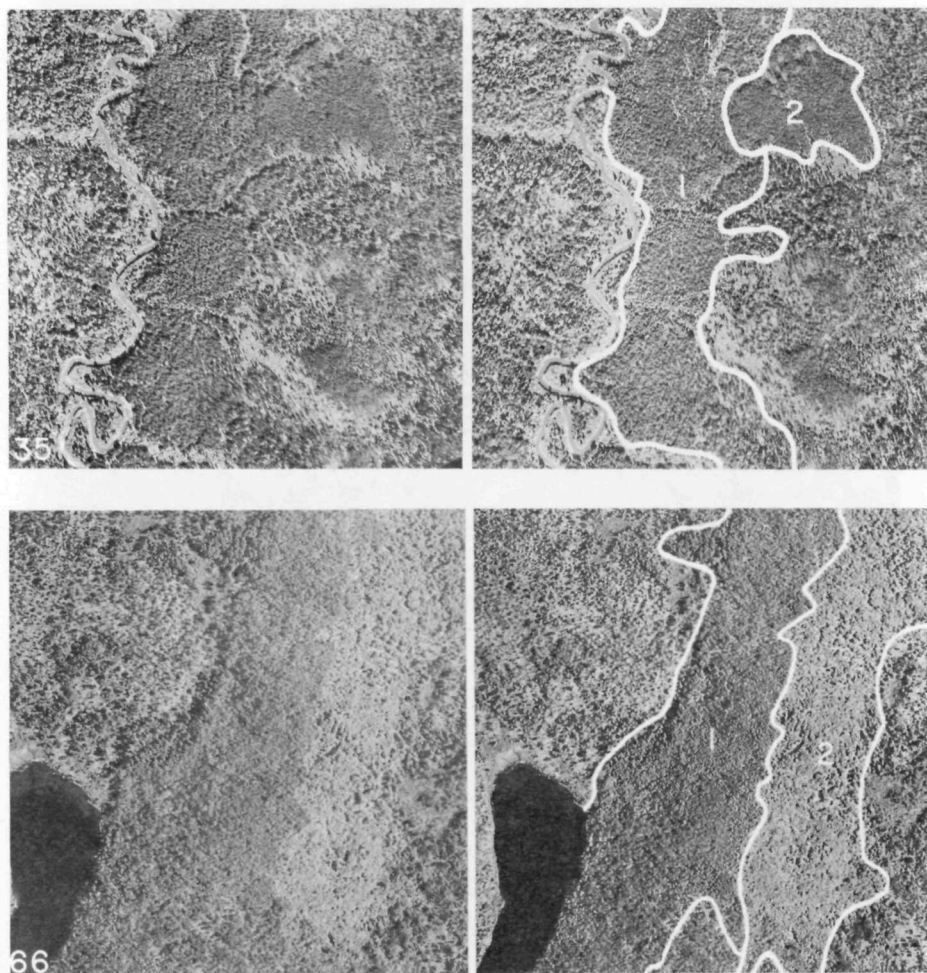


Figure 12.—Summer panchromatic photography in Ontario. In the upper stereogram (No. 35) stand 1 is balsam fir and stand 2 is black spruce. In the lower stereogram (No. 66) stand 1 is aspen-white birch and stand 2 is beech. Scale is 1,320 feet per inch. (Reprinted by permission of V. Zsilinszky, Ontario Department of Lands and Forests, Canada.)

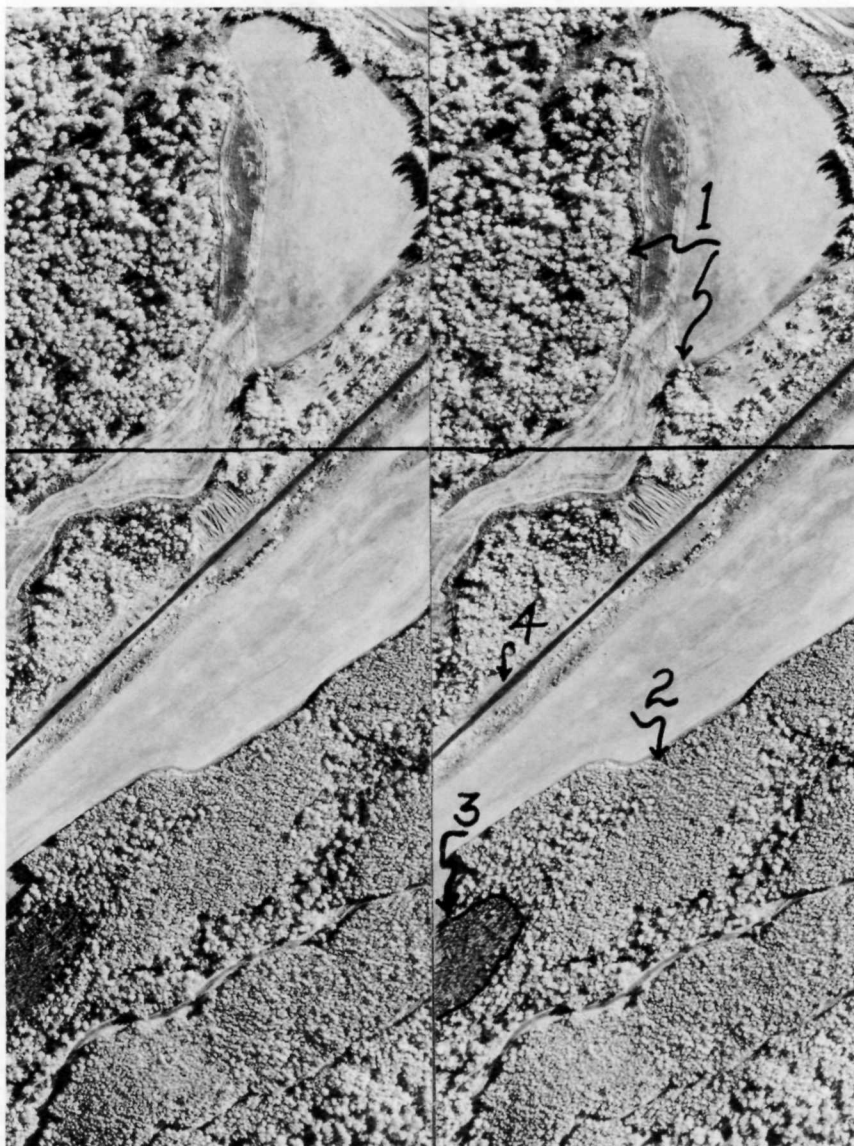


Figure 13.—Infrared stereogram illustrating forest associations in central Alaska. Types are (1) paper birch, (2) aspen, and (3) white spruce. A portion of the Alaska Railroad is shown at (4). Scale is about 420 feet per inch.



Figure 14.—USDA panchromatic stereogram from Del Norte County, Calif. Enclosed trees are primarily redwood, with lesser numbers of Douglas-fir, spruce, and hemlock. Clear stereo-viewing is hindered by the heavy displacement of trees, some of which are 250 to 300 feet tall. Scale is about 1,667 feet per inch.

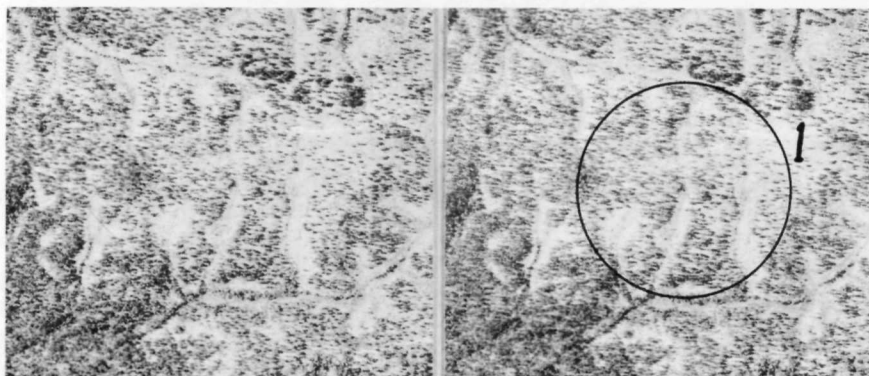


Figure 15.—USDA panchromatic stereograms from Jackson (above) and Clarke Counties, Miss. At (1) is a natural stand of longleaf and slash pines; loblolly-shortleaf pines are pictured at (2) and leafless upland hardwoods at (3). Scale is about 1,667 feet per inch.

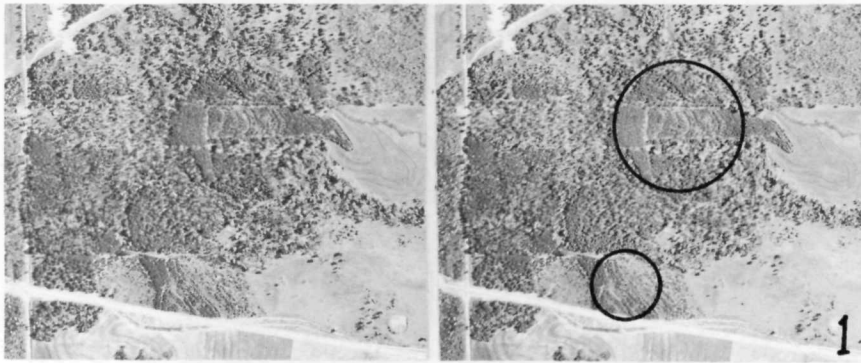


Figure 16.—USDA panchromatic stereograms from Columbia (above) and Sevier Counties, Ark. Two loblolly pine plantations are pictured at (1), while the mountainous terrain at (2) supports a mixture of upland hardwoods and short-leaf pine. Scale is about 1,667 feet per inch.

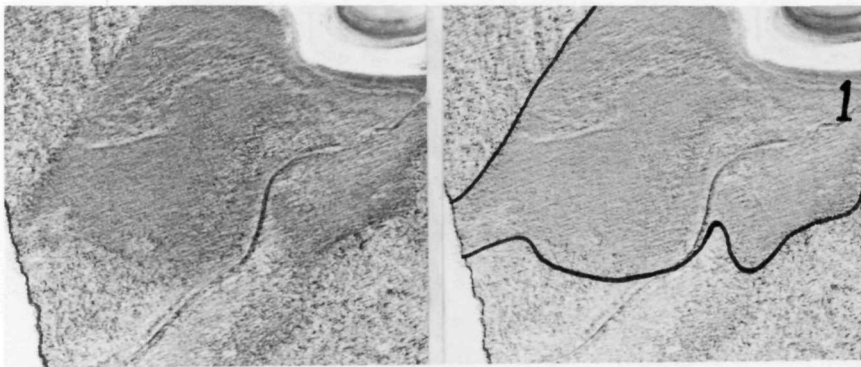
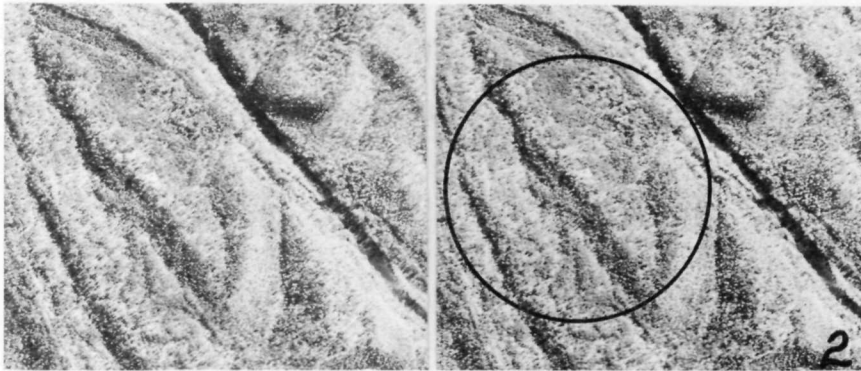


Figure 17.—USDA panchromatic stereograms from Bolivar County, Miss. The fine-textured stand at (1) is willow and cottonwood growing on a recent deposition of sand and silt. At (2) is a stand of bottom-land hardwoods, i.e., oaks, gums, maples, and other wet-site species. Scale is about 1,667 feet per inch.



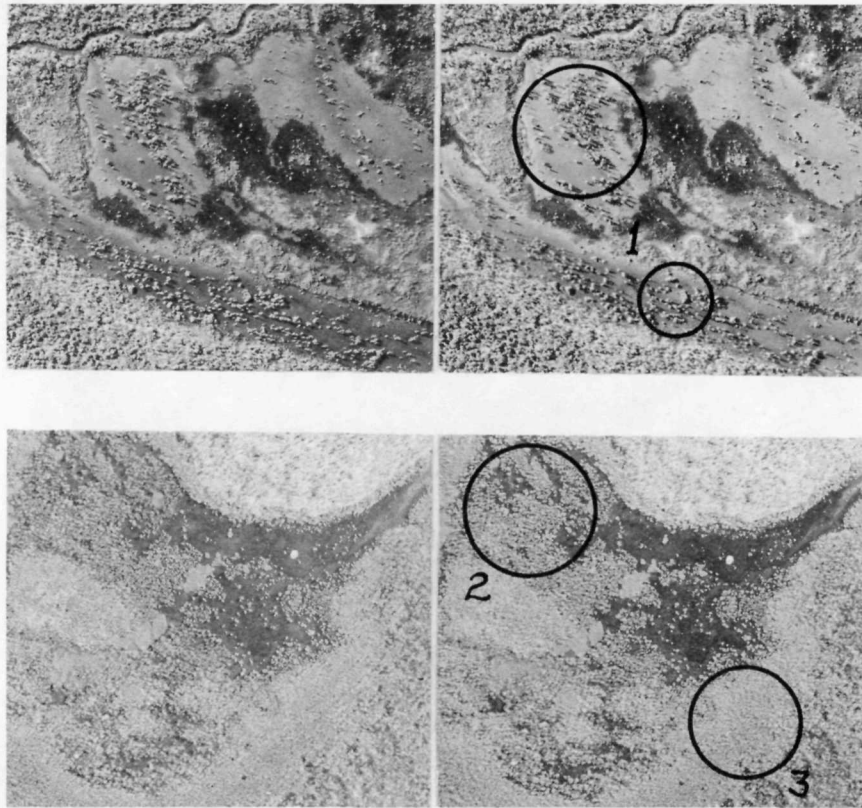


Figure 18.—USDA panchromatic stereograms from Lafayette County, Ark. Pure stands of southern cypress are shown at (1); the irregular and somewhat star-shaped crowns of this species can be clearly discerned against the water. At (2) is a mixture of cypress and tupelo gum, while a pure stand of tupelo gum is pictured at (3). Scale is about 1,667 feet per inch.

quately treated in several readily available publications (1, 17, 18), it will not be reviewed here.

General Land Office (GLO) plats.—Most of the United States west of the Mississippi River and north of the Ohio River, plus Alabama, Mississippi, and portions of Florida, was originally subdivided under the U.S. Public Land Survey. Township, range, and section lines are often visible on aerial photographs. If enough such lines and corners can be identified, GLO plats can be constructed for use as base maps from field notes available at State capitals or county offices. To do this, a GLO plat showing sections, quarter sections, and forties is drawn to average photo scale from field notes. As many as possible of the same lines and corners are pinpointed on the aerial photographs, preferably arranged in a systematic framework throughout the forest property. Ownership maps, county highway maps, and topographic quadrangle sheets may help to identify such corners, but additional points must usually be found by taking the photographs into the field. The accuracy of this method depends upon the number of grid lines and corners which can be pinpointed on the aerial photographs. The technique described is adapted from Johnson (7).

When photo interpretation of forest types has been completed, the detail is transferred to the plat, one square of the grid being completed at a time. If the plat and photographs are of the same scale, transfer can be made by direct tracing on a light table; where scales differ, a vertical sketchmaster is recommended (fig. 19). By moving this instrument up or down on its adjustable legs, maps can be drawn at scales of seven-tenths to one and one-half times the scale of the contact print. The sketchmaster accommodates a single, annotated print, which is placed face up on the platform under a large mirror. Photo images are reflected from the large mirror to a semisilvered mirror in the eyepiece housing. The semitransparent eyepiece mirror thus provides a monocular view of the reflected photo image superimposed on the base map. When the grid points on photograph and map have been matched, the transfer of detail becomes a simple procedure (fig. 20).

Topographic and county maps.—Topographic quadrangle sheets and county highway maps are often useful in preparing base maps and identifying features on aerial photographs. When available, 7½-minute quadrangle maps at a scale of 1:24,000 provide excellent base maps, and can be

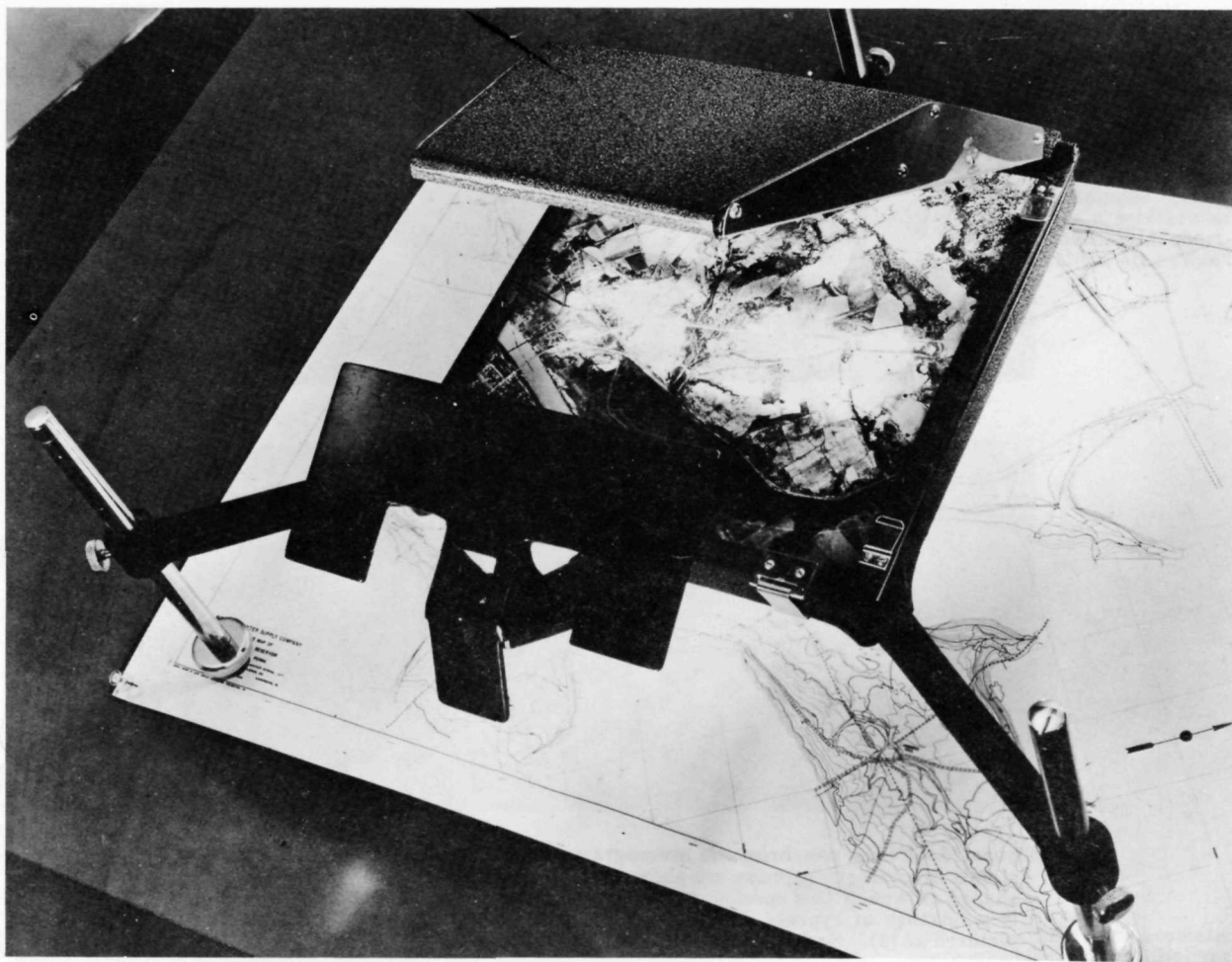


Figure 19.—Vertical sketchmaster for transferring detail from single contact prints to a base map. A semisilvered eyepiece mirror enables the operator to view photograph and map simultaneously. (Courtesy of Aero Service Corporation.)

purchased for about 30 cents per copy. Maps for areas west of the Mississippi River, including all of Louisiana and Minnesota, can be purchased from

U.S. Geological Survey
Distribution Section
Federal Center
Denver, Colo. 80225

For areas east of the Mississippi River, including Puerto Rico and the Virgin Islands, maps may be purchased from

U.S. Geological Survey
Distribution Section
Washington, D.C. 20240

Maps of Hawaii may be ordered at either address. All orders must be paid in advance. Other sources of topographic quadrangle maps are the Maps and Surveys Branch of the Tennessee Valley

Authority, Chattanooga, Tenn.; the Mississippi River Commission, U.S. Army Corps of Engineers, Vicksburg, Miss.; and the U.S. Coast and Geodetic Survey, Department of Commerce, Washington, D.C.

County maps, usually obtained from State highway departments, may serve as base maps when a high level of accuracy is not required. They show township, range, and section lines, in addition to geographic coordinates (longitude and latitude) to the nearest 5 minutes. They are usually printed at a scale of about one-half inch per mile. Although bearings of section lines are not shown, such maps are more reliable than oversimplified plats showing idealized sections oriented exactly with the cardinal directions. Portions of county maps can be enlarged to photo scale and sections subdivided into quarters or forties by proportionate measurement. These maps may be especially helpful in preparing GLO plats as previously outlined.



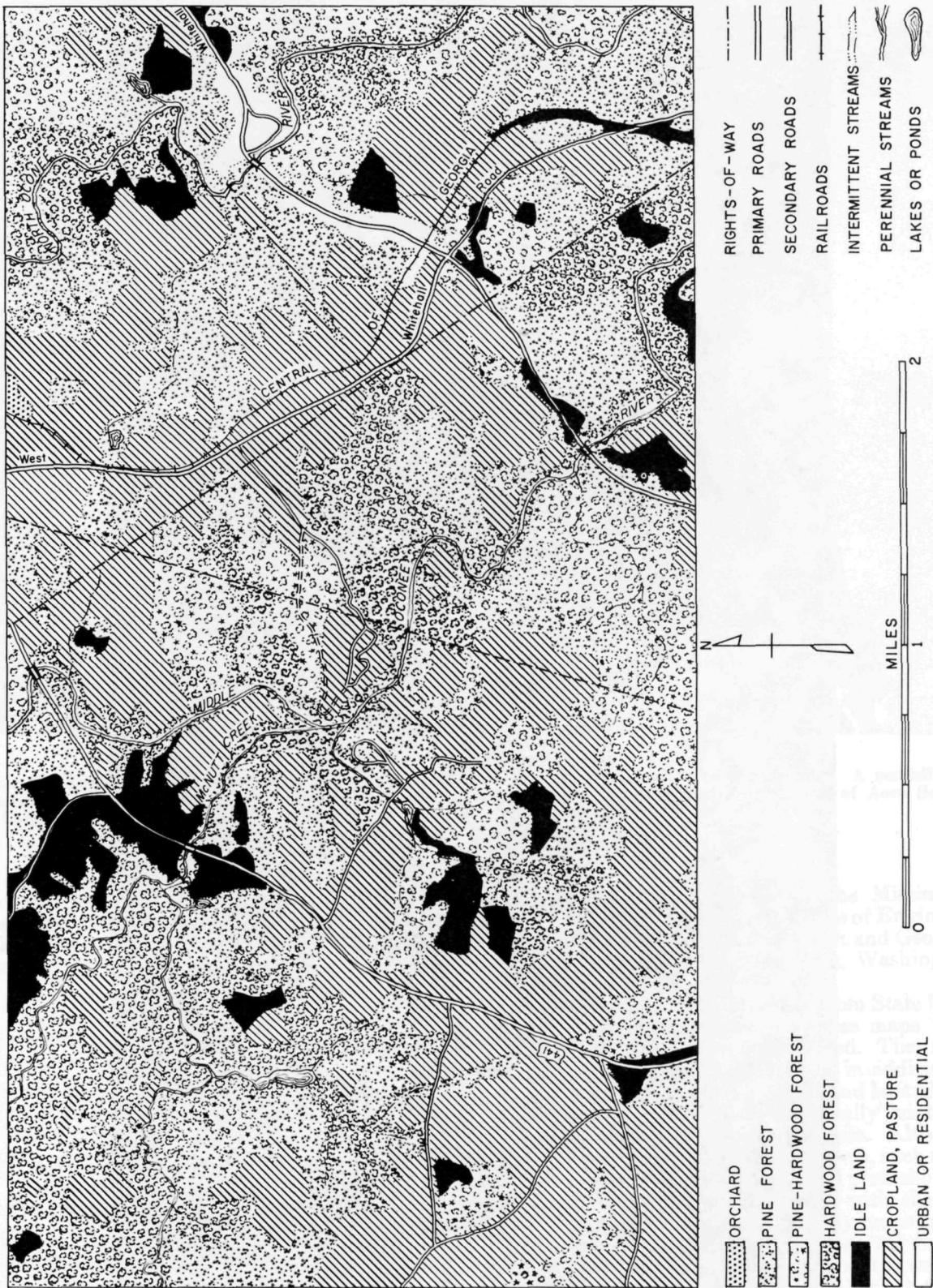


Figure 20.—Photo mosaic assembled from 1960 USDA prints, and corresponding map compiled with the vertical sketchmaster. The area is in Clarke County, Ga.

MEASURING AREAS

Both aerial and ground cruising require accurate measurement of forest areas. Photographs offer an inexpensive means of making such determinations. In locations where photo scales are not appreciably altered by topographic changes, areas can be measured directly on contact prints. Greater accuracy is possible if forest types are transferred to controlled base maps before area is determined. This procedure is essential for mountainous terrain. On the other hand, if only relative proportions of the forest types are needed and measurements are limited to the effective areas of contact prints, no bias results from using photographs, even when local relief ranges from 500 to 1,000 feet (12, 19). (This statement assumes that, for large tracts, errors in measurement of areas below the datum plane are compensated by errors of a similar magnitude above the datum plane.) Small tracts in rough topography should be measured on controlled maps. Measurement techniques are similar in both cases, so the procedures outlined for measuring area on photographs generally apply to map determinations.

Devices for area measurement.—The principal devices for area measurement are polar planimeters, transects, and dot grids.

The planimeter is relatively expensive and its use somewhat tedious. The pointer is carefully run clockwise around the boundaries of an area two or more times (for an average reading). From the vernier scale, the area is read in square inches and then converted to the desired units, usually acres, on the basis of photo or map scale.

The transect method is analogous to determining forest area by a strip cruise in which the chainage encountered in each forest type is recorded. An engineer's scale is alined on the photographs to cross topography and drainage at approximately right angles. The length of each type along the scale is recorded to the nearest tenth of an inch. Proportions for each type are developed by relating the total measure of that type to the total linear measure. For example, if six equally spaced parallel lines 6 inches long are tallied on a given photograph, the total transect length is 36 inches. If hardwoods are intercepted for a total measure of 7.2 inches, this particular type would be assigned an acreage equivalent to $7.2 \div 36$, or 20 percent of the total area. The transect method is simple and requires a minimum of equipment. For making rough area estimates on photo index sheets, special transparent overlays for location of transect lines can be improvised (9).

Use of a dot grid is the preferred method for determining area on aerial photographs. A dot grid is a transparent overlay with dots systematically arranged on a grid pattern. In use, the grid is alined with a straight-line feature to avoid positioning bias, and then dots are tallied for each

forest type (fig. 21). Type areas are calculated by proportions: the number of dots on a given type divided by the total number of dots counted yields a percentage value that is multiplied by the total area to obtain the acreage of the type. If total acreage is not known, the number of acres per square inch is determined. This figure is then divided by the number of dots per square inch to find the acreage represented by each dot.

Intensity of dot sampling.—The number of dots that must be counted for a given accuracy depends upon the estimated proportion of the total area occupied by the most important classification to be recognized. For example, suppose area breakdowns are needed for 10 square miles photographed at a scale of 1:15,840. Estimated proportions of each area classification are as follows: forest, 25 percent; agricultural lands, 60 percent; urban areas, 10 percent; and rivers and lakes, 5 percent. If the most important category is agricultural land, the dot grid intensity would be calculated on this basis. If the population being sampled is large, the number of samples may be computed by a formula based on the binomial distribution:

$$n = p(1-p) \left[\frac{t}{E} \right]^2$$

Where: n = total number of samples (dots) to be counted.

p = estimated proportion of the total area in the most important type classification (0.60 in this case).

t = a constant denoting the reliability of the estimate or level of statistical significance (the value 1.96 used here denotes a statistical probability of being correct 95 times in 100).

E = maximum permissible error, expressed as a percent of total area. (In this case, ± 2 percent or 0.02.)

Substituting the above values, we get:

$$n = 0.60(1-0.60) \left[\frac{1.96}{0.02} \right]^2 = 2,305 \text{ dots}$$

Thus if we are correct in the assumption that the true percentage of agricultural land is 60, then 2,305 dots should be spaced over the total area to insure a 95-percent probability of obtaining an estimated proportion lying between 58 and 62 percent. At the specified photo scale of 1:15,840, the total print area represented by 10 square miles would be 160 square inches. Therefore, the number of dots needed per square inch would be $2,305 \div 160$, or about 14. Here, it would be most expedient to select a square-spaced grid having 16 dots per square inch.

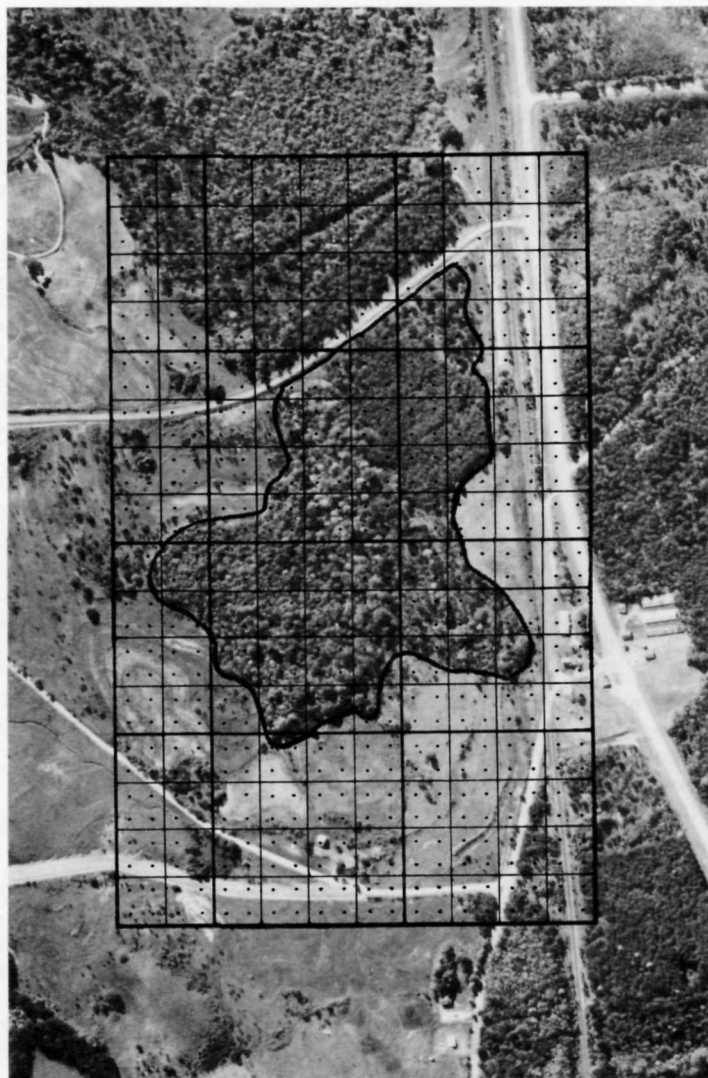


Figure 21.—Dot grid positioned over part of an enlarged USDA print for acreage determination. The delineated stand contains about 25 acres. Photo scale is 660 feet per inch.

The principal drawback to the formula method is that a prior knowledge of p is required, which is actually the value being sought. By definition, however, p always lies between 0 and 1, and it can be shown that $p(1-p)$ reaches a maximum value of 0.25 when p is set at 0.50 or 50 percent. Therefore, the equation may be revised to read:

$$n = 0.25 \left[\frac{t}{E} \right]^2$$

And, substituting values from the previous solution:

$$n = 0.25 \left[\frac{1.96}{0.02} \right]^2 = 2,401 \text{ dots, an increase of 96 dots over the first estimate.}$$

A grid with 16 dots per square inch will still be adequate for the desired degree of accuracy ($16 \times 16 = 2,560$ dots).

For areas of 1,000 acres or less, grids with closely spaced dots are needed. Grids with 64 dots per square inch are commonly used with 1:20,000 photographs. As 1 square inch equals 63.77 acres at photo scale, each dot represents 0.996 acres. For 1:15,840 photography (40 acres per square inch), grids having 40 dots per square inch are available. It is not essential, of course, that a separate grid be used for each photo scale or that the number of dots per square inch be equal to the acreage per square inch. Wherever feasible, the preceding equation should be used to determine the grid intensity.

TREE HEIGHT, CROWN DIAMETER, AND CROWN CLOSURE

Tree Height

Tree heights are commonly determined on aerial photographs by measuring either stereoscopic parallax or shadow lengths. Though more difficult for the beginner, the parallax method is faster, requires fewer calculations, and is more adaptable to a variety of stand conditions. Anyone who can use a stereoscope can train himself to measure stereoscopic parallax, and even the occasional interpreter will find this method of measuring heights advantageous.

Shadow-length measurements are reliable only in open-grown stands where individual shadows fall on level ground. Accurate measurement is almost impossible in dense, irregular stands or on slopes. Furthermore, the conversion of shadow length to tree height is complex in comparison to the conversion of parallax measurements. For these reasons only the parallax method will be discussed. Foresters interested in details of shadow-height calculations should refer to Johnson's article (8), which includes a special form for making tree-height conversions.

The concept of parallax.—*The Manual of Photogrammetry* (1) defines parallax as "the apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation." In measuring object heights on stereoscopic pairs of aerial photographs, two types of parallax must be measured or approximated—the absolute and the differential. The absolute stereoscopic parallax of a point is "the algebraic difference, parallel to the air base, of the distances of the two images from their respective principal points" (18). The parallax difference, or differential parallax, of an object being measured for height determination is the difference in the absolute stereoscopic parallax at the top and the base of the object, measured parallel to the air base or flight line.

The formula for converting parallax measurements to tree height on aerial photographs is:

$$h = \frac{H \times dP}{P + dP}$$

where h = height of object

H = altitude of aircraft above ground datum

P = absolute stereoscopic parallax at base of object being measured

dP = differential parallax

If object heights are to be determined in feet, the height of the aircraft (H) must also be in feet. Absolute stereoscopic parallax (P) and differential parallax (dP) must be expressed in the same units; ordinarily, these units will be thousandths of inches or hundredths of millimeters.

The height of the aircraft above ground datum

is calculated from the basic scale formula, transposed to the more convenient form: Flight altitude (H) = focal length $\times$ scale denominator. With photographs of 1:20,000 scale and a camera of 8.25-inch focal length, the flight altitude would be $0.6875 \times 20,000 = 13,750$ feet.

In flat terrain, the average photo base length is ordinarily substituted as the absolute stereoscopic parallax (P). If the ground elevation at the base of the tree being measured differs from the elevation of the principal points by more than 200 or 300 feet, however, the following method (17) should be used to calculate a new value for P :

1. Orient the stereo-pair with flight lines superimposed and images separated about 2.2 inches. Clip down photographs.
2. Measure the distance between the two principal points to the nearest 0.01 inch with an engineer's scale.
3. Measure the distance between corresponding images on the two photographs at or near the base of the tree to the nearest 0.01 inch.
4. Subtract (3) from (2) to obtain the absolute stereoscopic parallax at the base of the tree.

Differential parallax (dP) is usually measured stereoscopically with either a parallax wedge or parallax bar, employing the "floating mark" principle. Such instruments are discussed in the section that follows. The concept of differential parallax can be illustrated by direct measurement of severely displaced images such as in the large-scale stereogram of a water tank in figure 22. With a photo scale of 1:7,800 and a camera focal length of 6 inches, flight altitude above ground (H) is computed as $0.5 \times 7,800$ or 3,900 feet. Average photo base length (P) for the stereo-pair is 3.70 inches.

Absolute stereoscopic parallax at the base and top of the water tank is measured parallel to the line of flight with an engineer's scale; the difference (2.27–2.13 inches) is dP , the differential parallax of the displaced images. As the tank is somewhat tapered in form, measurements were made at the midpoint of the base and vertically above this position at the center of the top. Substituting in the parallax formula:

$$\text{Height of tank } (h) = \frac{3,900 \times 0.14}{3.70 + 0.14} = \frac{546.00}{3.84} = 142 \text{ feet}$$

Parallax wedges.—Parallax wedges are usually printed on transparent film or glass. The basic design consists of two rows of dots or graduated lines beginning about 2.5 inches apart and converging to about 1.8 inches apart. The graduations on each line are calibrated for making parallax readings to the nearest 0.002 inch. The "training wedge" in figure 23 is graduated for reading to the nearest 0.01 inch only.

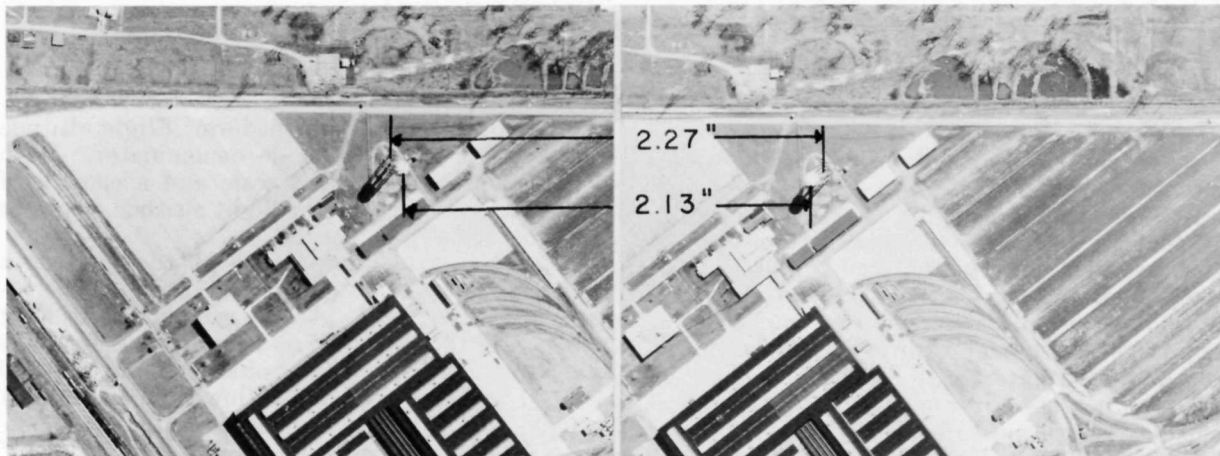


Figure 22.—Large-scale stereogram showing an industrial plant and heavily displaced water tank. Measurements of stereoscopic parallax shown can be used to determine height of the tank above ground. (Courtesy of Abrams Aerial Survey Corporation.)

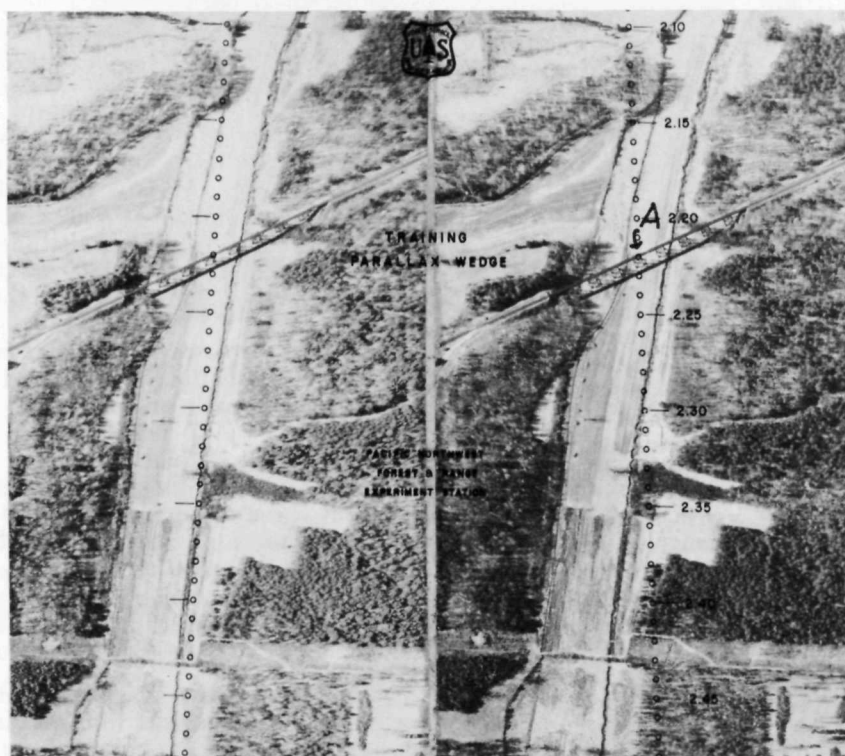


Figure 23.—Parallax wedge correctly oriented over a large-scale stereogram of a railroad trestle. Graduations on right-hand row of dots refer to separation of the converging lines in inches. (Courtesy of Abrams Aerial Survey Corporation.)

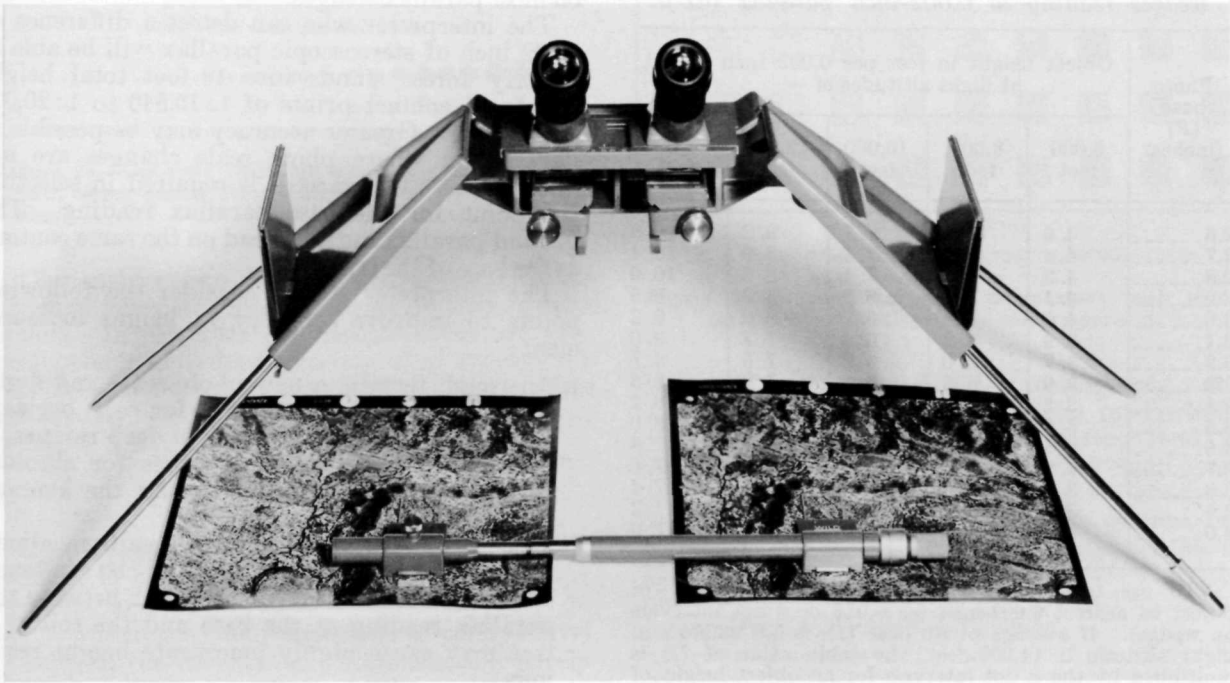


Figure 24.—Modern mirror stereoscope with inclined magnifying binoculars. Positioned across the two photographs is a parallax bar (stereometer) for measuring heights of objects. (Courtesy of Wild-Heerbrugg Instruments, Inc.)

The parallax wedge is placed over the stereoscopic image with the converging lines perpendicular to the line of flight and adjusted until a single fused line of dots or graduations is seen sloping downward through the stereoscopic image. If the photo images are separated by exactly 2 inches, a portion of the parallax wedge centering around the 2-inch separation of converging lines will fuse and appear as a single line. The line will appear to split above and below this section. Using the fused line of graduations, the differential parallax is obtained by counting the number of dots or intervals between the point where a graduation appears to rest on the ground and the point where a graduation appears to “float” in the air at the same height as the top of the object. In figure 23, for example, the dot resting on top of the railroad trestle yields a reading of 2.22 inches. When this value is subtracted from a ground reading of 2.26 inches, dP is determined as 0.04 inches. If flight altitude (H) of 4,000 feet and a photo base length of 3.56 inches, the parallax formula yields:

$$\text{Height of trestle } (h) = \frac{4,000 \times 0.04}{3.56 + 0.04} = \frac{160.00}{3.60} = 44 \text{ feet}$$

The interpreter should remember that the degree of stereoscopic parallax normally encountered on 1:12,000 to 1:20,000 USDA photographs is much less than that illustrated here. Nevertheless, the

principle and the methods of measurement are exactly the same. Where P is large in relation to dP , tables 2 and 3 can be used as shortcut approximations in converting parallax measurements to object heights on USDA photographs.

The parallax bar.—This instrument is more expensive than the parallax wedge and yields results of comparable accuracy. But many interpreters prefer the parallax bar because the floating dot is movable and thus easier to place on the ground and at crown levels. A parallax bar designed to measure heights with a mirror stereoscope is shown in figure 24.

The bar has two lenses attached to a metal frame that houses a vernier and a graduated metric scale. The left lens contains the fixed reference dot; the dot on the right lens can be moved laterally by means of the vernier. The bar is placed over the stereoscopic image parallel to the line of flight. The right-hand dot is moved until it fuses with the reference dot and appears to rest on the ground at the base of the tree. The vernier reading is recorded to the nearest 0.01 millimeter. The vernier is then turned until the fused dot appears to “float” at treetop level, and a second reading recorded. The difference between the readings is the parallax difference (dP) in millimeters. This value can be substituted in the parallax formula without conversion if the absolute parallax (P) is also expressed in millimeters.

Accuracy of height measurements.—Accuracy in

TABLE 2.—*Parallax-wedge conversion factors for wedges reading to 0.002-inch parallax (dP)¹*

Photo base (P) (inches)	Object height in feet per 0.002 inch of dP, at flight altitudes of —				
	6,000 feet	8,000 feet	10,000 feet	12,000 feet	14,000 feet
2.6-----	4.6	6.1	7.7	9.2	10.8
2.7-----	4.4	5.9	7.4	8.9	10.4
2.8-----	4.3	5.7	7.1	8.6	10.0
2.9-----	4.1	5.5	6.9	8.3	9.6
3.0-----	4.0	5.3	6.7	8.0	9.3
3.1-----	3.9	5.2	6.4	7.7	9.0
3.2-----	3.7	5.0	6.2	7.5	8.7
3.3-----	3.6	4.8	6.1	7.3	8.5
3.4-----	3.5	4.7	5.9	7.0	8.2
3.5-----	3.4	4.6	5.7	6.8	8.0
3.6-----	3.3	4.4	5.6	6.7	7.8
3.7-----	3.2	4.3	5.4	6.5	7.6
3.8-----	3.1	4.2	5.3	6.3	7.4
3.9-----	3.1	4.1	5.1	6.1	7.2
4.0-----	3.0	4.0	5.0	6.0	7.0

¹ To use table, measure parallax difference (dP) of object to nearest 0.002-inch (as 0.016 or 8 dot intervals on wedge). If average photo base (P) is 3.6 inches and flight altitude is 14,000 feet, the table value of 7.8 is multiplied by the 8 dot intervals for an object height of 62 feet.

TABLE 3.—*Parallax-bar conversion factors for use with devices reading to 0.01-mm. parallax (dP)¹*

Photo base (P) (inches)	Object height in feet per millimeter of dP at flight altitudes of—				
	6,000 feet	8,000 feet	10,000 feet	12,000 feet	14,000 feet
2.6-----	90	119	149	179	209
2.7-----	86	115	144	172	201
2.8-----	83	111	139	166	194
2.9-----	80	107	134	161	187
3.0-----	78	104	130	155	181
3.1-----	75	100	125	151	176
3.2-----	73	97	122	146	170
3.3-----	71	94	118	142	165
3.4-----	69	92	114	137	160
3.5-----	67	89	111	133	156
3.6-----	65	87	108	130	152
3.7-----	63	84	105	126	147
3.8-----	62	82	103	123	144
3.9-----	60	80	100	120	140
4.0-----	58	78	97	117	136

¹ To use table, measure parallax difference (dP) of object to nearest hundredth of a millimeter (as 0.57 mm., for example). If average photo base (P) is 3.1 inches and flight altitude is 12,000 feet, the table value of 151 is multiplied by 0.57 for an object height of 86 feet.

measuring total heights of trees and stands depends upon a number of factors, not the least of which is the interpreter's ability to determine stereoscopic parallax. Usually interpreters can detect differences in parallax of about 0.002 inch,

or 0.05 mm., and this graduation interval is used on most parallax wedges.

The interpreter who can detect a difference of 0.002 inch of stereoscopic parallax will be able to stratify forest stands into 10-foot total height classes on contact prints of 1:15,840 to 1:20,000 scales (18). Greater accuracy may be possible in flat terrain where photo scale changes are not pronounced and less skill is required in selecting the point for the base parallax reading. The ground parallax must be read on the same contour as the base of the tree.

The interpreter should consider the following points to improve accuracy in height measurement:

1. In rough terrain, a new photo scale and flight altitude should be calculated for each overlap. For stands on high ridges or in deep ravines, it is better to calculate new values for absolute stereoscopic parallax than to use the average photo base length.
2. Once a pair of photographs have been alined for stereo-viewing, they should be fastened down. A slip of either photograph between the parallax reading at the base and the top of a tree may cause highly inaccurate height readings.
3. To avoid single measurements of high variability, several measurements should be made of the same tree or stand and the results averaged.

Tree Crown Diameter

For most conifers and many hardwoods, tree crown diameter is related to stem diameter. It is thus a useful photographic measurement when estimating individual tree volumes or stand-size classes. Actual determination of crown diameter is a distance measurement, somewhat complicated by the small sizes of tree images and the effects of crown shadows.

Crown diameters are measured with either wedges or dot-type scales reading in thousandths of an inch. With a crown wedge, the diverging lines are placed tangent to both sides of the crown for making the reading. Dot-type scales have circles of graduated sizes for direct comparison with tree crowns (fig. 25). For converting measurements, the scale of photography is calculated in feet per thousandth of an inch. At 1:20,000, each 0.001 inch of crown measure equals 1.667 feet. A reading of 0.010 inch would imply a crown diameter of 17 feet (table 4).

Tree crowns are rarely circular, but, because individual limbs are often invisible on aerial photographs, they usually appear roughly circular or elliptical. Since only the parts visible from above can be evaluated, photo measures of crown diameter are often lower than ground checks of the same trees. Nevertheless, most interpreters can determine average crown diameter with reasonable precision if they take several readings.

CROWN DIAMETER SCALE
CENTRAL STATES FOREST EXPERIMENT STATION

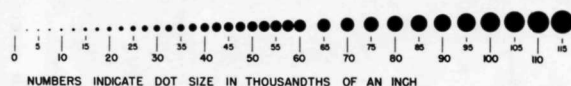


Figure 25.—Dot-type scale for measuring crown diameters. Such scales are usually printed on transparent film.

Obviously, crown diameter measurements of individual trees are most accurate in open-grown stands. In dense stands, measurements are generally confined to determination of an average for the dominant trees. Crowns of mature conifers can usually be classified into 5-foot classes without difficulty (18).

Tree Crown Closure

Crown closure percent, also referred to as crown density, is the proportion of the forest canopy occupied by trees. Crown density may refer to all crowns in the stand regardless of canopy level or only to the dominants. Estimates are purely ocular, and stands are commonly grouped into 10-percent density classes. Printed density scales (fig. 26) may aid the interpreter, though the patterns of black dots on a white background bear little resemblance to photographic images of trees. Comparative stereograms illustrating various stand densities have also proved useful (fig. 27).

Evaluation of crown closure is much more subjective than the determination of tree height or crown diameter. Actual measurement is virtually

CROWN DENSITY SCALE

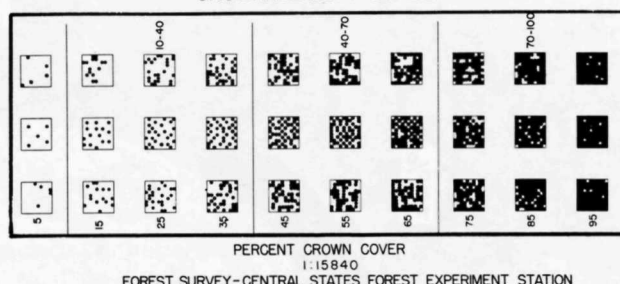


Figure 26.—Density scale for comparison with photo images in estimating crown closure percent.

impossible on most USDA photographs, and accuracy is thus dependent on the interpreter's judgment. Inexperienced interpreters tend to overestimate closure by ignoring small stand openings or including portions of crown shadows. Devices for checking closure on the ground fail to provide estimates that are truly comparable to those made on vertical photographs. Thus the neophyte must rely on practice, checked by skilled interpreters, to develop proficiency.

Crown closure is useful because of its relation to stand volume per acre. It is applied in lieu of basal area or number of trees per acre, as these cannot be accurately determined on available photography. Measurements of crown diameter and estimates of closure should always be made under the stereoscope.

Tree counts.—Complete tallies of individual trees can seldom be made accurately on available USDA photographs. In dense stands, suppressed trees and many intermediates cannot be seen. Clumps of two or three trees often appear as single

TABLE 4.—Actual crown widths for various photo-crown widths and photo scales

Photo crown width (thousandths of an inch)	1:10,000 or 833 ft./in.	1:12,000 or 1,000 ft./in.	1:15,840 or 1,320 ft./in.	1:18,000 or 1,500 ft./in.	1:20,000 or 1,667 ft./in.	1:24,000 or 2,000 ft./in.
	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>
2.5.....	2	3	3	4	4	5
5.0.....	4	5	7	8	8	10
7.5.....	6	8	10	11	13	15
10.0.....	8	10	13	15	17	20
12.5.....	10	13	17	19	21	25
15.0.....	12	15	20	23	25	30
17.5.....	15	18	23	26	29	35
20.0.....	17	20	26	30	33	40
22.5.....	19	23	30	34	38	45
25.0.....	21	25	33	38	42	50
27.5.....	23	28	36	41	46	55
30.0.....	25	30	40	45	50	60
32.5.....	27	33	43	49	54	-----
35.0.....	29	35	46	53	58	-----
37.5.....	31	38	50	56	63	-----
40.0.....	33	40	53	60	67	-----
42.5.....	35	43	56	-----	-----	-----
45.0.....	37	45	59	-----	-----	-----
47.5.....	40	48	63	-----	-----	-----
50.0.....	42	50	66	-----	-----	-----

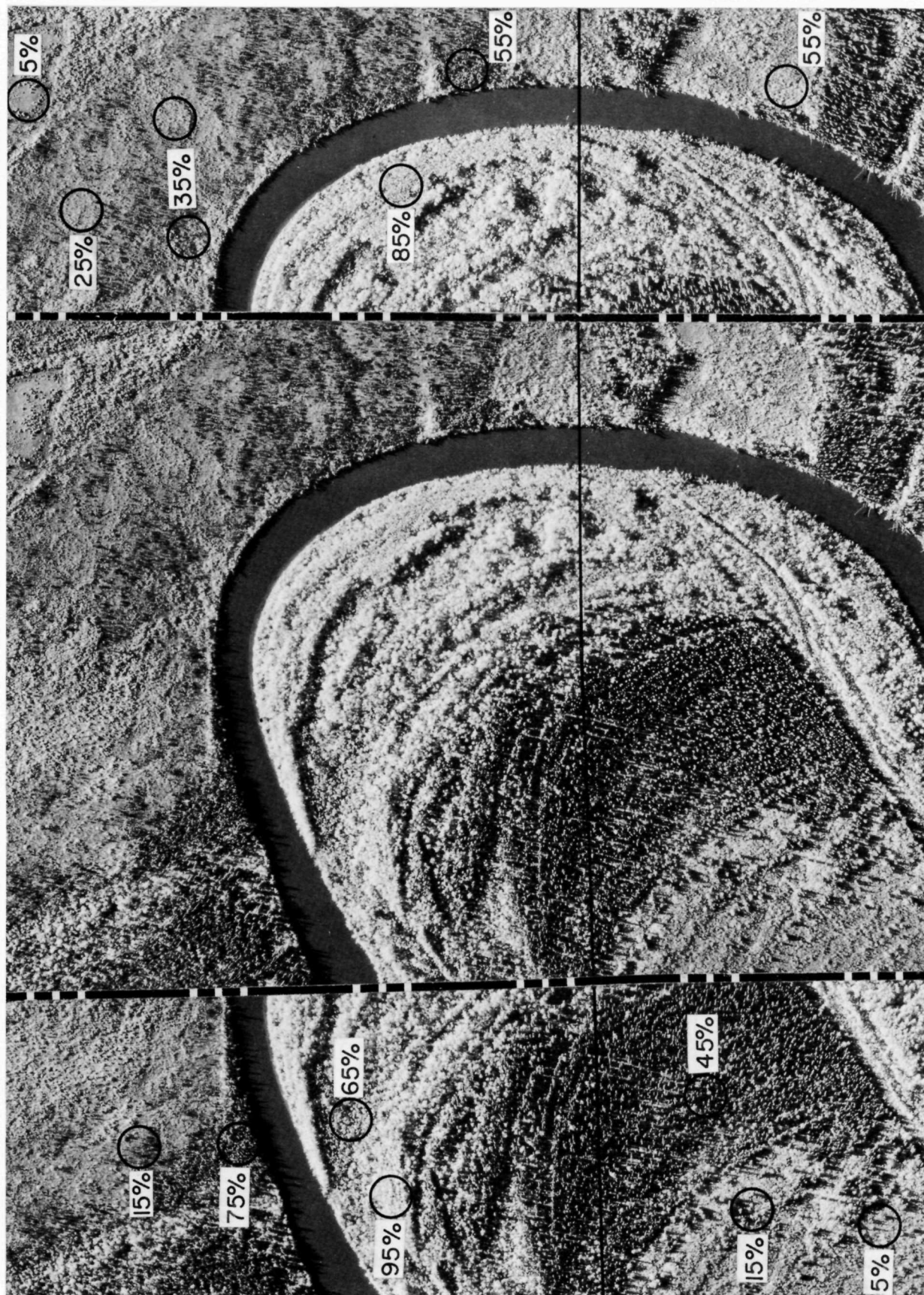


Figure 27.—Infrared stereo-triplet from central Alaska, showing estimates of tree crown closure. Scale is about 420 feet per inch; each circle represents approximately 0.25 acre. The solid black line indicates the path of the aircraft.

crowns, and ragged individual crowns may look like two trees. Only in even-aged, open-grown forests can all trees in a stand be separated. Counting all trees on a plot is tedious, and this

measure of density is seldom used. Where large-scale photographs are available (1:1,000 to 1:5,000), individual-tree counts may be much more reliable.

AERIAL CRUISING

Individual Tree Volumes

Ordinary tree volume tables can be easily converted to aerial volume tables when correlations can be established between tree crown diameters and stem diameters (10). The photographic determinations of crown diameter and total tree height are merely substituted for the usual field measures of stem diameter (d.b.h.) and merchantable height, respectively (fig. 28). Photographic measurements are usually limited to well-defined open-grown trees, and crown counts are required to obtain total volume for a given stand of timber.

The construction and application of aerial tree volume tables depends on a well-established relationship between photographic measures of crown diameter and ground determinations of tree d.b.h. Such relationships can often be established for individual species or species groups, notably even-aged conifers in the middle diameter classes (18). By contrast, stem-crown diameter correlations rarely have been used for estimating volumes of mixed hardwoods.

The aerial tree table (table 5) provides volumes in terms of gross cubic feet. In making an aerial

cruise, photographic measurements may include all trees on 0.2- to 1-acre circular plots, or stands may be delineated according to height classes for determination of the average tree per unit area. In the latter instance, a tree count must be made to obtain the total stand volume.

In general, the individual-tree approach to aerial cruising is of limited value when the interpreter is restricted to use of 1:12,000 to 1:20,000 USDA photographs. At this scale, images are usually too small for accurate assessment of individual trees.

Stand Volume Per Acre

If recent photographs and reliable aerial stand-volume tables can be obtained, average stand volume per acre can be estimated with a minimum of field work. Estimates are made in terms of gross volume, as amount of cull or defect cannot be adequately evaluated. Even-aged stands of simple species structure are best suited for this type of estimating, especially if gross and net volumes are essentially identical. All-aged stands of mixed hardwoods are more difficult to assess, but satisfactory results can be obtained if field checks are made to adjust the photographic estimate of stand volume per acre and to determine allowance for defect. Though volumes from photographs cannot be expressed by species and diameter classes, total gross volumes for areas as small as 40 acres can be estimated within 10 to 15 percent of volumes derived from conventional ground cruises (13).

Most aerial stand-volume tables for mixed species are constructed in terms of cubic feet per acre. Tables for species in pure stands, such as Douglas-fir, may be expressed either in board feet or cubic feet per acre. Three photographic measurements of the dominant stand are generally required for entering an aerial stand volume table: average total height, crown diameter, and crown closure percent.

Aerial volume tables have been constructed for many of the important timber associations in the United States. Included here are tables for Douglas-fir (table 6), Rocky Mountain conifers (table 7), and Kentucky hardwoods (table 8). Composite tables, applicable in mixed stands, are presented for northeast Mississippi (table 9) and for northern Minnesota (table 10). Crown diameter was eliminated as a variable in tables 6 and 10.

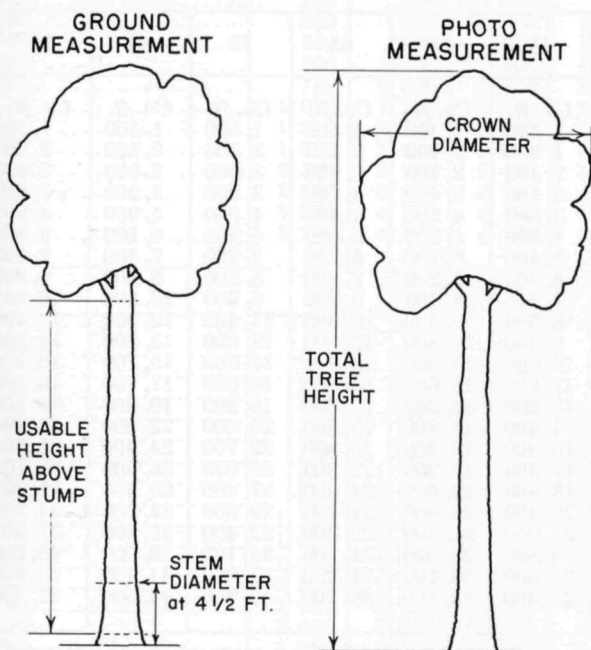


Figure 28.—Comparison of ground and photographic measurements in the determination of individual tree volumes.

TABLE 5.—*Volumes of individual second-growth southern pines*¹

Crown diameter class (feet)	Total tree height, in feet						
	50	60	70	80	90	100	110
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
10.....	9.5	11.5	12.5	15.0	17.5	19.5	-----
12.....	12.5	14.5	16.5	18.0	20.5	22.5	-----
14.....	15.0	17.0	19.0	23.5	25.0	27.5	30.5
16.....	17.5	20.5	24.0	27.5	30.5	33.0	36.0
18.....	-----	23.5	27.0	30.5	34.5	38.0	42.5
20.....	-----	28.0	33.5	36.0	40.0	45.5	49.0
22.....	-----	32.5	37.0	42.5	46.5	52.0	57.5
24.....	-----	37.0	42.5	48.5	54.5	60.0	66.0
26.....	-----	42.5	47.5	54.0	61.0	67.5	75.5
28.....	-----	-----	53.0	60.5	70.5	76.0	83.0
30.....	-----	-----	60.5	68.0	78.0	85.5	94.5

¹ Based on 342 trees in Arkansas, Louisiana, and Mississippi. Gross volumes are inside bark and include the merchantable stem to a variable top averaging 6 inches i.b. Reprinted from (4).

One of the several procedures for making aerial volume estimates is as follows:

1. Outline tract boundaries on the photographs, utilizing the effective area of every other print in each flight line. This assures stereoscopic

coverage of the area on a minimum number of photographs and avoids duplication of measurements.

2. Delineate all forest types. Except where type lines define stands of relatively uniform stocking and total height, they should be further broken down into homogeneous units so that measures of height, density, and crown diameter will apply to the entire unit. Generally it is unnecessary to recognize stands smaller than 5 to 10 acres.
3. Determine the acreage of each condition class with dot grids. This determination can often be made on contact prints.
4. By stereoscopic examination, measure the variables for entering the aerial stand volume table. From the table, obtain the average volume per acre for each condition class.
5. Multiply gross volumes per acre from the table by condition class areas to determine gross volume.
6. Add class volumes for the total gross volume on the tract.

A practical application is illustrated by the stereogram in figure 29 and the corresponding cordwood volume summary. In this particular inventory, hardwood components in each stand were ignored, and estimates were derived only for pine timber. The aerial cruise, fortified by fre-

TABLE 6.—*Aerial stand volume per acre values*¹ for even-aged Douglas-fir in the Pacific Northwest

Stand height ² (feet)	Crown closure percent ³								
	15	25	35	45	55	65	75	85	95
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
40.....	500	800	1,100	1,300	1,400	1,500	1,500	1,400	1,300
50.....	700	1,100	1,500	1,800	2,000	2,100	2,200	2,100	2,000
60.....	900	1,500	2,000	2,400	2,700	2,900	3,000	2,900	2,800
70.....	1,200	1,900	2,500	3,100	3,400	3,700	3,900	3,900	3,800
80.....	1,400	2,400	3,100	3,800	4,300	4,600	4,800	4,900	4,900
90.....	1,700	2,800	3,800	4,500	5,200	5,600	5,900	6,100	6,100
100.....	2,100	3,300	4,500	5,400	6,100	6,700	7,200	7,400	7,500
110.....	2,400	3,900	5,200	6,300	7,200	7,900	8,500	8,800	9,000
120.....	2,800	4,500	6,000	7,300	8,300	9,200	9,900	10,300	10,600
130.....	3,100	5,100	6,800	8,300	9,500	10,600	11,400	12,000	12,400
140.....	3,500	5,700	7,700	9,400	10,800	12,100	13,000	13,800	14,300
150.....	4,000	6,400	8,600	10,500	12,200	13,600	14,800	15,700	16,300
160.....	4,400	7,100	9,600	11,800	13,600	15,300	16,600	17,700	18,500
170.....	4,900	7,900	10,600	13,000	15,200	17,000	18,500	19,800	20,800
180.....	5,400	8,700	11,700	14,400	16,800	18,800	20,600	22,000	23,200
190.....	5,900	9,500	12,800	15,800	18,400	20,800	22,700	24,400	25,700
200.....	6,400	10,400	14,000	17,300	20,200	22,800	25,000	26,900	28,400
210.....	7,000	11,300	15,200	18,800	22,000	24,900	27,400	29,500	31,300
220.....	7,500	12,200	16,500	20,400	23,900	27,100	29,800	32,200	34,200
230.....	8,100	13,200	17,800	22,000	25,900	29,300	32,400	35,100	37,300
240.....	8,700	14,200	19,200	23,800	28,000	31,700	35,100	38,000	40,600
250.....	9,400	15,200	20,600	25,600	30,100	34,200	37,900	41,100	43,900
260.....	10,000	16,300	22,100	27,400	32,300	36,700	40,800	44,300	47,400

¹ Gross volume, in trees 5.0 inches and larger, from stump to top limit of 4.0 inches diameter inside bark. Reprinted from (15).

² Average height of dominants and codominants as measured in the field.

³ Average estimates of several experienced interpreters includes all trees in the major canopy (occasionally excludes small trees definitely below the general canopy).

TABLE 7.—*Aerial volume per acre for Rocky Mountain conifers*¹

4- TO 7-FOOT CROWN DIAMETER

Average stand height (feet)	Crown closure percent									
	5	15	25	35	45	55	65	75	85	95
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
30		100	300	450	550	650	750	850	1,000	1,150
35		200	400	550	650	750	850	1,000	1,200	1,400
40		300	500	650	750	850	1,000	1,150	1,400	1,650
45	50	400	600	750	850	950	1,100	1,300	1,550	1,800
50	100	500	700	850	1,000	1,150	1,350	1,600	1,850	2,100
55	200	600	850	1,050	1,200	1,400	1,600	1,850	2,100	2,350
60	350	800	1,100	1,350	1,600	1,800	2,000	2,250	2,500	2,750
65	500	1,050	1,400	1,700	1,950	2,150	2,350	2,550	2,800	3,050

8- TO 12-FOOT CROWN DIAMETER

30		150	350	500	600	700	800	950	1,200	1,350
35		250	450	600	750	850	950	1,100	1,300	1,500
40		350	550	700	850	950	1,050	1,250	1,500	1,750
45		400	650	800	950	1,100	1,250	1,450	1,700	1,950
50	100	500	700	950	1,100	1,250	1,450	1,700	1,950	2,150
55	300	700	900	1,100	1,300	1,500	1,750	2,000	2,225	2,500
60	450	900	1,200	1,500	1,750	1,950	2,150	2,350	2,550	2,650
65	700	1,200	1,600	1,900	2,100	2,300	2,500	2,700	2,900	3,100
70	900	1,600	2,000	2,300	2,500	2,700	2,850	3,000	3,200	3,300
75	1,200	2,000	2,400	2,700	2,850	3,000	3,200	3,400	3,600	3,800
80	1,700	2,500	2,800	3,100	3,300	3,450	3,600	3,800	4,000	4,200
85	2,200	3,000	3,300	3,550	3,750	3,950	4,150	4,350	4,550	4,750

13- TO 17-FOOT CROWN DIAMETER

30		200	400	550	700	800	900	1,050	1,200	1,350
35		300	500	700	800	900	1,050	1,200	1,500	1,700
40		400	600	800	900	1,000	1,250	1,450	1,700	1,950
45	100	500	700	850	1,000	1,150	1,350	1,600	1,850	2,100
50	200	600	850	1,000	1,150	1,350	1,600	1,850	2,100	2,350
55	300	750	1,000	1,250	1,500	1,700	1,900	2,150	2,350	2,550
60	500	1,000	1,300	1,600	1,850	2,050	2,250	2,450	2,650	2,850
65	750	1,300	1,700	2,000	2,200	2,400	2,600	2,800	3,000	3,200
70	1,000	1,700	2,100	2,400	2,600	2,750	2,900	3,100	3,300	3,500
75	1,300	2,100	2,500	2,750	2,950	3,150	3,300	3,500	3,700	3,900
80	1,800	2,600	2,900	3,200	3,400	3,600	3,750	3,900	4,100	4,300
85	2,300	3,100	3,450	3,700	3,900	4,050	4,200	4,400	4,600	4,800
90	2,800	3,600	3,900	4,150	4,350	4,500	4,650	4,850	5,050	5,250
95	3,300	4,100	4,400	4,600	4,800	5,000	5,200	5,400	5,600	5,800
100	3,700	4,500	4,850	5,150	5,350	5,550	5,750	5,950	6,150	6,350

18- TO 22-FOOT CROWN DIAMETER

30		300	500	700	800	900	1,050	1,200	1,400	1,600
35		400	650	800	900	1,050	1,200	1,400	1,600	1,800
40	100	500	750	900	1,050	1,200	1,400	1,600	1,800	2,000
45	200	600	850	1,050	1,200	1,400	1,600	1,800	2,000	2,200
50	350	750	1,000	1,200	1,400	1,600	1,800	2,050	2,250	2,450
55	450	850	1,150	1,400	1,650	1,900	2,100	2,300	2,500	2,700
60	650	1,150	1,500	1,800	2,050	2,250	2,450	2,650	2,850	3,050
65	850	1,500	1,900	2,200	2,400	2,600	2,750	2,900	3,100	3,300
70	1,100	1,900	2,300	2,550	2,750	2,900	3,100	3,300	3,500	3,700
75	1,600	2,400	2,700	2,950	3,100	3,250	3,450	3,650	3,850	4,050
80	1,950	2,750	3,050	3,300	3,500	3,700	3,900	4,100	4,300	4,500
85	2,500	3,300	3,600	3,850	4,050	4,250	4,400	4,550	4,750	4,950
90	2,900	3,700	4,050	4,300	4,500	4,700	4,850	5,050	5,300	5,500
95	3,400	4,200	4,500	4,800	5,000	5,200	5,400	5,600	5,800	6,000
100	3,900	4,700	5,000	5,300	5,500	5,700	5,900	6,100	6,300	6,500
105	4,600	5,400	5,800	6,000	6,200	6,400	6,550	6,700	6,850	7,050
110	5,200	6,000	6,400	6,600	6,800	7,000	7,200	7,400	7,600	7,800

TABLE 7.—*Aerial volume per acre for Rocky Mountain conifers*¹—Continued
23-FOOT AND LARGER CROWN DIAMETER

Average stand height (feet)	Crown closure percent									
	5	15	25	35	45	55	65	75	85	95
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
30.....	100	500	750	900	1,050	1,250	1,450	1,650	1,900	2,150
35.....	200	650	850	1,050	1,250	1,450	1,650	1,850	2,100	2,350
40.....	300	750	1,000	1,200	1,400	1,600	1,800	2,050	2,300	2,550
45.....	400	850	1,100	1,350	1,600	1,800	2,000	2,250	2,500	2,750
50.....	550	1,000	1,300	1,600	1,850	2,050	2,250	2,450	2,650	2,850
55.....	700	1,200	1,600	1,900	2,100	2,300	2,500	2,700	2,900	3,100
60.....	850	1,550	1,950	2,250	2,450	2,650	2,850	3,050	3,250	3,450
65.....	1,200	1,900	2,300	2,550	2,750	2,900	3,100	3,300	3,500	3,700
70.....	1,550	2,250	2,650	2,900	3,100	3,300	3,450	3,650	3,850	4,050
75.....	2,050	2,750	3,050	3,300	3,500	3,650	3,800	4,000	4,200	4,400
80.....	2,450	3,150	3,450	3,700	3,900	4,050	4,200	4,400	4,600	4,800
85.....	2,900	3,600	3,950	4,200	4,400	4,550	4,700	4,900	5,100	5,300
90.....	3,400	4,100	4,400	4,650	4,850	5,050	5,250	5,450	5,650	5,850
95.....	3,850	4,550	4,850	5,150	5,350	5,550	5,750	5,950	6,150	6,350
100.....	4,400	5,100	5,400	5,700	5,900	6,100	6,250	6,400	6,600	6,800
105.....	5,100	5,800	6,100	6,400	6,550	6,700	6,850	7,000	7,150	7,300
110.....	6,600	6,400	6,700	6,900	7,050	7,200	7,350	7,500	7,700	7,850
115.....	6,150	6,900	7,200	7,400	7,600	7,750	7,900	8,050	8,200	8,350

¹ Based on 168 field plots taken in southeastern Idaho, southwestern Wyoming, and northeastern Utah. Aggregate deviation: Table 1.5 percent low. Standard error of estimate: ± 48 percent of average plot volume. Reprinted from (11).

TABLE 8.—*Aerial volume per acre for Kentucky hardwoods*¹
10- TO 14-FOOT AVERAGE CROWN DIAMETER

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
30.....	300	375	450	475	500	570	635	700	770
40.....	350	425	500	550	600	650	700	750	800
50.....	400	475	550	625	700	770	835	900	970
60.....	550	675	800	875	950	1,035	1,115	1,200	1,285
70.....	900	1,075	1,250	1,325	1,400	1,470	1,535	1,600	1,670

15- TO 19-FOOT AVERAGE CROWN DIAMETER

30.....	350	400	450	500	550	620	685	750	820
40.....	400	450	500	575	650	720	785	850	920
50.....	450	525	600	675	750	835	920	1,000	1,085
60.....	600	725	850	950	1,050	1,100	1,150	1,200	1,250
70.....	1,000	1,150	1,300	1,400	1,500	1,550	1,600	1,650	1,700
80.....	1,500	1,625	1,750	1,825	1,900	1,970	2,035	2,100	2,170

20- TO 29-FOOT AVERAGE CROWN DIAMETER

40.....	500	625	750	850	950	1,035	1,115	1,200	1,285
50.....	600	750	900	1,000	1,100	1,185	1,270	1,350	1,435
60.....	900	1,050	1,200	1,275	1,350	1,420	1,485	1,550	1,620
70.....	1,350	1,475	1,600	1,675	1,750	1,820	1,885	1,950	2,020
80.....	1,750	1,900	2,050	2,125	2,200	2,270	2,335	2,400	2,470
90.....	2,220	2,360	2,500	2,575	2,650	2,720	2,785	2,850	2,920
100.....	2,700	2,850	3,000	3,075	3,150	3,200	3,250	3,300	3,350

TABLE 8.—*Aerial volume per acre for Kentucky hardwoods*¹—Continued
30-FOOT AND LARGER AVERAGE CROWN DIAMETER

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
40.....	850	1,025	1,200	1,275	1,350	1,420	1,485	1,550	1,620
50.....	1,050	1,200	1,350	1,425	1,500	1,570	1,635	1,700	1,770
60.....	1,300	1,450	1,600	1,650	1,700	1,785	1,870	1,950	2,035
70.....	1,700	1,850	2,000	2,075	2,150	2,220	2,285	2,350	2,420
80.....	2,150	2,275	2,400	2,500	2,600	2,670	2,735	2,800	2,870
90.....	2,600	2,725	2,850	2,925	3,000	3,070	3,135	3,200	3,270
100.....	3,050	3,175	3,300	3,375	3,450	3,500	3,550	3,600	3,650
110.....	3,600	3,700	3,800	3,875	3,950	4,020	4,085	4,150	4,220

¹ Gross volumes include the merchantable stems of all trees 5 inches d.b.h. and larger to a 4-inch top diameter i.b. Expanded from (14) by linear interpolation.

TABLE 9.—*Composite aerial volume per acre for northeast Mississippi*¹
10-FOOT AVERAGE CROWN DIAMETER

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
30.....	190	310	430	560	690	810	940	1,060	1,180
40.....	230	380	530	690	840	990	1,140	1,300	1,450
50.....	260	440	620	800	980	1,150	1,330	1,510	1,680
60.....	300	500	690	890	1,090	1,290	1,490	1,680	1,880
70.....	340	570	800	1,030	1,260	1,490	1,720	1,950	2,180
80.....	380	640	890	1,140	1,400	1,650	1,910	2,160	2,420

15-FOOT AVERAGE CROWN DIAMETER

30.....	210	350	500	640	780	930	1,070	1,220	1,360
40.....	260	430	610	780	950	1,130	1,300	1,480	1,650
50.....	310	510	730	930	1,140	1,350	1,550	1,770	1,970
60.....	360	590	830	1,070	1,300	1,550	1,780	2,030	2,260
70.....	400	660	940	1,200	1,460	1,740	2,000	2,280	2,540
80.....	440	740	1,040	1,330	1,620	1,930	2,220	2,530	2,820
90.....	480	800	1,140	1,450	1,770	2,100	2,420	2,760	3,070

20-FOOT AVERAGE CROWN DIAMETER

40.....	270	450	630	820	1,000	1,190	1,370	1,550	1,720
50.....	320	540	750	970	1,190	1,410	1,630	1,840	2,040
60.....	360	610	860	1,110	1,360	1,600	1,850	2,100	2,330
70.....	410	680	960	1,240	1,520	1,800	2,080	2,360	2,610
80.....	450	760	1,070	1,380	1,690	2,000	2,310	2,620	2,900
90.....	500	840	1,190	1,530	1,870	2,220	2,560	2,900	3,220
100.....	540	920	1,290	1,670	2,040	2,410	2,790	3,160	3,500

25-FOOT AVERAGE CROWN DIAMETER

50.....	320	550	770	1,000	1,220	1,450	1,670	1,900	2,120
60.....	370	620	880	1,130	1,390	1,650	1,900	2,160	2,410
70.....	410	700	980	1,270	1,550	1,840	2,130	2,410	2,700
80.....	460	780	1,100	1,420	1,740	2,060	2,380	2,700	3,020
90.....	510	860	1,220	1,570	1,930	2,280	2,640	2,990	3,350
100.....	550	940	1,320	1,710	2,090	2,480	2,860	3,250	3,630

¹ Gross volumes are inside bark and include the merchantable stem to a variable top not smaller than 3 inches i.b. Reprinted from (3).

TABLE 10.—Composite aerial volume per acre ¹ for northern Minnesota ²

Average total height (feet)	Crown closure percent									
	5	15	25	35	45	55	65	75	85	95
	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
30.....	40	120	200	280	360	440	520	600	680	760
35.....	80	190	300	410	520	630	740	850	960	1,070
40.....	180	310	440	570	700	830	960	1,090	1,220	1,350
45.....	460	590	720	850	980	1,110	1,240	1,370	1,500	1,630
50.....	740	870	1,000	1,130	1,260	1,390	1,520	1,650	1,780	1,910
55.....	1,020	1,150	1,280	1,410	1,540	1,670	1,800	1,930	2,060	2,190
60.....	1,300	1,430	1,560	1,690	1,820	1,950	2,080	2,210	2,340	2,470
65.....	1,580	1,710	1,840	1,970	2,100	2,230	2,360	2,490	2,620	2,750
70.....	1,860	1,990	2,120	2,250	2,380	2,510	2,640	2,770	2,900	3,030
75.....	2,140	2,270	2,400	2,530	2,660	2,790	2,920	3,050	3,180	3,310
80.....	2,420	2,550	2,680	2,810	2,940	3,070	3,200	3,330	3,460	3,590
85.....	2,700	2,830	2,960	3,090	3,220	3,350	3,480	3,610	3,740	3,870
90.....	2,980	3,110	3,240	3,370	3,500	3,630	3,760	3,890	4,020	4,150
95.....	3,260	3,390	3,520	3,650	3,780	3,910	4,040	4,170	4,300	4,430
100.....	3,540	3,670	3,800	3,930	4,060	4,190	4,320	4,450	4,580	4,710

¹ Gross volumes are inside bark and include all trees 5.0 inches d.b.h. and larger from stump to a variable top diameter not less than 4.0 inches i.b. Volumes may be converted to rough cords per acre by dividing by 80.

² Based on 50 1-acre plots in Carlton County, Minn. Heavy lines indicate limits of basic data. Reprinted from (5).

quent field checks, was within 10 percent of a ground inventory made by an independent agency.

Adjusting volumes by field checks.—When aerial volume tables are not sufficiently reliable for acceptance of pure photographic estimates and allowance must be made for defective trees, some of the plots interpreted should be mechanically selected for field measurement. For example, if 350 plots were interpreted and every 10th plot selected, 35 plots would be visited in the field. If the field volumes averaged 600 cubic feet per acre as opposed to 800 cubic feet per acre for the photo plots, the adjustment ratio would be $600 \div 800$ or 0.75. If the 35 field plots are representative of the total, the ratio can be applied to the average photo volume per acre to determine the adjusted volume. Ratios should be computed by forest types, because hardwoods are likely to require larger adjustments than conifers.

The accuracy of aerial cruises depends not only upon the volume tables but also on the availability of recent photographs and the interpreter's ability to measure correctly. This last item may be the greatest single source of error. Each photo variable should be measured twice for an average, or two interpreters should assess each plot.

Photo estimates of pine cordwood volumes for a tract in the Georgia Piedmont ¹

County: Oconee

Photo No.: BQ-3BB-85, 86

Owner: J. Reynolds

Photo date: 11-1-60

Pine area: 177 acres

Scale: 1,667 ft./inch

Pine stand ²	Stand area	Total height	Crown diameter	Crown closure	Pine volumes per acre		Stand volume
	Acres	Feet	Feet	Per-cent	Cubic feet	Cords	Cords
1-----	18	40	10	25	380	4.75	85.5
2-----	29	30	10	5	60	.75	21.8
3-----	11	30	10	5	60	.75	8.3
4-----	18	40	15	35	610	7.62	137.2
5-----	5	30	10	15	190	2.37	11.8
6-----	11	40	15	35	610	7.62	83.8
7-----	9	30	10	65	810	10.12	91.1
8-----	17	40	15	15	260	3.25	55.2
9-----	20	50	15	15	310	3.87	77.4
10-----	27	40	15	25	430	5.37	145.0
11-----	12	30	10	15	190	2.37	28.4

Total pine volume (cords)..... 745.5

¹ Cubic volumes derived from table 9 and divided by 80 for conversion to cords.

² Stands are numbered as in figure 29.

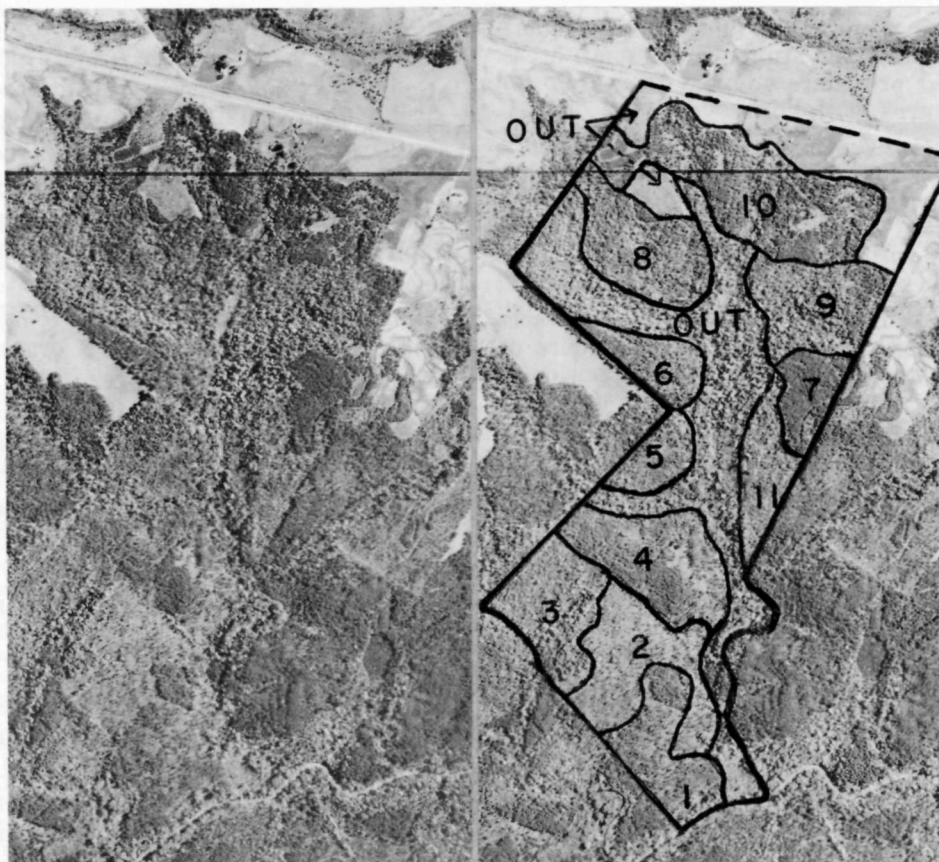


Figure 29.—USDA panchromatic stereogram of a forest area in the Georgia Piedmont. Area and pine volume estimates were made for each of the stands numbered. Scale is about 1,667 feet per inch.

PHOTO STRATIFICATION FOR GROUND CRUISING

A photo-controlled ground cruise combines the features of both aerial and ground estimating, offering a means of obtaining timber volumes with maximum efficiency. Photographs are used for area determination, for allocation of field samples by forest type and stand-size classes, and for designing the pattern of field work. Tree volumes, growth, cull percents, form class, and other data are obtained on the ground by conventional methods. A photo-controlled cruise may increase the efficiency, while reducing the total cost, of an inventory on tracts as small as 100 acres.

The approach to an inventory of this kind depends largely on the types of strata recognized and the method of allocating field samples. Cost and the statistical accuracy required determines the total number of field samples to be measured. Once this number has been determined, there are several ways in which the samples may be distributed among various photo classifications:

1. By area of each class. Though sometimes used, this method is often unsatisfactory because stands of low value may occupy the greatest acreage while high-value stands may be insufficiently sampled. The opposite extreme may result if value alone (volume-per-acre classes) is used.
2. By applying different cruising intensities to each class. A 20-percent cruise might be used for high-value stands, 10 percent for medium value, and 5 percent or less for low-value areas. This arbitrary method is better than using acreage alone, but it may not be the most economical and efficient.
3. By statistical methods. A preliminary cruise or a good estimate of the variability within each class must be made before the required number of plots per class can be computed. This approach is best for large tracts; for small ones it may be costly or unwieldy.

4. By a combination of area and value (volume). This is the preferred approach for small areas. A suggested procedure adopted from Johnson (6) and Spurr (18) follows.

Plot allocation by area and volume.—Assume that the tract is 1,600 acres and that 400 field plots are to be distributed among three forest types (pine, pine-hardwood, and hardwood) and three volume classes within each type (5, 8, and 12 cords per acre).

1. Stratify each forest type into volume-per-acre classes on the basis of personal experience or with aerial stand-volume tables. Precision is not required, as the volume classes are used only as a guide. Tabulate by type and acreage:

Cords per acre	Pine (acres)	Pine- hardwood (acres)	Hardwood (acres)
5-----	120	200	100
8-----	100	500	350
12-----	80	100	50
Total-----	300	800	500

2. Multiply the number of acres in each class by the cord volume per acre. The product is the number of cords per class:

Pine	Pine-hardwood	Hardwood
5×120= 600	5×200=1,000	5×100= 500
8×100= 800	8×500=4,000	8×350=2,800
12× 80= 960	12×100=1,200	12× 50= 600
2,360	6,200	3,900

3. Add the cordage in each class to get the total for the entire area: 2,360+6,200+3,900=12,460 cords. Divide by the number of plots to get the number of cords to be represented by each plot:

$$\frac{12,460}{400} = 31.15 \text{ cords per plot}$$

4. Divide the volume for each class (item 2) by the cord volume per plot to get the number of plots assigned to each class. Round to the nearest whole number. Add the plots for each class to make sure the total (400) is correct.

Pine	Pine-hardwood	Hardwood
$\frac{600}{31.15} = 19.26(19)$	$\frac{1,000}{31.15} = 32.10 (32)$	$\frac{500}{31.15} = 16.05(16)$
$\frac{800}{31.15} = 25.68(26)$	$\frac{4,000}{31.15} = 128.41(128)$	$\frac{2,800}{31.15} = 89.88(90)$
$\frac{960}{31.15} = 30.82(31)$	$\frac{1,200}{31.15} = 38.52 (39)$	$\frac{600}{31.15} = 19.26(19)$
(76)	(199)	(125)
Total: 400 plots		

Arrangement of ground samples.—If type boundaries have been accurately delineated and stands are homogeneous within the recognized classes, field plots can sometimes be taken along routes of easy travel without introducing much bias. Usually, though, it is necessary to lay out line-plot or strip cruises at right angles to topography. The cruise lines should be drawn to scale on a type map in such a way that the required number of samples within each class can be obtained. The number of plots or chains of strip that a crew can complete per day is the basis for calculating the lengths of the lines. To minimize travel, lines may be triangular or U-shaped, beginning and ending near the same starting point on a road or trail. Compass bearings and distances can be determined on the map to avoid location bias in the field. The cruise lines can then be placed on the photographs for use in the field, if desired.

Field measurements are taken by conventional procedures. Cumulative tally sheets or point-sampling may be employed to speed the tree tally. After the cordage per acre for each volume class has been determined by field sampling, the values are multiplied by the appropriate stand acreages. The result is the total volume on the tract, by forest types:

Assumed volume class (cords per acre)	Field plots (number)	Field volumes per acre (cords)	Type area (acres)	Volume per class (cords)
PINE TYPE				
5-----	19	3.9	120	468.0
8-----	26	8.2	100	820.0
12-----	31	11.3	80	904.0
Total-----	76		300	2,192.0

PINE-HARDWOOD TYPE				
5-----	32	5.8	200	1,160.0
8-----	128	7.7	500	3,850.0
12-----	39	14.1	100	1,410.0
Total-----	199		800	6,420.0

HARDWOOD TYPE				
5-----	16	4.7	100	470.0
8-----	90	8.6	350	3,010.0
12-----	19	13.5	50	675.0
Total-----	125		500	4,155.0

LITERATURE CITED

1. American Society of Photogrammetry.
1952. Manual of photogrammetry. Ed. 2, 876 p., illus.
Manasha, Wis.: Banta.
2. American Society of Photogrammetry.
1960. Manual of photographic interpretation. 868 p.,
illus. Menasha, Wis.: Banta.
3. Avery, T. Eugene.
1958. Composite aerial volume table for southern
pines and hardwoods. J. For. 56: 741-745, illus.
4. Avery, T. Eugene.
1962. Interpretation of aerial photographs. 192 p.,
illus. Minneapolis, Minn.: Burgess.
5. Avery, T. Eugene and Meyer, Merle P.
1959. Volume tables for aerial timber estimating in
northern Minnesota. U.S. Dep. Agri. For. Serv.
Lake States For. Exp. Stn. Stn. Pap. 78, 21 p., illus.
6. Johnson, Evert W.
1952. Timber volume determinations using aerial
photographs. Ala. Polytech. Inst., 43 p. illus.
7. Johnson, Evert W.
1954. Ground control for planimetric base maps. J.
For. 52: 89-95, illus.
8. Johnson, Evert W.
1954. "Shadow-height" computations made easier.
J. For. 52: 438-442, illus.
9. Kramer, P. R., and Sturgeon, E. E.
1942. Transect method of estimating forest area
from aerial photo index sheets. J. For. 40: 693-
696, illus.
10. Minor, C. O.
1951. Stem-crown diameter relations in southern
pine. J. For. 49: 490-493, illus.
11. Moessner, Karl E.
1957. Preliminary aerial volume tables for conifer
stands in the Rocky Mountains. U.S. Dep. Agric.
For. Serv. Intermountain Forest and Range Exp.
Stn. Res. Pap. 41, 17 p. illus.
12. Moessner, Karl E.
1957. How important is relief in area estimates
from dot sampling on aerial photos? U.S. Dep.
Agric. For. Serv. Intermountain Forest and Range
Exp. Stn. Res. Pap. 42, 16 p., illus.
13. Moessner, Karl E. and Jensen, C. E.
1951. Timber cruising on aerial photos. U.S. For.
Serv. Central States For. Dep. Agric. Exp. Stn.
Tech. Pap. 126, 27 p., illus.
14. Moessner, Karl E., D. F. Brunson, and C. E. Jensen.
1951. Aerial volume tables for hardwood stands in
the Central States. U.S. Dep. Agric. For. Serv.
Central States For. Exp. Stn. Tech. Pap. 122, 15 p.,
illus.
15. Pope, Robert B.
1962. Constructing aerial photo volume tables. U.S.
Dep. Agric. For. Serv. Pacific Northwest Forest
and Range Exp. Stn. Res. Pap. 49, 25 p., illus.
16. Sayn-Wittgenstein, Leo.
1961. Recognition of tree species on air photographs
by crown characteristics. Photogrammetric
Engin. 27: 792-809, illus.
17. Society of American Foresters.
1955. Forestry handbook. 23 sects., illus. N.Y.:
Ronald Press.
18. Spur, S. H.
1948. Aerial photographs in forestry. 340 p., illus.
N.Y.: Ronald Press.
19. Wilson, R. C.
1949. The relief displacement factor in forest area
estimates by dot templates on aerial photographs.
Photogramm. Eng. 15: 225-236, illus.
20. Zsilinszky, Victor, G.
1963. Photographic interpretation of tree species in
Ontario. Ontario Dep. Lands and Forests, 80 p.,
illus.

SELECTED ADDITIONAL REFERENCES

- Aldred, A. H., and J. K. Hall.
1975. Application of large-scale photography to a forest
inventory. For. Chron. 51(1): 1-7, illus.
- Aldred, A. H., and L. Sayn-Wittgenstein.
1972. Tree diameters and volumes from large-scale
aerial photographs. Canadian Forest Service, Ottawa.
Inf. Rep. FMR-X-40, 39 p., illus.
- Aldrich, Robert C.
1971. Space photos for land use and forestry. Photo-
gramm. Eng. 37: 389-401, illus.
- Avery, T. Eugene.
1977. Interpretation of aerial photographs. 3rd. ed. 392
p., illus. Burgess Publishing Company, Minneapolis,
Minn.
- Avery, T. Eugene.
1970. Photo-interpretation for land managers. Eastman
Kodak Company, Rochester, N.Y. Publication M-76,
26 p., illus.
- Bonner, G. M.
1968. A comparison of photo and ground measurements
of canopy density. For. Chron. 44(3): 12-16, illus.
- Ciesla, W. M.
1974. Forest insect damage from high-altitude color-IR
photos. Photogramm. Eng. 40: 683-689, illus.
- deSteiguer, J. E.
1978. Forestry applications of NASA remote sensing
programs. J. For. 76: 208-211, illus.
- Dodge, Arthur G., Jr. and Emily S. Bryant.
1976. Forest type mapping with satellite data. J. For.
74: 526-531, illus.
- Heller, Robert C. (tech. coord.)
1975. Evaluation of ERTS-1 data for forest and range-
land surveys. USDA For. Serv. Res. Pap. PSW-112,
67 p. Pacific Southwest Forest and Range Exp. Stn.,
Berkeley, Calif.
- Heller, Robert C. (tech. coord.)
1971. Detection and characterization of stress symp-
toms in forest vegetation. Proceedings of the Inter-
national Workshop on Earth Resource Survey Sys-
tems. Government Printing Office, Washington, D.C.,
p. 109-50, illus.
- Hitchcock, Harry C., III.
1974. Constructing an aerial volume table from existing
tariff tables. J. For. 72: 148-49, illus.
- Johnson, E. W., and L. R. Sellman.
1974. Forest cover photo-interpretation key for the
Piedmont habitat region in Alabama. For. Dep. Series
6. 51 p., illus. Auburn University, Auburn, Ala.
- Kippen, F. W., and L. Sayn-Wittgenstein.
1964. Tree measurements on large-scale, vertical 70-mm
air photographs. Pub. 1053, 16 p., illus. For. Res. Br.,
Can. Dep. For.
- Lanly, J. P.
1973. Manual of forest inventory, with special reference
to mixed tropical forests. 200 p., illus. Food and Agri-
culture Organization of the United Nations, Rome.
- Madill, R. J. and A. H. Aldred.
1977. Forest resource mapping in Canada. The Can.
Surv. (March) 9-20 p., illus.
- Meyer, M. P., and D. W. French.
1967. Detection of diseased trees. Photogramm. Eng. 33:
1035-40, illus.
- Reeves, Robert G., ed.
1975. Manual of Remote Sensing, 2 Vols. 2,144 p., illus.
Am. Soc. Photogramm., Falls Church, Va.



Figure 1.—An aerial stereo-pair, from 9- by 9-inch contact prints. Note that the print showing the time of day is the last one in the flight line. The principal point (PP) of one photo coincides with the conjugate principal point (CPP) on the overlapping print. The flight path of the aircraft is indicated by the lines connecting the PP and CPP.

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USGS-NPS National Vegetation Mapping Program: Sunset Crater Volcano National Monument, Arizona, Vegetation Classification and Distribution

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LIST OF ABBREVIATIONS AND TERMS

AA	Accuracy Assessment
ABI	Association for Biodiversity Information (offshoot from TNC)
AML	Arc Macro Language
BOR	Bureau of Reclamation (Also USBR)
BRD	Biological Resource Discipline of the USGS
CBI	Center for Biological Informatics of the USGS/BRD
CIR	Color Infra-Red photography
CPRS	Colorado Plateau Research Station of the USGS/BRD
DEM	Digital Elevation Model
DLG	Digital Line Graph
DOQQ	Digital Orthophoto Quarter Quad(s)
DRG	Digital Raster Graphic
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System(s)
GPS	Global Positioning System
MMU	Minimum mapping unit
NAD	North American Datum
NBII	National Biological Information Infrastructure
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NVCS	National Vegetation Classification Standard
OHV	Off-Highway Vehicle
PLGR	Precision Lightweight GPS Receiver
RSGIG	Remote Sensing and Geographic Information Group of the Bureau of Reclamation
SBSC	Southwest Biological Science Center of the USGS
SUCR	Sunset Crater Volcano National Monument
TES	Terrestrial Ecosystem Survey
TNC	The Nature Conservancy
USBR	United States Bureau of Reclamation
USDA-FS	United States Dept. of Agriculture – Forest Service
USDA-SCS	United States Dept. of Agriculture – Soil Conservation Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VMP	Vegetation Mapping Program

SUMMARY

Sunset Crater Volcano National Monument (SUCR) Vegetation Mapping Project was initiated in the spring of 1999 as part of and in accordance with the U.S. Geological Survey-National Park Service (USGS-NPS) Vegetation Mapping Program and was completed in the spring of 2004. The Vegetation Mapping Program is administered jointly by the Center for Biological Informatics (CBI), Biological Resources Discipline (BRD) of the USGS, Denver, Colorado, and was initiated as part of the NPS Inventory & Monitoring Program. The primary goal of the Vegetation Mapping Program is to classify, describe, and map vegetation for approximately 250 NPS units.

This mapping project was performed by the following organizations under contract to the CBI:

- The Remote Sensing and GIS Group (RSGIG), Technical Service Center, Bureau of Reclamation (BOR), Department of Interior, Denver, Colorado
- The Colorado Plateau Research Station (CPRS), Southwest Biological Science Center (SBSC), USGS, Flagstaff, Arizona
- NatureServe, Boulder, Colorado

Sixteen vegetation map classes with five modifiers, three land cover map classes, and six Anderson Level II land-use map classes were used for interpretation of approximately 18,750 acres encompassing the monument (~3,040 acres) and surrounding environs (15,710 acres). Vegetation map classes were determined through extensive field reconnaissance, data collection, and analysis in accordance with the National Vegetation Classification Standard (NVCS). The vegetation map was created from photographic interpretation of 1996, 1:12,000 scale color infrared aerial photographs (0.5 hectare minimum mapping unit). All vegetation and land-use information was then transferred to a GIS database using the latest grayscale USGS digital orthophoto quarter-quads (DOQQs) as the base map and a combination of on-screen digitizing and scanning techniques. Overall thematic map accuracy for the entire mapping effort was assessed at 70.3% using the acceptable error criteria with a Kappa Index of 68.0%. The overall 90% confidence interval is 69.0% to 84.0%.

Final products are presented in this report and on the accompanying CD-ROM (Appendix A).

- Vegetation Classification Descriptions
- Land-use Classification System
- Vegetation Classification Key
- Digital and Hard Copy Vegetation Map
- Digital Project Boundaries
- Digital Field Points Coverage (Observation, Classification, Accuracy Assessment)
- Photos of Field Sites
- Accuracy Assessment Results
- FGDC-compliant Metadata

SUCR and similar National Park vegetation mapping databases can be accessed at the USGS-NPS website: <http://biology.usgs.gov/npsveg>.

1. INTRODUCTION

The Vegetation Mapping component of the NPS Inventory and Monitoring Program is a cooperative effort by the U.S. Geological Survey (USGS) and the National Park Service (NPS) to classify, describe, and map vegetation communities in more than 270 national park units across the United States.

The vegetation mapping efforts are an important part of the NPS Inventory and Monitoring Program, a long-term effort to develop baseline data for all national park units that have a natural resource component. Project activities are based on peer-reviewed, objective science. Comprehensive vegetation information is provided at national and regional levels, while also serving local management needs of individual parks. Stringent quality control procedures ensure that products are accurate and consistent for initial inventory purposes and replicable for monitoring purposes. The spatially enabled digital products produced by these efforts are available on the World Wide Web (<http://biology.usgs.gov/npsveg>).

The goals of these vegetation mapping projects are to provide comprehensive mapping of NPS vegetation resources that:

1. Is highly accurate
2. Meets scientific and FGDC standards
3. Has a nationally consistent, hierarchical, classification scheme
4. Has a level of detail useful to park management
5. Uses existing data when appropriate

This report details the park vegetation mapping study for Sunset Crater Volcano National Monument (SUCR) under the USGS-NPS Vegetation Mapping Program. The vegetation study for SUCR includes these components:

1. Collection and analysis of vegetation data
2. Creation of vegetation and mapping classifications based on the National Vegetation Classification Standard (NVCS)
3. Development of a spatial database of the SUCR vegetation using aerial photography and Geographic Information System (GIS) techniques
4. Production of final products including digital and hard copy vegetation maps, assessed to be at least 80% accurate

Because producing an accurate, detailed, digitized vegetation map is a complicated undertaking, several government agencies and private organizations were involved in the project's successful completion.

The Remote Sensing and Geographic Information Group (RSGIG), United States Bureau of Reclamation (USBR), Denver Federal Center, Lakewood, Colorado¹:

¹ The Remote Sensing and Geographic Information Group, organized in 1975, provides assistance and advice regarding the application of remote sensing and geographic information systems (GIS) technologies to meet the spatial information

1) attended planning meetings, 2) conducted aerial photosignature field review and observation point data collection, 3) provided aerial photointerpretation, 4) attended a vegetation classification map class development meeting, 5) created the GIS vegetation database and 6) provided support and content for the final report.

The Southwest Biological Science Center (SBSC), Colorado Plateau Research Station (CPRS), USGS-BRD, Flagstaff, Arizona¹ 1) attended planning meetings, 2) conducted field data collection and analysis, 3) provided data analysis and classification, 4) prepared the vegetation classification key and descriptions, 5) provided accuracy assessment data collection and analysis, 6) conducted the vegetation map accuracy assessment, and 7) prepared the final project report.

NatureServe's Western Regional Office in Boulder, Colorado² provided a review of CPRS vegetation data analyses and CPRS local vegetation descriptions as well as prepared global descriptions for the vegetation associations determined at SUCR.

¹ The Colorado Plateau Research Station is one of four research stations within the Southwest Biological Science Center. This research station was originally established in 1989 as a National Park Service Cooperative Park Studies Unit at Northern Arizona University in Flagstaff and was merged into the USGS Biological Resources Discipline in 1996. Major categories of research include ecoregional studies and conservation planning; endangered species studies; vegetation distribution, ecology, and dynamics; data management and dissemination; inventory and monitoring studies; and wildlife ecology.

² NatureServe has its roots in The Nature Conservancy (TNC), which in 1974 began establishing and supporting state natural heritage programs. By 1994 the natural heritage programs expanded significantly and The Nature Conservancy established a new network, the Association for Biodiversity Information. Now known as NatureServe, it has assumed in managing the National Vegetation Classification (NVC) and providing scientific and technical support to the network. The NatureServe network now includes 74 independent natural heritage programs and conservation data centers across the Western Hemisphere.

2. PROJECT AREA

Sunset Crater Volcano National Monument (SUCR) was authorized by Congress and the proclamation was signed by President Herbert Hoover in 1930. This 3,040-acre unit features the geologically young and approximately 8,029 ft (2,447 m) high Sunset Crater cinder cone (NPS 1997). SUCR lies approximately 13 miles northeast of Flagstaff, Arizona and is reached via U.S. Highway 89 north of Flagstaff (Figure 1). The monument is best known for extensive geologic processes and exposures relating to volcanism (i.e., cinder cones, cinder beds, and lava flows). Recreational and educational activities include hiking, scenic drives and vistas, wildlife viewing, visitor natural history education, and research opportunities. In addition to the monument, a buffer or environs of approximately 15,710 acres (6,360 hectares) of surrounding USDA Forest Service (USDA-FS) lands and privately owned residential land is also included in the project. The total project area is 18,750 acres (7,590 hectares) (Figure 2).



Figure 1. Location of Sunset Crater Volcano National Monument.

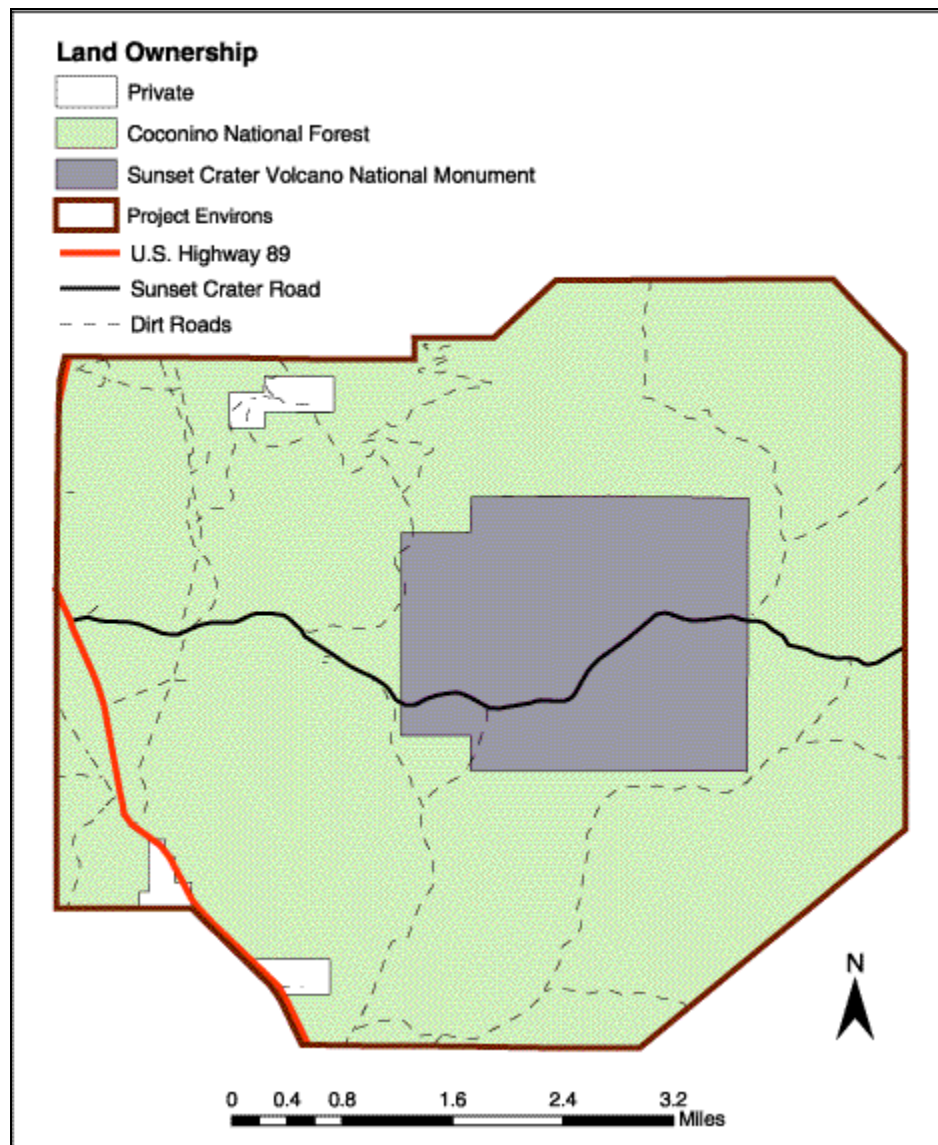


Figure 2. SUCR project boundaries and land ownership.

Location and regional setting

SUCR is situated on the southwestern Colorado Plateau of north-central Arizona, within the San Francisco Peaks Volcanic Field (Cordasco et al. 1998, Zion Natural History Association 1985). It is bounded on the north by O’Leary Peak, Robinson Mountain, Darton Dome, and Black Mountain; to the south by Lenox Crater, Little Cinder Basin, and Double Crater; on the east by Kana-a Wash; and on the west by Bonito Park and U S Highway 89. Access is provided by U.S. Highway 89, as well as county roads and USDA-FS roads through the adjacent Coconino National Forest. The NPS Visitor Center is on USDA-FS managed land just west of the monument at the edge of Bonito Park, and a Visitor Contact Station is maintained at the Bonito Lava Flow inside SUCR. A number of hiking trails and scenic overlooks are maintained in the monument and adjacent project area for visitor access and include the Lava Flow Nature Trail, Lenox Crater Trail, Bonito Park Overlook, Cinder Hills Overlook, and Painted Desert Vista.

Climate

SUCR has a semi-arid, continental climate that includes moderately hot, moist summers and cold, dry winters (Appendix B). Precipitation events, often in the form of violent thunderstorms, occur from July through September. For example, during 1997, NOAA records show that 45% of the annual 20 inches of precipitation fell during this three-month period (Cordasco et al. 1998, NOAA 1997). Summer maximum temperatures range between 80-95 degrees F., while winter minimum temperatures may reach down to -25 degrees F. The prevailing winds are southwesterly.

Geology and topography

SUCR lies near the northeastern edge of the San Francisco volcanic field, which covers approximately 1,800 square miles of the southern Colorado Plateau in north-central Arizona (Priest et al. 2001). The volcanic field, whose major feature is the 12,600 foot high San Francisco Peaks, formed during the latter part of the Cenozoic era. Lava flows, cinders, tuffs, and other volcanic units are well exposed throughout the monument (NPS 1997 and Zion Natural History Association 1985). The monument's namesake landform, Sunset Crater (Figure 3), a cinder cone, is a relatively recent landscape feature that formed during an eruption period that began sometime between 1040 and 1100 A.D. (Ort et al. 2002). This period of activity, was short-lived from a period of days to years, blanketed much of the surrounding area in a thick bed of cinders and produced two contemporaneous lava flows, the Kana-a and the Bonito flow (Ort et al. 2002) (Figure 4).



Figure 3. Sunset Crater cinder cone (foreground) and San Francisco Peaks (background).



Figure 4. Bonito Lava Flow inside Sunset Crater Volcano National Monument.

The volcanic units comprising the San Francisco Peaks Volcanic Field overlie a sequence of ancient, sedimentary rock formations. These Precambrian and Paleozoic strata are the same or similar units seen in the Grand Canyon to the northwest (Chronic 1988). Many of the sedimentary rocks underlying the region formed in a number of environments associated with an ancient sea. Sandstones formed as outwash deposited on low-lying plains or as remnants of ancient sand dunes, and shales and limestones formed as the region was periodically submerged under a transgressing sea (Zion Natural History Association 1985). Subsequent uplift of this massive sequence of rocks promoted erosion that later exposed several of these older sedimentary units. These are most readily seen in the Painted Desert to the north and east of SUCR, but also can be seen in other localities to the west and south.

The SUCR landscape contains outcrops and slopes of both basalt and more silicic rocks, exposed beds of volcanic tuff, some with high iron concentrations, aa lava flows, and cinder hills and beds ranging from black to reddish brown in color (Figure 5). Because of northern Arizona's relatively cool dry climate, Sunset Crater and other volcanic features of the monument have not weathered significantly since their formation. The porous nature of the cinders resists furrowing by runoff. However, lichens now cover much of the lava, and areas of vegetation occur in pockets where humus has built up from wind-blown pine needles, cinders, and decayed plant matter.



Figure 5. Black cinder beds and adjacent cinder cone, Lenox Crater, among ponderosa pine trees and apache plume shrubs.

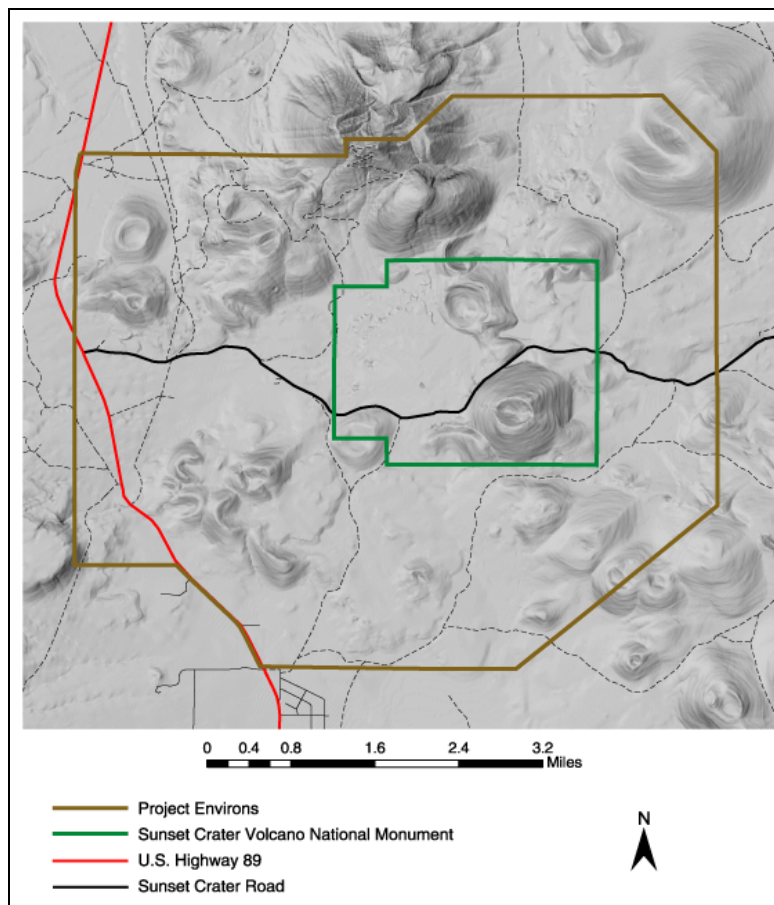


Figure 6. Shaded relief map of the project area.

Topography of SUCR consists of steep peaks, rolling hills, slopes, broad flats, and small drainages (Figure 6). The elevations of several prominent landscape features are as follows: O'Leary Peak (2,355m/8,940ft), Darton Dome (2,560m/8,410ft), Black Mountain (2300m/7,555ft), Robinson Mountain (2,400m/7,911ft), Sunset Crater (2,450m/8,039ft), and Lenox Crater (2,210m/7,250ft). Lower elevation flats include Kana-a Wash (2,040m/6,700ft), Bonito Park (2,100m/6,900ft), and just outside the monument boundary, Cinder Lake (2,010m/6,660ft). Though the cinders, lava flows, and cinder cone of Sunset Crater are the park's major features, other volcanic landforms are evident, in particular O'Leary Peak and Darton Dome, two steep-sided dacite domes along the park's northern boundary.

Wildlife

The ponderosa pine (*Pinus ponderosa*) woodland that covers much of SUCR strongly influences the fauna of the area. This is particularly true for the birds, with many of the most common and most conspicuous species at the monument being those typical of ponderosa pine woodlands. Such species include Lewis' Woodpecker (*Melanerpes lewis*), Steller's Jay (*Cyanocitta stelleri*), Mountain Chickadee (*Parus gambeli*), Pygmy Nuthatch (*Sitta pygmaea*), Yellow-rumped Warbler (*Dendroica coronata*), and Grace's Warbler (*Dendroica graciae*). Other common and frequently seen small birds in and around the monument include Williamson's Sapsucker (*Sphyrapicus thyroideus*), Pinyon Jay (*Gymnorhinus cyanocephalus*), Clark's Nutcracker (*Nucifraga columbiana*), Western Bluebird (*Sialia mexicana*), Western Tanager (*Piranga ludoviciana*), and Dark-eyed Junco (*Junco hyemalis*). Among larger birds, the most commonly seen species are Common Raven (*Corvus corax*), Turkey Vulture (*Cathartes aura*), and Red-tailed Hawk (*Buteo jamaicensis*). Occasional Golden Eagles (*Aquila chrysaetos*) may be seen at any time of year, and Bald Eagles (*Haliaeetus leucocephalus*) are present in small numbers during the winter.

The most conspicuous small mammal at the monument, the Abert's squirrel (*Sciurus aberti*), is also closely associated with ponderosa pine for both food and nest sites. Although not as frequently seen, porcupines (*Erethizon dorsatum*) are also fairly common and frequently found in ponderosa pine. Other common small mammals include desert cottontail (*Sylvilagus audubonii*), deer mouse (*Peromyscus maniculatus*), and pinyon mouse (*P. truei*). Among larger mammals, there are a variety of small and medium-sized carnivores in and around SUCR. Most frequently seen are coyotes (*Canis latrans*) and raccoons (*Procyon lotor*), particularly around the campground and housing area. The gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), striped skunk (*Mephitis mephitis*) and long-tailed weasel (*Mustela frenata*) are also present. Black bears (*Ursus americanus*) and mountain lions (*Felis concolor*) are both present at least occasionally, but are rarely seen. Among ungulates, mule deer (*Odocoileus hemionus*) are the most common native species at SUCR. Elk (*Cervus elaphus*) were not originally native to northern Arizona, but introduced animals have expanded into the area and small numbers are now seen seasonally. Herds of pronghorn (*Antilocapra americana*) occur in grasslands and one-seed juniper (*Juniperus monosperma*) savannas at lower elevations, and migrate seasonally to the vicinity of SUCR. Javelina (*Pecari tajacu*) are a new addition to the mammal list. This species has been expanding its range northward from southern and central Arizona, and individuals have recently been recorded within the monument boundaries.

The amphibian and reptile fauna at SUCR is depauperate, because of the relatively high elevation and dry conditions. No amphibian species have been positively documented at the monument, though there is an unconfirmed report of tiger salamander (*Ambystoma tigrinum*). The most conspicuous lizard species in and around the monument are the eastern fence lizard (*Sceloporus undulatus*) and tree lizard (*Urosaurus ornatus*). The greater short-horned lizard (*Phrynosoma hernandesi*) and plateau striped whiptail (*Cnemidophorus velox*) are also present, but are not as frequently seen. Only two snakes are known from the immediate area of the monument: the gopher snake (*Pituophis melanoleucus*) and the western rattlesnake (*Crotalus viridis*); although both are rare at this elevation.

Vegetation

Vegetation of SUCR and its environs is diverse, including nearly barren beds of cinder or lava and rock outcrops, to grassy meadows, open stands of trees with sparse understory shrublands, and dense forests on more moist aspects of the highest slopes, drainages, and ridges (Figure 7). SUCR is probably most noted for the sparsely vegetated cinder cones, lava beds, and lava rock outcrops. Most of these geologically dominated landform features consist of very sparse to no vegetation and cover approximately 20% of the project area.

Woodlands, which are open forest canopies, dominate the project area and occur on flats, slopes, hills, drainages, and ridges. The most common tree species in the project area is ponderosa pine (*Pinus ponderosa*). Ponderosa pine woodlands are typically found on cinder soils with little to no understory cover. Ponderosa pine may be present in nearly pure stands or may intermix with other coniferous trees common to the area, including Douglas-fir (*Pseudotsuga menziesii*), limber pine (*Pinus flexilis*), pinyon pine (*Pinus edulis*), and Utah juniper (*Juniperus osteosperma*). The second most common tree species is pinyon pine and often co-occurs with Utah juniper. Limber pines and Douglas-fir are confined to a mixed conifer zone on O'Leary Peak and Darton Dome. Small stands of quaking aspen (*Populus tremuloides*) are present throughout the project area. Quaking aspen grow along the edges of lava beds, within the lava beds, and in small stands on O'Leary Peak and Darton Dome, often adjacent to stands of Douglas-fir.

Shrublands occur mainly in small patches on rock outcrops, on sparse cinder slopes, in the openings of woodland canopies, and can co-dominate with grasses in open meadows. Shrublands are rarely observed without seedling or sapling trees present. The most widely distributed and common shrub is Apache plume (*Fallugia paradoxa*); it occurs on sparse cinder slopes and is also a common understory shrub. Other shrubs which dominate small stands or patches in lava outcrops, on scree, and rock outcrops include rabbitbrush (*Ericameria nauseosa*), three-leaved sumac (*Rhus trilobata*), ocean spray (*Holodiscus dumosus*), pericome (*Pericome caudata*), brickellbush (*Brickellia californica*), and wax currant (*Ribes cereum*).

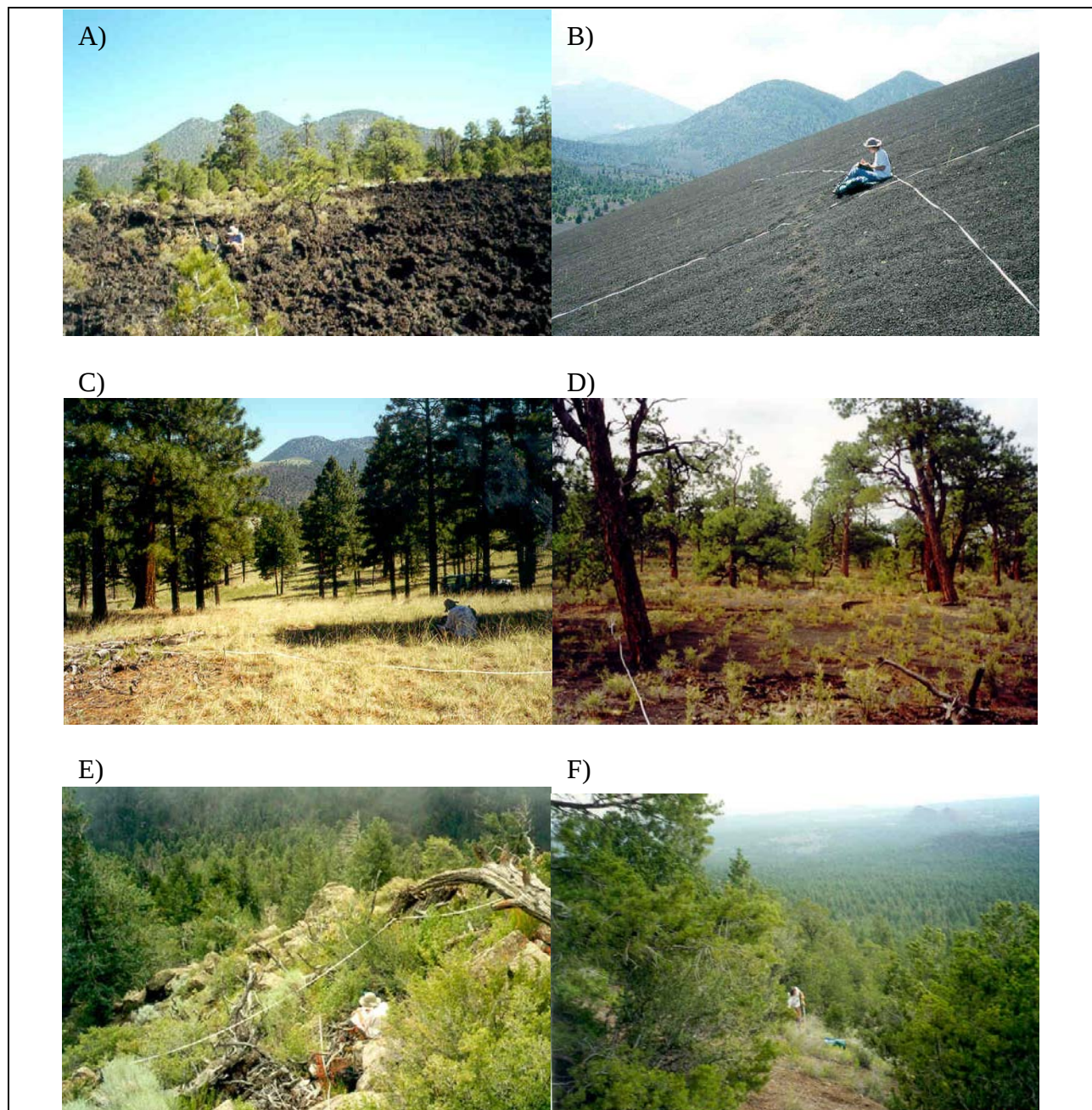


Figure 7. Vegetation typical of SUCR includes A) islands of vegetation in lava beds, B) sparsely vegetated cinder barrens, C) grassy meadows within surrounding woodlands, D) sparse shrub understory in open woodlands and E) and F) dense forests at higher elevations.

Grasses commonly occur as the understory in tree canopies, in smaller patches between tree canopies, as well as in more open meadow-like areas. Blue grama (*Bouteloua gracilis*) and mountain muhly (*Muhlenbergia montana*) are the dominant species in these grassland areas.

Blue grama is the most common grass species. It occurs in larger meadows or parks, such as Bonito Park (an open-grassland area west of SUCR that is co-managed by the USDA-FS) and often is in vegetation co-dominated by rabbitbrush (*Ericameria nauseosa*). Less common in the grassland patches are western wheatgrass (*Pascopyrum smithii*) and sand bluestem (*Andropogon hallii*). Sand bluestem is a bunchgrass that occurs mostly in sparse patches in the eastern section of the project area. Western wheatgrass is often used in re-seeding efforts (FEIS 2001) and is found mainly in the recently burned areas northwest of the monument. Disturbed areas also facilitate introduced annual grasses, particularly cheatgrass (*Bromus tectorum*), native forbs such as meadow-rue (*Thalictrum fendleri*) and Carruth's sagewort (*Artemisia caruthii*), and non-native species such as toadflax (*Linaria dalmatica ssp. dalmatica*) and mullein (*Verbascum thapsus*).

Land use

Various types of land use occur in the project area today; however, mapped land use (including transportation, communication, and utility areas; facilities; residential land; reservoirs and trick tanks; strip mines, quarries, and gravel pits; and croplands and pastures) covers less than 1% of the project area (480 acres). Historically pioneers altered the landscape for agricultural activities, resulting in remnant historic agricultural fields that are visible on the aerial photography.

Current land use includes access/recreational roads and trails, monument and USDA-FS facilities, pumice quarry sites, residences, and limited amounts of agricultural activity. Pumice is mined to incorporate into soap products and is also used in the stone-washed blue jean manufacturing process. U. S. Highway 89 was widened through the project area during the course of the study, resulting in land use changes that are not evident on the 1996 aerial photos used in this project.

South of the monument, off-highway vehicle (OHV) use on cinder beds is heavy, resulting in unsightly tracks, damage to, and in some cases elimination of, sparse vegetation, and introduction sites for exotic plant species including knapweed (*Centaurea* spp.). OHV tracks, as seen on the 1996 aerial photographs, were mapped. These tracks are constantly changing and it is likely that they will need to be re-evaluated for current extent of OHV use in and around the monument. Residential housing in the southern section of the project environs, specifically Lenox Park, has also increased since the 1996 aerial photography was acquired. A controlled burn also occurred in the project environs since 1996, possibly changing understory species composition and density as delineated in the photography.

3. METHODS

In mapping and classifying the vegetation of SUCR, we used the protocols and procedures established by the USGS/BRD (Appendix C) and described in *Field Methods for Vegetation Mapping, Standardized National Vegetation Classification System* (TNC and ERSI 1994a). The general work tasks were:

1. Project scoping and planning
2. Existing information review
3. Preliminary data collection
4. Aerial photography and base map acquisition
5. Sampling design development
6. Field data collection
7. Vegetation classification and characterization
8. Vegetation map preparation
9. Accuracy assessment

Project scoping and planning

SUCR vegetation mapping incorporated the combined expertise and oversight of several organizations: 1) oversight and programmatic considerations were managed by the Center for Biological Informatics (CBI) of the USGS/BRD, 2) NPS and SUCR personnel provided additional guidance on specific monument needs, 3) aerial photointerpretation and cartographic mapping were provided by the USBR/RSGIG, 4) the CPRS provided field data collection, data analysis, the plant association local descriptions and key, and accuracy assessment, and 5) NatureServe provided data analysis review and the global plant association descriptions. The specific technical responsibilities assigned to the cartographic and ecological teams are listed below:

RSGIG responsibilities and deliverables

1. Obtain existing color-infrared aerial photography from NPS
2. Collect photointerpretive observation point data to determine photosignatures, determine a preliminary classification, and familiarize interpreters with plant community characteristics and their range of variation
3. Prepare a preliminary photointerpretation to assist field data gathering efforts
4. Attend a meeting to determine final mapping classes, both vegetated and land use, to be used for the final photointerpretation
5. Interpret aerial photographs
6. Transfer interpreted information to a digital spatial database and produce hard copy (paper) vegetation maps
7. Create digital vegetation coverages including relevant attribute information
8. Conduct field verification of the accuracy of the draft vegetation map
9. Produce Arc/Info export file of photointerpretive observation point locations
10. Provide any ancillary digital files developed during the mapping process
11. Document FGDC compliant metadata files (Appendix A) for all created spatial data

12. Prepare materials for the final report describing procedures used in preparing products

CPRS responsibilities and deliverables

1. Develop a preliminary vegetation classification for the study area from existing data
2. Determine field data sampling locations and strategy
3. Collect field data to identify and describe plant associations in the project area
4. Analyze field data and prepare a final classification, local association descriptions, and a key to plant associations
5. Field test the final classification, descriptions, and plant association key
6. Collect accuracy assessment points, analyze them against the final photointerpretation and prepare statistics describing map accuracy
7. Produce Arc/Info export file of sampling locations, vegetation relevé and accuracy assessment locations, and Access database file of relevé and accuracy assessment data and jpeg image files of relevé photos
8. Develop FGDC compliant metadata files (Appendix A) for all vegetation classification relevés and accuracy assessment observation coverages and databases.
9. Prepare a final report CD with all compiled products

NatureServe responsibilities and deliverables

1. Review vegetation classification developed by CPRS
2. Develop global plant association descriptions
3. Include newly described plant associations into National Vegetation Classification Standard (NVCS) and present on a public web site (www.natureserve.org/explorer/)

A scoping meeting was held in March 1999 at the NPS office in Flagstaff, AZ with all interested parties. The purpose of this meeting was to inform monument staff and interested neighbors about the USGS-NPS Vegetation Mapping Program, learn about the monument's management and science issues and concerns, identify existing data sources, develop a preliminary schedule with assigned tasks, obtain a commitment from the monument to issue collecting permits, identify possible areas of cooperation with neighbors and partners, and define project boundaries.

Park management issues and concerns that a vegetation map could help with were identified during the scoping meeting and included: to identify quaking aspen (*Populus tremuloides*) stands, to better understand the microhabitats and vegetation communities associated with the lava flows, to determine the stand structure of the ponderosa pine (*Pinus ponderosa*) communities, to understand the importance of Bonito Park to Native American communities, and to protect the rare endemic species Sunset Crater Penstemon (*Penstemon cluteii*).

The total mapping area was set at 18,750 acres, including 3,040 acres within SUCR. This boundary was selected in order to include a 1-mile buffer area around the monument and other areas of special interest such as Bonito Park.

Preliminary data collection and review of existing information

To minimize duplication of previous work and to aid in the overall mapping project, we obtained existing data including maps and reports from various sources. Monument staff provided digital and/or hard-copy background maps for the project border and miscellaneous other digital files. We obtained site maps from the NPS and the Coconino National Forest, and topographic maps, digital elevation models (DEMs), digital line graphics (DLGs), and digital raster graphics (DRGs) from the USGS. Babbitt Ranches provided a copy of their recently completed Biological Assessment (Cordasco, et al. 1998). A preliminary list of plant associations and local land use types was prepared following a field reconnaissance survey conducted at the time of the scoping meeting.

Aerial photography and base map acquisition

Aerial photography covering the entire project area was received by RSGIG from USGS/BRD. The color infrared (CIR) photographs were acquired on October 8, 1996 by Merrick, & Company, Aurora, Colorado, and were taken at 1:12,000 (1inch=1,000 feet) scale. Hardcopies of the photographs were provided as 9 inch x 9 inch diapositives. Overlap for these photos averaged approximately 50-60% and sidelap between flight lines is approximately 30-40%. Flight lines for the aerial photos are shown in Figure 8. The team used these photos primarily for delineation of vegetation map classes and secondarily to inform field characterization of the vegetation.

The base maps, standard USGS digital orthophoto quarter quads (DOQQs) for geo-referencing or registration of delineated map classes were created from aerial photographs flown in October 1997. These maps are grayscale, with 1 meter per pixel resolution, UTM coordinate system, and NAD83 datum. The DOQQs used for this project are O'Leary Peak (SE and SW quarter-quads), Strawberry Crater (SW quarter-quad), Sunset Crater East (NW quarter-quad), and Sunset Crater West (NE and NW quarter-quads).

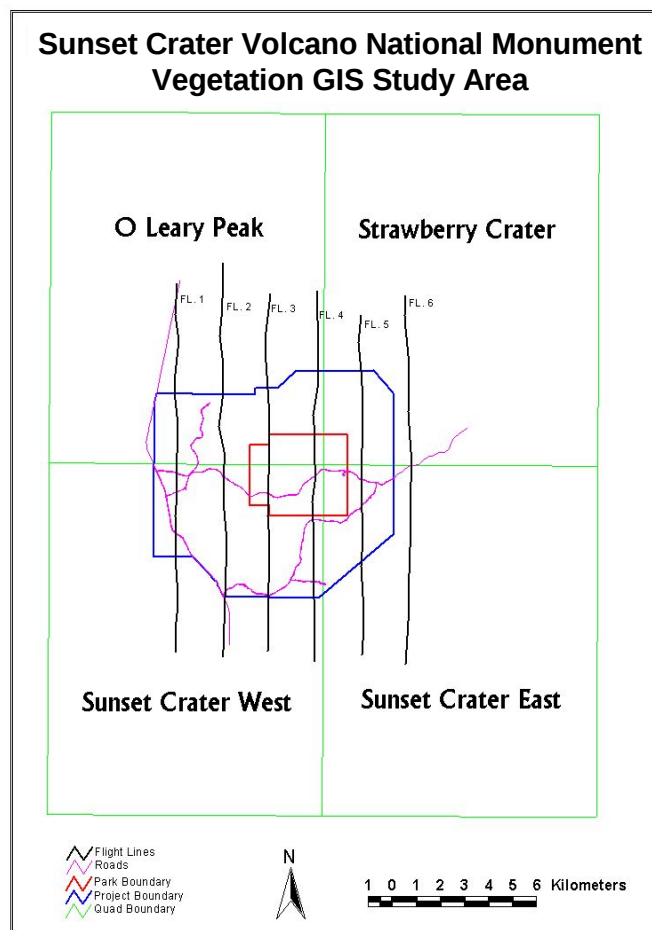


Figure 8. Mapping project area and aerial photo flightlines.

Sampling design development

A gradsect sampling design was used to divide the park into 'environmental types' to stratify for field sampling. The environmental types were developed using habitat types identified in the USDA-FS Terrestrial Ecosystem Survey (TES) mapping (Miller et al. 1991). We also identified, in a scoping session with USGS, BOR, and NPS scientists and managers, four additional aspect and elevation characteristics that could be derived from a Digital Elevation Model (DEM). We developed a digital map (coverage) of environmental types in a GIS by overlaying a coverage of habitat types and the four derived topographic characteristics. The result was 40 possible 'environmental types'. A total of over 100 potential relevé locations were allocated among the environmental types based on the percent contribution of each environmental type to the total study area. The allocated relevés were used to guide sampling. Within the environmental types we initially determined placement of relevés based on road accessibility and land ownership access.

Several environmental types were inaccessible due to extensive sharp lava beds causing high safety risks for the field crew. The Center of Biological Informatics (CBI) lent the field team laser binoculars. The binoculars provide locality information in UTM, using the distance and azimuth offset of targeted locations in conjunction with the GPS Precision Lightweight GPS

Receiver (PLGR) system. Additional laser relevés were completed in SUCR until all environmental types within the gradsect sampling area were sampled.

Field data collection

RSGIG staff conducted field surveys in support of the aerial photointerpretation in June 1999, with some follow-up work to clarify photosignatures in early May 2000. Two RSGIG plant ecologists collected the data and simultaneously took representative photographs of plant associations and their position in the landscape. These observation points were used to describe the plant association characteristics and their occurrence relative to aerial photosignatures. Field notes were transcribed directly on Mylar overlays of aerial photography. The RSGIG team also conducted joint field sessions with CPRS plant ecologists to exchange observations, observe field methodologies for vegetation classification relevé data collection, and discuss the project area.

RSGIG ecologists collected data at 46 photointerpretive observation points to document the plant association characteristics associated with particular photographic signatures. Photointerpretive observation points also helped the photointerpreters understand the range of variation of each plant community. In general, sampling included basic information on habitat and vegetation structure and composition. Specific information recorded included UTM coordinates using the NAD83 datum, dominant species cover data, and a brief summary of environmental characteristics. The datasheet used to collect the photointerpretive observation points can be located in Appendix D.

A two person team of CPRS plant ecologists conducted field surveys from mid-June thru mid-August 1999 and sampled 114 field relevés in the project area. The standard relevé method was used to quantify the vegetation community (Muller-Dombois and Ellenberg 1974, USGS-NPS 2000). The field team subjectively determined field relevé positioning within each environmental type visited so as to represent vegetation assemblages that were relatively dominant, homogenous, and covered a minimum mapping unit area of half a hectare. The field team also sampled special features and unique vegetation types within the environmental assemblages that are of specific interest to the park.

Typically we measured 1,000m² circular relevés; however, in areas of dense vegetation we would lower our relevé size to 400m². We selected 1000m² relevé as our standard as the vegetation of the area is relatively sparse and this size better represents the 0.5ha minimum mapping unit (MMU) than a 400m² relevé (20% vs. 8%). Other vegetation studies of arid lands have also used this relevé size (Thomas et al 2003) and State Heritage ecologists recommended this size for arid and semi-arid vegetation (T. Keeler-Wolf pers. comm.). Additionally, if the patch shape was better represented by rectangular or square relevés we used this relevé layout instead, as in lava bed outcrops. The habitat of the site was characterized by the relevé slope, aspect, elevation, soil characteristics, topographic position, landform type, and whether it was wetland or upland. We also took two photographs that best represented the vegetation of the site and recorded the angles they were photographed from. We documented site UTM coordinates, landownership, and USGS quad. We recorded leaf phenology, leaf type, and physiognomic class for the overall vegetation. For all perennial species we also recorded strata layer (tree, shrub, and ground) and percent species cover. Total cover for all vegetation was estimated for each strata layer (total tree, shrub, and

ground cover). We also measured each tree with >10cm dbh (diameter at breast height). In addition, we included calculations of percent cover for exotic species, individually and combined. Similarly, we measured percent cover for all sensitive species (as identified by the NPS). The classification relevé datasheet is located in Appendix D.

The relevé data was entered into a Microsoft Access 2000 (version 9.0) database. Plant names were standardized to the USDA PLANTS (USDA NRCS 1999) nomenclature. After the data was entered we performed spatial and data entry quality control checks.

Vegetation classification and characterization

Vegetation classification was based on guidelines developed from the National Vegetation Classification (NVC) (TNC and ERSI 1994b) and the National Vegetation Classification Standard (NVCS) adopted by the FGDC (1997). The NVCS classifies vegetation on seven hierarchical levels with the finest levels of the classification being the alliance and the association (Figure 9).

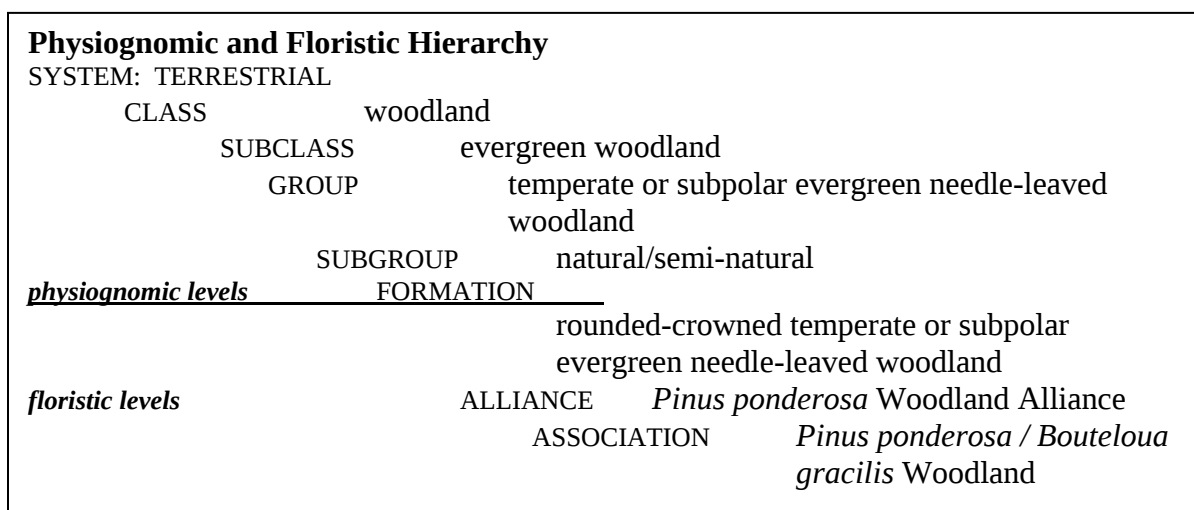


Figure 9. An example of the NVCS physiognomic and floristic hierarchy using the *Pinus ponderosa* / *Bouteloua gracilis* association.

The goal of the USGS-NPS Vegetation Mapping Program is to classify vegetation types to the association level. The definition of an association as put forward by the Ecological Society of America Vegetation Classification Panel is “A vegetation classification unit consistent with a defined range of species composition, diagnostic species, habitat conditions, and physiognomy” (Jennings et al. 2003). Occasionally, a vegetation type cannot be defined to the association level, and the vegetation is described to the courser alliance level. An alliance consists of a group of plant associations that share a uniform physiognomy and is characterized by one or more diagnostic species, which at least one of these species is found in the uppermost vegetation stratum (Mueller-Dombois and Ellenberg 1974).

Associations are named by the dominant and/or indicator species occurring in the community. If more than one species is characteristic of the association, then the species in the dominant strata is listed first and separated by a forward slash (/) from species in the lower strata, or if species occur in the same strata they are separated by a dash (-). Parentheses are used when species are frequently present, but do not necessarily occur all the time, yet are considered an important part of the community structure when present. The nomenclature for alliances is based on the dominant and diagnostic species, and includes at least one species from the uppermost stratum in the alliance name.

Vegetation was initially analyzed using multivariate classification analyses. Matrices of species absolute cover organized by relevé and species were extracted from the field relevé for use in a vegetation classification and ordination software program, PC-Ord, v 4.10 (McCune and Mefford 1999). Six matrices based on division of relevés by lifeform were examined: 1) all relevés, 2) relevés with greater than 60% cover tree species, 3) relevés with greater than 25% (but less than 60%) cover tree species, 4) relevés with greater than 25% cover shrub species (and less than 25% cover tree and herbaceous species), 5) relevés with greater than 25% cover grass and forb species (but less than 25% cover tree or shrub species) and 6) relevés with less than 25% cover. The cover of trees, shrubs or grasses in a relevé was calculated by adding the separate cover estimates for each species of that particular lifeform. Cover estimates needed to be summed, since the total vegetation calculated in the field was based on the strata layer, not on the lifeform. Many species occur in all three strata layers (for example, ponderosa pine commonly occurred in the ground (small saplings), shrub (medium saplings), and tree layer). The percentage used to separate each lifeform type is based on FGDC criteria for NVCS formation classes and as interpreted by NatureServe (Grossman et al. 1998, Reid 2000 pers. comm.). Some relevés had greater than 25% total cover but less than 25% of tree, shrub or herbaceous cover. In those cases the relevé was assigned a formation class based on the dominant lifeform.

We used two different algorithms within PC-Ord to examine species association patterns in each matrix. A divisive method, Two-Way Indicator Species Analysis (TWINSpan), was used to review the relevé. TWINSpan produces a table that classifies sites and species. Initial species and relevé groupings were identified with this step. An agglomerate group averaging method, Unweighted Pair Group Method Using Arithmetic Mean (UPGMA), commonly known as cluster analysis, was next applied with the distance measure defined as Sorensen's coefficient (also known as the Czekanowski or Jaccard coefficient). Each relevé in the cluster analysis was labeled with preliminary alliance and association label based on iterative examination of the cluster analysis graphic output (a dendrogram), preliminary alliance descriptions for the western states (Reid et al. 1999) and the cover values for species in each relevé.

NatureServe reviewed the results of the data analysis, and the initial placement of relevés within associations and alliances. A number of vegetation types identified from the analysis represented associations already documented in the NVCS, and registered in NatureServe Explorer, an online encyclopedia of life (www.natureserve.org/explorer/). In some cases the vegetation types from the analysis did not correspond to existing associations in the NVCS (i.e. appeared to be new associations), and these were treated in three different ways according to the amount of information supporting them from the project. Those with a number of relevés (3-5 or more), or with fewer relevés but covering substantial mapping area were incorporated into the NVCS as

new plant associations. Those with some relevés (typically <3), but seemingly uncommon or of uncertain floristic composition, were designated as “provisional” plant associations in the NVC, and require additional sampling to fully understand their floristic and ecological characteristics. The last group of vegetation types was those represented by only one or two relevés, or that seemed essentially unique to SUCR. Until further inventory is completed, these should be thought of as “local” vegetation assemblages and we describe these throughout the report as local assemblages. A few relevés were classified only to the coarser alliance level.

A dichotomous key to the vegetation association/alliances as well as to the corresponding map classes (described below) was developed prior to the 2001 accuracy assessment field season. The key was used in the 2001 data collection for accuracy assessment. We made slight modifications before using the key in the second round of accuracy assessment data collection during the 2002 field season (Appendix E).

Vegetation map preparation

Four basic elements were used to create the SUCR vegetation map: 1) map class development, 2) aerial photography interpretation, 3) digital transfer, and 4) map validation. Following these steps, a formal accuracy assessment determined errors of omission and commission with the goal of achieving a minimum of 80% map accuracy.

Map class development

A relatively simple vegetation and land use classification was prepared to guide a preliminary aerial photointerpretation, completed by RSGIG in June 1999. CPRS ecologists also used this preliminary work to more fully examine the landscape and vegetation features of the project area during vegetation relevé sampling activities. So as not to bias field researchers, each polygon delineated was given a consecutive number, with attributes for each polygon number listed in a separate table.

Final SUCR map classes used for interpreting the aerial photographs were derived (1) from plant associations described by CPRS, (2) from the Anderson (1976) Level II land use classification system, and (3) from special requests by NPS staff. In some cases, one NVCS association corresponded to one mapping class; more often, because of difficulties in interpreting the CIR photographs, map classes described more than one plant association and were combined into mosaics or complexes of associations. For instance, we combined the two mountain meadow grassland associations (*Bouteloua gracilis* Herbaceous Vegetation and *Muhlenbergia montana* Herbaceous Vegetation) into a Montane Grassland map class. In some instances, NVCS association map classes provided less detail than could be photo-delineated. In these instances, we used modifiers to define and map additional modifiers of vegetation cover and understory species composition (e.g. Ponderosa Pine / Apache Plume Woodland was photo-delineated as >25% total vegetation cover, <25% total vegetation cover, and with >10% pinyon pine). This level of detail provided additional refinement in the map classes; however, only the map class and not the modifier was assessed in the accuracy assessment. The Anderson Level II land use classes included semi-natural vegetation and cultural types, i.e. roads, facilities, residential land, croplands and pastures, etc. Finally, special map classes were created for surficial geology or vegetation types recognized by NPS staff or the photointerpreters, but not part of the NVCS.

These special map classes include Cinder Sparse Mosaic, Lava Beds, and Rock Outcrop and Scree Shrubland.

Aerial photograph interpretation

As a preliminary step prior to actual interpretation, sheets of translucent (single-frosted) Mylar were taped over all of the 9" x 9" photos. The fiducial points (corner and side tics), flight line number, and photograph number were transferred from each photo onto the Mylar using a 0.5 mm lead pencil. Aerial photos and their overlays were backlit on a light table and examined for photographic signatures, using a stereoscope to identify the three-dimensional features. Where photographic signatures were unclear, the diapositives were examined in stereo to make a final determination of the appropriate polygon boundary and/or map class. Only the center portion of each aerial photograph was interpreted, to minimize the effects of edge distortion inherent to 9" x 9" stereo photographs.

The actual interpretation of aerial photographs involved three steps. First, all photos were interpreted into broad classes based solely on standard photointerpretation signature characteristics. These included: tone, texture, color, pattern, topographic position, size, and shadow. Second, field notes and observation points were used to assign the correct map classes. Finally, digital transfer specialists reviewed all of the interpreted photos for consistency and accuracy.

Digital transfer

An ArcInfo GIS database was built for SUCR using in-house protocols for creating vegetation GIS databases. The protocols consist of a shell of Arc Macro Language (AML) scripts and menus that automate the transfer process and insure that all spatial and attribute data are consistent and stored properly. The actual transfer of information from the interpreted aerial photographs to a digital, geo-referenced format involved two techniques. First the Mylar overlays were scanned and warped to fit the DOQQs; second, additional polygons were added using on-screen digitizing with the DOQQs as a background. Both techniques required a background image or base map, in this case the USGS black-and-white DOQQ's. These digital base maps were delivered to RSGIG in November 2000 and data transfer began immediately.

The scanning technique used for SUCR involved a multi-step process whereby the Mylar overlays with their interpreted line work were scanned into a digital image file (.tif file). The digital image file was then converted to a vector file, which was then geo-referenced to the DOQQ base maps. Essential to this process is to match the scale and position of features on the photographs (Mylars) with the scale and position of the same features on the DOQQs. This was accomplished by adjusting the scale of the photo Mylar between numbered control points (Figure 10). AMLs executed the actual manipulation of the vector files until the adjustment was considered a good fit by technicians. Any remaining land use polygons that were not included on the Mylars were transferred through on-screen digitizing. This process enters polygons directly into the GIS database by manually tracing digital lines (using a mouse) on a computer monitor screen with the DOQQ as a background image. Finally, the complete set of digitized line work files were linked into a single file, the polygon topology created, and polygon attribute information added to produce a completed digital coverage.

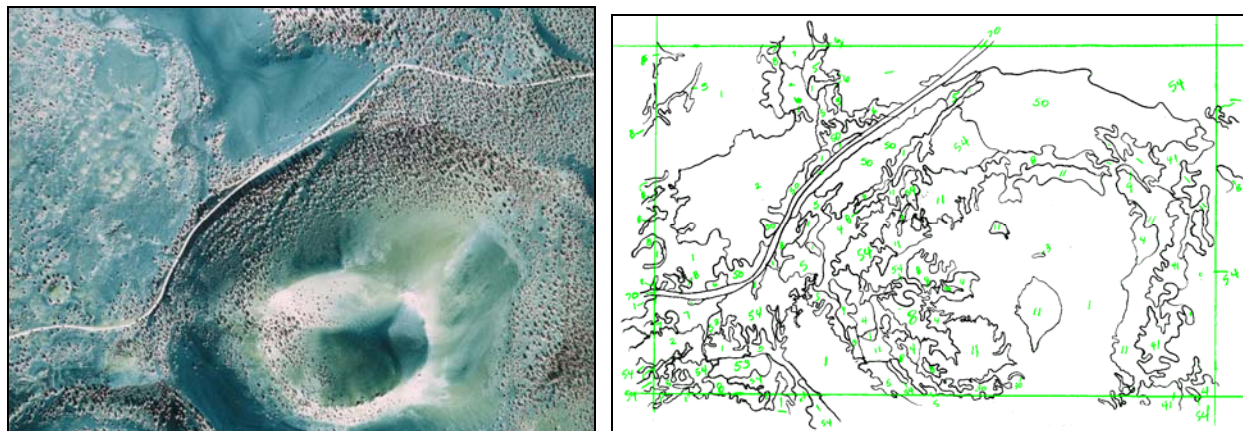


Figure 10. Aerial photo 4-7 and corresponding (scanned) Mylar overlay.

Map validation

A draft of the vegetation map was printed at the 1:12,000 scale and checked against the interpreted aerial photographs. As an internal accuracy check, we applied photointerpretive observation points over the vegetation map to determine if the map classes matched the field data.

Finally, field verification and revision of the draft map occurred prior to the accuracy assessment analysis. Field trips to validate the map were taken in January and May 2001. These trips included collecting additional photointerpretive observation points and ground-truthing aerial photograph signatures using landmarks and global positioning system (GPS) waypoints. We modified the map classes as a result of field verification and used the modified classes in the final photointerpretation. The final map revision was completed in September 2002.

Accuracy assessment

The CPRS field staff conducted the formal accuracy assessment of the SUCR vegetation map and vegetation association key. We conducted the field surveys in two phases, from August 1 to September 27, 2001 and from October 24 to November 8, 2002. Phase one of sampling was done with a preliminary vegetation map to allow for a majority of accuracy assessment reference points to be collected. Phase two was done with the final vegetation map to ensure that all reference points were collected. Data collection and analysis was done according to standard protocols developed by the USGS-NPS Vegetation Mapping Program, described in the Program Document, Accuracy Assessment Procedures (TNC and ERSI, 1994c) and “USGS-NPS Vegetation Mapping Program: 4.0 Sample Collection for Accuracy Assessment”, 4.4.2 second approach (<http://biology.usgs.gov/npsveg/aa/toc.html>, as of 11/12/2002), and were modified as needed (see below). As is common practice in measuring uncertainty in mapped classes, a sample of locations for each map class, referred to as reference points, were compared to a source of higher accuracy – ground truthing obtained by direct field observation.

Prior to selecting reference points, we checked topology and data structure of the coverage by running a check for node errors and label errors in the GIS dataset. We also dissolved the GIS dataset, removing polygon boundaries when adjoining polygons had the same value using GIS.

Reference point locations were then selected for each map class based on the total cover of each class in the mapping area, where map classes with more cover had more reference points assigned, and vice versa. The number of polygons to be sampled was determined by the number of polygons in each vegetation class and the total area of each vegetation class within the spatial vegetation dataset (Table 1). These standards were determined by USGS-NPS Vegetation Mapping Program criteria to ensure a 90% confidence level. Eight map classes were lumped together for accuracy assessment sampling design and analysis because several map classes were variations of the same plant association (map classes 8-10, 11-12 and 17-19). For example, map class 8 (montane grassland) was lumped together with map class 9 (montane grassland with rabbitbrush) and map class 10 (montane grassland occurring in Bonito Park), and these map classes were treated as a single map class. A table was compiled with vegetation types, the number of polygons and area in hectares for each vegetation type, and the number of polygons to be sampled (Table 1).

Table 1. USGS-NPS Vegetation Mapping Program criteria for sampling numbers for accuracy assessment

Scenario	Description	Polygons in class	Area occupied by class	Recommended number of samples in class
A	Abundant. Many polygons that cover a large area.	≥ 30	≥ 50 ha	30
B	Relatively abundant. Class has few polygons that cover a large area.	< 30	≥ 50 ha	20
C	Relatively rare. Class has many polygons, but covers a small area. Many polygons are close to the MMU.	> 30	< 50 ha	20
D	Rare. Class has few polygons, which may be widely distributed. Most or all polygons are close to the MMU.	$\geq 5, \leq 30$	< 50 ha	5
E	Very rare. Class has too few polygons to permit sampling. Polygons are close to the MMU.	< 5	< 50 ha	Visit all and confirm

We assigned random numbers to polygons for each map class and selected the target number of polygons plus 5 to 10 extra in case targeted polygons could not be accessed. Of the 500 reference points initially chosen, 355 points were sampled in the field in the first phase and 131 in the second phase. We discarded some accuracy assessment points from the initial phase when multiple reference points occurred within a single polygon in the final vegetation map. In such cases, we selected the reference point that contained the largest area of the polygon assessed in the initial round of sampling as the point used for the final round of accuracy assessment.

In the first phase of sampling we used reference points from sampled polygons greater than the minimum mapping unit (MMU) of 0.5 hectares; however, if not enough samples of the map class were available from polygons greater than the MMU, we then sampled polygons less than the MMU. In polygons greater than the MMU, we assigned reference point coordinates randomly in the polygon excluding a 5-meter buffer from the polygon edge (Random Point Generator v.1.1, available at www.ESRI.com (ESRI 2002)). In polygons that were less than the MMU, the centroid of the polygon was used to locate the reference point so as to minimize edge effects from adjacent polygons. We gave the field team a list of UTM coordinates and a radius to survey around the points. In polygons greater than the MMU, a 0.5 hectare area (MMU) was surveyed. In polygons less than the MMU, a radius (less than the MMU) was provided to the field team to ensure that they would not survey in an adjacent polygon and they were to survey the entire radius prior to determining the map class. If the polygon size was less than a 10-meter radius (less than 0.03 hectares), then a polygon map was provided to the field team to orient them within the polygon and the whole polygon was to be surveyed.

In the second phase of sampling, polygons that were equal to or greater than MMU were given a 5-meter buffer from the outside polygon edge. Then a location within the polygon was chosen using a random point generator to add one point to each polygon. We selected the centroid as the sampling point in polygons less than the MMU. For each polygon to be sampled, the field team was provided a polygon map. In polygons greater than the MMU, the field team was to survey an area equivalent to the MMU prior to making a final determination of the map class. In polygons less than the MMU, the entire polygon was surveyed.

Data collection

The CPRS field team had a list of the UTM coordinates for each reference point, the area and perimeter of the polygon encompassing its location, and the shortest distance to an adjacent map class. In the first round of accuracy assessment sampling, polygon shapes were provided for small polygons (<0.5 hectares), which contained a distance scale and direction orientation. In the second round of accuracy assessment sampling, polygon shapes were provided for all polygons that were sampled. The field ecologists recorded accuracy assessment observations on a field form (Appendix D), including the following: the vegetation association/map class within the radius of the reference point, confidence in the decision according to the descriptions of the association/map classes in the field key (using the following four categories: exact, good (some problems), poor, or none that fit), explanation of confidence if less than exact, UTM coordinates (easting, northing), altitude, and GPS error (using the Garmin 45XL, Garmin Corporation, 1996).

During the fieldwork, ongoing discussions between the field ecologists and CPRS plant ecologists allowed for refinement of the plant association/map class key, as well as some of the vegetation classifications. These changes were implemented in the key and may have influenced

the interpretation of the association/map class concepts between the first and second round of sampling. We accounted for these changes during the accuracy assessment analysis described below.

Accuracy assessment analysis

Accuracy assessment statistics were prepared by comparing the map class observed in the field (accuracy assessment observation or reference data) with the map class mapped at the same location on the final vegetation map (map class data). We made these comparisons using both standard accuracy assessment analysis identified as part of the USGS/NPS Vegetation Mapping Program (<http://biology.usgs.gov/npsveg/aa/toc.html>) and a modified ‘fuzzy set’ accuracy assessment analysis (Klopfer et al. 2002). Accuracy assessed observations were overlain onto the final vegetation map to determine the corresponding map class for each location except for those places that were remotely assessed in 2002.

For each standard and fuzzy set comparison, a contingency table was developed to compare the reference data with the map class data. The contingency table lists reference data values in the columns and map class values in the rows. The number of each reference data and map class pair for all sampling locations is located at each row/column intersection in the matrix (see Table 7 for an example). Correct mappings are indicated on the table where the row and column values are the same and typically occur on the diagonal on the matrix (yellow highlight on Table 7). The contingency table is used to calculate a variety of statistics describing the map performance: omission accuracy (also known as producer’s accuracy), commission accuracy (also known as user’s accuracy), the overall accuracy, and the Kappa index.

Initial analysis revealed a low overall accuracy and therefore we examined the errors associated with each observation using a modified ‘fuzzy set’ analysis to rank the type of error (Klopfer et al. 2002, Falzarano and Thomas In Press). In this assessment, we use five criteria (exact match, acceptable error, understandable error, vague similarity, and complete error) to assess the fit between the reference data and map class sampling location (Table 2) (Klopfer et al. 2002). We included only criteria 5, 4, and 3 in our analysis, since criteria 2 and 1 did not provide any additional information to our accuracy assessment analysis.

Table 2. Definitions used in the 'fuzzy set' analysis classifications.

Criteria	Descriptions
5	Exact Match: The reference data is an exact match to the map class.
4	Acceptable Error: If any of the following criteria were met than the case was considered acceptable error: 1) The reference data is the same as a map class in the nearest adjacent polygon and is within 35 meters of that polygon (distance chosen based on project specific considerations), 2) The reference data is in a 2001 polygon that became an inclusion below the MMU in 2002 and had similar floristic and structural composition of the larger 2002 polygon, 3) An alternative correct reference class was described in the field, or 4) The reference class described using the 2001 plant association field key was an alternative map class described using the 2002 map class field key.
3	Understandable Error: The map class has similar structural composition and species dominance.
2	Vague Similarity: The map class has a similar formation type, but not similar species composition.
1	Complete Error: No similarity in the species or structural composition.

A contingency table was created for three criteria: 1) standard or exact match—a correct map class was considered to occur where there was exact match between the reference data and map class data, 2) acceptable error—a correct label was represented by exact (criteria 5) and acceptable (criteria 4) matches between reference data and map class data, and 3) understandable error—a correct label was represented by exact (criteria 5), acceptable (criteria 4) and understandable (criteria 3) matches between reference data and map class data. We would like to point out that the standard accuracy assessment is the same criteria as an exact match in the modified fuzzy set analysis.

An example of acceptable error is the case of a field observation of Cinder Sparse Mosaic mapped as Lava Beds. In this example, the field observation is 25 meters from the nearest polygon, has an error of 15 meters, and that polygon is labeled Lava Bed. We have categorized the classification relevé as acceptable since it is in close proximity to the correct map class and we believe that the apparent misclassification may be a locational error either on the map or in the field rather than a photointerpretation misclassification.

The 2001 vegetation map was developed to vegetation associations (1:1 relationship), however in 2002 the vegetation map was developed to contain aggregates of associations. Concurrently the field key in 2001 was strictly to associations and did not reflect the 2002 map class descriptions. As a result, interpretation of the accuracy of a 2001 classification relevé might be more restrictive than in 2002. For example, consider a classification relevé in 2001 of Apache Plume / Cinder Sparse Vegetation on lava. In 2002 any vegetation association occurring in a lava bed outcrop was defined as Lava Bed Sparse Vegetation, and the map class is Lava Bed Sparse Vegetation. In this case the 2001 observation was acceptable according to the final definitions of map classes.

Another case for acceptable error occurred in the switch between the 2001 and 2002 map. For example, a classification relevé of Montane Grassland was made in 2001 and its location was in a small (10 meter radius) polygon based on the preliminary map. However, on the final map, the sampling location for this classification relevé was found to now be included in a larger polygon (7.5 hectares) labeled Ponderosa Pine / Montane Grass Mosaic. The notes for the original observation described the field situation as small grassland around scattered ponderosa pine. In this case, where the scale of consideration changed, the classification relevé was considered to be an acceptable match to the final map class.

An example of understandable error is if the field observation has a similar species composition and structure as the map class assigned to the polygon containing the observation. For example, Ponderosa Pine / Invasive Herbaceous Vegetation as the reference label and Ponderosa Pine / Montane Grass Mosaic as the map class have the same structure and species composition, except for the understory community. In this case, it is likely that it was difficult for the photointerpreters to delineate the understory community.

Vaguely similar would include the case where the classification relevé (Pinyon Pine - Utah Juniper / Blue Grama Woodland) structure is similar to the map class (Ponderosa Pine / Apache Plume Woodland), however the species composition is not similar. An example of complete error is when the reference label (Ponderosa Pine Invasive Herbaceous Vegetation) has no similarity with the map class (Apache Plume / Cinder Sparse Vegetation) in terms of structure or species composition.

Where the field observation was determined to ‘fit’ the map class for a particular criteria, the field observation was ‘reassigned’ to the map class for the purposes of constructing the error matrix. Hence the diagonals on the error matrix show the sum of all accuracy assessment observation/map class pairs that were matches under the particular criteria being applied.

Overall total accuracy for each contingency table criteria as described above (standard analysis, acceptable error, and understandable error) was calculated by dividing the total number of correctly classified reference data points by the total number of reference data points. Individual map class accuracies were also assessed for each of the criteria described above. To calculate the probability that a reference data observation has been correctly classified (producer’s accuracy or omission error), the number of reference data points correctly classified is divided by the total number of reference data points in that map class. To calculate the probability that the mapped vegetation associations represent the associations actually found on the ground (user’s accuracy or commission error), the number of correctly identified reference samples was divided by the total number of samples classified or mapped to that vegetation association.

Equations to calculate statistics for each criteria described occur in the program document, Accuracy Assessment Procedures (<http://biology.usgs.gov/npsveg/aa/toc.html>) and TNC and ERSI (1994c). Two-tailed, 90% confidence intervals for the binomial distribution were also calculated using JMP statistical software (SAS Institute 1989-2000) using Score Confidence Interval Tables. Score Confidence Interval Tables are known to have better coverage probabilities with smaller sample sizes (Agresti and Coull 1998). To account for correct

classifications due to chance, a Kappa index (Foody, 1992; TNC-ERSI, 1994c) was calculated also using JMP statistical software.

4. RESULTS

Field surveys

We observed forty-six observation photointerpretation sites and 114 classification relevés, including 2 laser obtained relevés (Figure 11). At each classification relevé we took two photos. Information recorded for each relevé and relevé photos are on the project CD (see Appendix A).

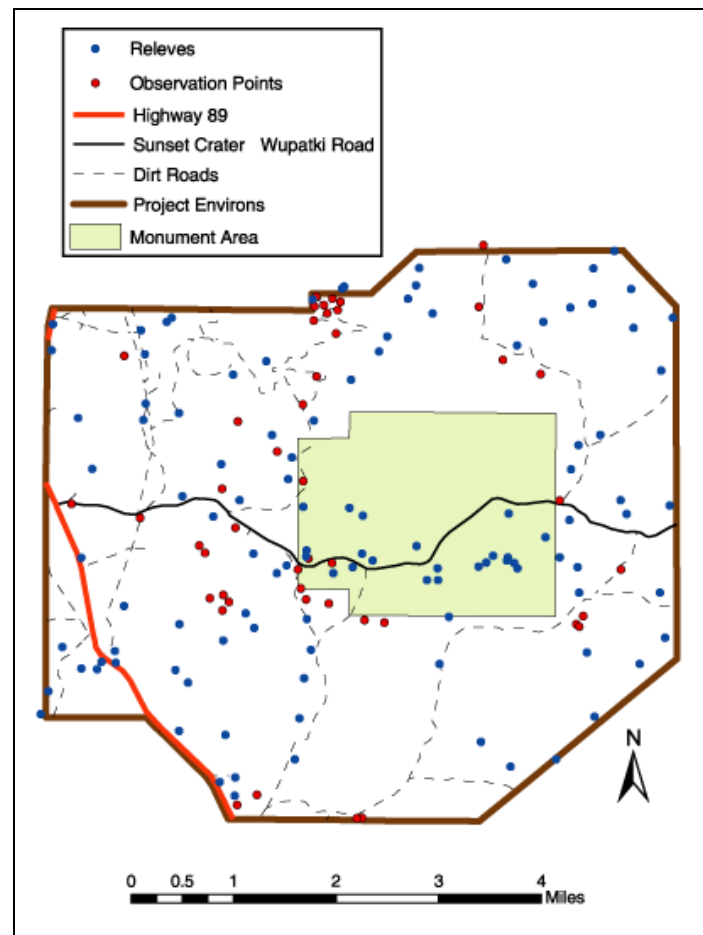


Figure 11. Location of photointerpretation observation and classification relevés.

Vegetation classification

The NVCS classification resulted in a total of 12 alliances, 15 associations, and five monument specific local assemblages (Table 3). Full descriptions of the SUCR vegetation associations and provisional associations are located in Appendix F. A listing of all species identified during the course of this study can be found in Appendix G. Five local assemblages were identified as possibly being unique to SUCR; these assemblages need further sampling on the Colorado Plateau to determine if they represent local vegetation types unique to SUCR or if they are found across the landscape. Four alliances and seven associations are newly described in the NVCS. The alliances, as grouped by formation, consist of two forest, three woodland, one shrubland,

four herbaceous, and three sparse alliances. The associations consist of two forest, six woodland, four herbaceous, and three sparse classes. The plant associations, local associations, Anderson land-use classes, and geologic exposures are related to the aerial photointerpretation map classes and are listed in Appendix H. A field key to both the map classes and alliance/association classification is listed in Appendix E.

Table 3. Sunset Crater Volcano National Monument NVCS assignments

Formation Class	Assignment	NVCS Alliance	NVCS Association	Relevé #
Forest	Association	<i>PINUS EDULIS</i> FOREST ALLIANCE	<i>Pinus edulis</i> / Sparse Understory Forest	SC-091
	Alliance	<i>PSEUDOTSUGA MENZIESII</i> FOREST ALLIANCE	No Association	SC-078
	Association	<i>PSEUDOTSUGA MENZIESII</i> FOREST ALLIANCE	<i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest	SC-079
Woodland	Association	<i>PINUS EDULIS</i> - (<i>JUNIPERUS SPP.</i>) WOODLAND ALLIANCE	<i>Pinus edulis</i> - (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland	SC-008, SC-012, SC-036, SC-037, SC-092, SC-096, SC-102
	Alliance	<i>PINUS FLEXILIS</i> WOODLAND ALLIANCE	No Association	SC-075
	New Association	<i>PINUS PONDEROSA</i> WOODLAND ALLIANCE	<i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland	SC-105
	Association	<i>PINUS PONDEROSA</i> WOODLAND ALLIANCE	<i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland	SC-004, SC-005, SC-013, SC-025
	New Association	<i>PINUS PONDEROSA</i> WOODLAND ALLIANCE	<i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland	SC-015, SC-019, SC-024, SC-042, SC-044, SC-045, SC-049, SC-064, SC-065, SC-066, SC-069, SC-076, SC-077, SC-081, SC-085, SC-087, SC-088, SC-089, SC-090, SC-095, SC-100, SC-101, SC-103, SC-108, SC-109, SC-110, SC-112
	Association	<i>PINUS PONDEROSA</i> WOODLAND ALLIANCE	<i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland	SC-001, SC-010, SC-026, SC-027, SC-031, SC-032, SC-034, SC-035, SC-041, SC-052, SC-055, SC-059
	New Association	<i>PINUS PONDEROSA</i> WOODLAND ALLIANCE	<i>Pinus ponderosa</i> / Cinder Woodland	SC-006, SC-009, SC-016, SC-017, SC-018, SC-022, SC-029, SC-038, SC-039, SC-040, SC-051, SC-054, SC-058, SC-061, SC-062, SC-063, SC-071, SC-073, SC-094, SC-104, SC-106, SC-111
	Local Assemblage	<i>POPULUS TREMULOIDES</i> WOODLAND ALLIANCE	<i>Populus tremuloides</i> / Cinder Woodland	SC-093
	New Alliance and Association	<i>FALLUGIA PARADOXA</i> SHRUBLAND ALLIANCE	<i>Fallugia paradoxa</i> - (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Shrubland	SC-014, SC-048, SC-083, SC-097
	Local Assemblage	undefined	<i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> – (<i>Holodiscus dumosus</i>) Scree Shrubland	SC-067, SC-074, SC-080
	Local Assemblage	undefined	<i>Pinus ponderosa</i> / <i>Rhus trilobata</i> Shrubland	SC-033

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Formation Class	Assignment	NVCS Alliance	NVCS Association	Relevé #
Herbaceous	Association	ANDROPOGON HALLII HERBACEOUS ALLIANCE	<i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation	SC-047, SC-050
	Association	BOUTELOUA GRACILIS HERBACEOUS ALLIANCE	<i>Bouteloua gracilis</i> Herbaceous Vegetation	SC-002, SC-003, SC-007, SC-011, SC-053
	Association	MUHLENBERGIA MONTANA HERBACEOUS ALLIANCE	<i>Muhlenbergia montana</i> Herbaceous Vegetation	SC-068
	New Alliance and Association	PASCOPYRUM SMITHII HERBACEOUS ALLIANCE	<i>Pascopyrum smithii</i> Herbaceous Vegetation	SC-028, SC-043
	Local Assemblage	undefined	<i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation	SC-056, SC-057, SC-060, SC-070
Sparse	Local Assemblage	undefined	<i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation	SC-099
	New Alliance and Association	ERIOGONUM CORYMBOSUM SPARSELY VEGETATED ALLIANCE	<i>Eriogonum corymbosum</i> Cinder Sparse Vegetation	SC-046
	New Alliance and Association	AA LAVA BED SPARSELY VEGETATED ALLIANCE	<i>Pinus ponderosa</i> -(<i>Populus</i> <i>tremuloides</i>) / <i>Fallugia</i> <i>paradoxa</i> -(<i>Holodiscus</i> <i>dumosus</i>) Lava Bed Sparse Vegetation	SC-021, SC-023, SC-072, SC-113, SC-114

Unvegetated to sparsely vegetated cinder, lava beds, and rock outcrops are very common in the project area. Although, they are considered a geologic type and are not classified to a NVCS association, they are prevalent and comprise approximately 16% (3,050 acres) of the total area mapped. In some areas lichen cover is high on the lava rocks, and annual vegetation communities, although sparse, are consistent. Annual species and small herbaceous perennial species often include phacelia (*Phacelia* sp.), Newberry's twinpod (*Physaria newberryi*), and blazingstar (*Mentzelia* sp.). Sparsely vegetated shrublands often occur on cinder and lava beds and are most often dominated by wild buckwheat (*Eriogonum corymbosum*) and Apache plume (*Fallugia paradoxa*). Sparsely vegetated areas also often occur as islands of vegetation in lava outcrops. These outcrops may include isolated trees such as ponderosa pine (*Pinus ponderosa*) and quaking aspen (*Populus tremuloides*) as well as groups of shrubs including Apache plume and ocean spray (*Holodiscus dumosus*).

Forests only occur at the highest elevations of the project area and cover less than 1% (72 acres) of the project area. Only one map class (Douglas-fir Forest) is mapped as a forest type. Douglas-fir (*Pseudotsuga menziesii*) can form dense stands on the slopes of O'Leary Peak. Due to high density (crown cover) in some pinyon pine stands, these areas are also classified as forest alliances rather than woodland alliances. However, these dense stands were not mapped separately from the woodland types and were aggregated into the Pinyon Pine – Utah Juniper / Blue Grama Woodland map class.

Woodlands are the predominant vegetation type, covering approximately 60% of the project area (12,548 acres) and occur on all landforms including flats, slopes, hills, drainages, and ridges. Seventy-five of the total 114 relevés sampled were classified as woodlands (Table 3). This includes four alliances and seven associations among the alliances. Three of the associations are newly described. Ponderosa pine woodlands occur most frequently in the park and are found on nearly every landform, except the driest south-facing slopes and at the highest elevations.

Ponderosa pine most often occurs in pure stands; however, it can intermix in areas of high elevation with Douglas-fir or limber pine (*Pinus flexilis*). In drier areas, on south-facing and steep slopes, ponderosa pine can also co-occur with pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*). Pinyon pine and Utah juniper persist on the dry south-facing flanks of cinder cones and their rims, mountain toeslopes, and lower elevation dry flats. Quaking aspen occurs only in very small stands and patches within the lava beds, in small areas along the lava beds, and in small stands on cinder beds.

Shrublands cover less than 1% (11 acres) of the project area and occur mainly in small patches. Only one map class (Rock Outcrop and Scree Shrubland) was classified as a shrubland type. All of the relevés in this map class were classified as local associations, with unique species composition, and did not have enough data to support classification under the NVCS shrubland formation class. Two of the sparse vegetation map classes are sparse shrublands. Shrubs also often occur in small patches under tree canopy. Shrubs can also co-dominate with grasses in open meadows. Apache plume occurs most frequently in the park and is often associated with ponderosa pine trees. It also occurs in sparse cinder open areas and in lava beds. Other shrubs are also common to these geologic features and include species such as rabbitbrush (*Ericameria nauseosa*), three-leaved sumac (*Rhus trilobata*), ocean spray, pericome (*Pericome caudata*), brickellbush (*Brickellia californica*), and wax currant (*Ribes cereum*). These shrubs also occur on a variety of substrates and landforms.

Grasslands often occur in small patches in or near ponderosa pine woodlands and covers 9% (1,708 acres) of the project area. Blue grama (*Bouteloua gracilis*) and mountain muhly (*Muhlenbergia montana*) are the two most dominant species in these grassland meadow areas. Blue grama is most associated with the lower to mid-elevation areas of the project area and is probably the most common grass species. Blue grama occurs in Bonito Park and in some areas is co-dominant with rabbitbrush. Mountain muhly dominates the upper elevation meadows and often co-dominates with blue grama at mid-elevations. Sand bluestem (*Andropogon hallii*) is a bunchgrass that occurs mostly in sparse patches in the eastern section of the project area and often occurs with ponderosa pine. Western wheatgrass (*Pascopyrum smithii*) is a common understory species in the recently burned areas northwest of the project area. Western wheatgrass was probably used in seed mixes for re-seeding efforts and was found only in the burned areas. Four percent (760 acres) of these grasslands contain recently disturbed areas with evidence of thinning and burning of ponderosa pine. In these areas introduced annual grasses, particularly cheatgrass (*Bromus tectorum*), native forbs such as meadow-rue (*Thalictrum fendleri*) and Carruth's sagewort (*Artemisia caruthii*) and the invasive non-native toadflax (*Linaria dalmatica* ssp. *dalmatica*) and mullein (*Verbascum thapsus*) are common.

Vegetation map classes

A total of 26 map classes, including 5 modifiers, were recognized in the SUCR vegetation map (Table 4). These map classes consist of 21 vegetation classes, including 5 modifiers, and 6 Anderson Level II (Anderson et al. 1976) land-use classes.

Table 4. SUCR Map classes and their NVCS components

Map Code	Map Class	Map Class NVCS Name
1	Cinder Sparse Mosaic	none (Land Cover Class)
2	Lava Beds	none (Land Cover Class)
3	Rock Outcrop and Scree Shrubland	<i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> – (<i>Holodiscus dumosus</i>) Scree Shrubland (Local Assemblage), <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage)
4	Wild Buckwheat - Sand Bluestem Sparse Vegetation	<i>Eriogonum corymbosum</i> - <i>Andropogon hallii</i> Sparse Vegetation
5	Apache Plume / Cinder Sparse Vegetation	<i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation
6	Lava Bed Sparse Vegetation	<i>Pinus ponderosa</i> - (<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> - (<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation
7	Sand Bluestem Herbaceous Vegetation	<i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation
8-10	Montane Grassland (Rabbitbrush, Bonito Park)	<i>Bouteloua gracilis</i> Herbaceous Vegetation, <i>Muhlenbergia montana</i> Herbaceous Vegetation
11-12	Pinyon Pine - Utah Juniper / Blue Grama Woodland (Sparse)	<i>Pinus edulis</i> - (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland, <i>Pinus edulis</i> / Sparse Understory Forest
13	Limber Pine Woodland	<i>Pinus flexilis</i> Woodland Alliance
14	Ponderosa Pine / Cinder Woodland	<i>Pinus ponderosa</i> / Cinder Woodland
15	Ponderosa Pine / Montane Grass Mosaic	<i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland, <i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland
16	Ponderosa Pine Invasive Herbaceous Vegetation	<i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage), <i>Pascopyrum smithii</i> Herbaceous Vegetation
17-19	Ponderosa Pine / Apache Plume Woodland (Pinyon, Sparse)	<i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland
20	Ponderosa Pine / Sand Bluestem Woodland	<i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland
21	Douglas-fir Forest	<i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest, <i>Pseudotsuga menziesii</i> Forest Alliance
22	Transportation, Communications, and Utilities	- none (Anderson Land Use class)
23	Facilities	- none (Anderson Land Use class)
24	Residential Land	- none (Anderson Land Use class)
25	Reservoirs and Trick Tanks	- none (Anderson Land Use class)
26	Strip Mines, Quarries, and Gravel Pits	- none (Anderson Land Use class)
27	Croplands and Pastures	- none (Anderson Land Use class)

Three of the map classes; Montane Grassland (map codes 8-10), Pinyon Pine – Utah Juniper / Blue Grama Woodland (map codes 11-12), and Ponderosa Pine / Apache Plume Woodland (map codes 17-19); were further subdivided by two or three modifiers. These modifiers represent variations of the NVCS vegetation association that were easily mapped and were useful to resource management (for example, map class Montane Grassland is mapped as pure Montane Grassland (map code 8), Montane Grassland with a greater than 10% rabbitbrush (*Ericameria nauseosa*) (map code 9), and Montane Grassland that occurs in Bonito Park (map code 10). The final map classes were determined in a series of meetings among NPS, USGS, and BOR participants using the information obtained from photointerpretation observations, classification

relevés, and preliminary photointerpretation. While the ideal situation is to have each map class correspond to one NVCS plant association, we had to deviate from this in cases where NVCS associations could not be discerned from the aerial photography, such as some of the canopied woodland types. Also, some map classes did not directly correspond to NVCS associations but were included as “park specials” to aid with SUCR’s management needs.

A few of the map classes occurred consistently in patches smaller than the minimum mapping unit (0.5 hectares), particularly Rock Outcrop and Scree Shrubland (map code 3). Because of the importance of these classes for wildlife habitat and monument management priorities, a decision was made to map them where possible regardless of size.

The map classes for SUCR can be described by four categories:

1. NVCS associations represented by a unique photosignature and topographic position (one map class to one plant association)
2. Multiple NVCS associations that together are represented by a unique signature (one map class represents a mosaic of several related plant associations)
3. Stands of vegetation that were not addressed by the NVCS but are seen as management concerns for SUCR and could be recognized on the aerial photography (“park special” map classes)
4. Geologic formations/exposures and land-use classes that are not described within the NVCS

Each map class for SUCR can be crosswalked to their NVCS association using the aggregations described below:

One Map Class to One Plant Association

These map classes were developed by directly translating a NVCS vegetation association into a map class onto the aerial photography.

Map Code	Map Class	NVCS Plant Association
4	Wild Buckwheat - Sand Bluestem Sparse Vegetation	<i>Eriogonum corymbosum</i> - <i>Andropogon hallii</i> Sparse Vegetation
5	Apache Plume / Cinder Sparse Vegetation	<i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation
6	Lava Bed Sparse Vegetation	<i>Pinus ponderosa</i> -(<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> -(<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation
7	Sand Bluestem Herbaceous Vegetation	<i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation

- 13 Limber Pine Woodland
 Pinus flexilis Woodland Alliance

- 14 Ponderosa Pine / Cinder Woodland
 Pinus ponderosa / Cinder Woodland Alliance

- 17-19 Ponderosa Pine / Apache Plume Woodland (Pinyon, Sparse)
 Pinus ponderosa / *Fallugia paradoxa* Woodland

- 20 Ponderosa Pine / Sand Bluestem Woodland
 Pinus ponderosa / *Andropogon hallii* Woodland

Multiple Associations-to-One Map Class

NVCS associations and local assemblages identified in the aerial photography were too intermixed to identify as unique photosignatures. NVCS associations were aggregated with ecologically similar NVCS associations to form mosaics.

Map Code	Map Class NVCS Plant Association/Alliance
3	Rock Outcrop and Scree Shrubland <i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> –(<i>Holodiscus dumosus</i>) Scree Shrubland (Local Assemblage) <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage)
5	Apache Plume / Cinder Sparse Vegetation <i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation
8-10	Montane Grassland (Rabbitbrush, Bonito Park) <i>Bouteloua gracilis</i> Herbaceous Vegetation <i>Muhlenbergia montana</i> Herbaceous Vegetation
11-12	Pinyon Pine - Utah Juniper / Blue Grama Woodland (Sparse) <i>Pinus edulis</i> - (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland <i>Pinus edulis</i> / Sparse Understory Forest
15	Ponderosa Pine / Montane Grass Mosaic <i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland <i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland
16	Ponderosa Pine Invasive Herbaceous Vegetation <i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage) <i>Pascopyrum smithii</i> Herbaceous Vegetation

- 21 Douglas-fir Forest
Pseudotsuga menziesii / *Muhlenbergia montana* Forest
Pseudotsuga menziesii Forest Alliance

Park Special Map Classes

Only one map class at SUCR is considered a park special. This map class was developed based on local vegetation assemblages identified in the classification relevés.

Map Code	Map Class
	NVCS Plant Association

- 3 Rock Outcrop and Scree Shrubland
Fallugia paradoxa – *Brickellia grandiflora* –(*Holodiscus dumosus*) Scree Shrubland (Local Assemblage)
Ericameria nauseosa - *Pericome caudata* Rock Outcrop Sparse Vegetation (Local Assemblage)

Aerial photograph interpretation

The SUCR project area is represented mostly by sparse vegetation growing from cinder beds, lava flows, and woodlands growing from a number of substrates. The lava flows contain some sparse woodland and shrubland types, but are mostly barren or support a unique flora of lichens and mosses. Cinder beds are both black and red in color, but regardless of color, support sparse forblands, grasslands, and woodlands. Downwind from the pumice mines and near areas subjected to OHV use, the cinder beds are covered by a heavy dust layer.

Interpretation of the late fall, color-infrared aerial photographs for SUCR relied heavily on substrate and landscape position to help determine classes for vegetation polygons since the usual cues of color, shape, and texture were not distinctive for many of the map classes. Long tree shadows were present in the forest and woodland landscapes, partially or completely obscuring the understory. Because the aerial photographs were acquired in October when most of the grass species were dormant, color could not be used to distinguish among the different grassland types. An illustrated guide to the map classes, including a brief description of each map class, its distribution on the landscape, and its photosignature characteristics appears in Appendix H.

GIS database and maps

The SUCR GIS database consists of 11 coverages, 1 basemap imagery file, and associated metadata in ArcInfo format and is archived on a CD (Appendix A) accompanying this report. The coverages and imagery are:

- Accuracy assessment observation points.
- Aspen map. Small photointerpreted aspen (*Populus tremuloides*) patches.
- Classification relevé points.

- d. DOQQ and USGS Quad maps for Sunset Crater, Wupatki, and Walnut Canyon National Monuments.
- e. DOQQ basemap imagery (MrSid images) for SUCR.
- f. Flightline boundary for Sunset Crater, Wupatki, and Walnut Canyon National Monuments.
- g. OHV map. Photointerpreted tracks of off-highway vehicle use.
- h. SUCR park boundary.
- i. Photointerpretative observation points.
- j. Project boundary.
- k. Vegetation map clipped to the National Monument boundary.
- l. Vegetation map for the entire project area. This main product coverage consists of a single Arc Info coverage, developed from a mosaic of 46 aerial photographs (Figure 12), with 1,205 classified polygons covering a total area of approximately 7,590 hectares (18,750 acres). Table 5 shows the total number of polygons and hectares per map class in the project area.

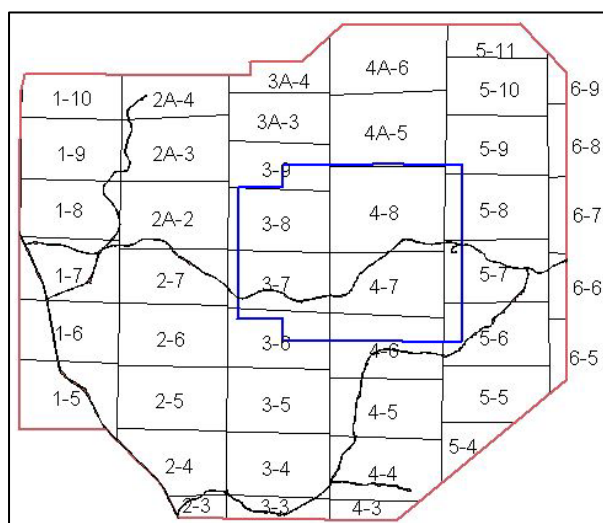


Figure 12. Aerial photograph boundaries

A readme file (Appendix A) further describes these coverages.

A hard copy map was created of the vegetation coverage with a legend identifying the color of each map class. For clarity, the map code was printed only on polygons with an area greater than 5000 m² (0.5 hectare). The hard copy map is presented in a folder sleeve (Appendix I).

Table 5. Map class occurrence in Sunset Crater Volcano National Monument and the environs.

Map Code	Map Class Common Names	Monument		Environs	
		Polygons	Hectares	Polygons	Hectares
1	Cinder Sparse Mosaic	51	379	204	620
2	Lava Beds	10	221	2	10
3	Rock Outcrop and Scree Shrubland	2	0.1	11	4
4	Wild Buckwheat – Sand Bluestem Sparse Vegetation	11	15	23	32
5	Apache Plume / Cinder Sparse Vegetation	33	27	159	202
6	Lava Bed Sparse Vegetation	50	79	8	5
7	Sand Bluestem Herbaceous Vegetation	10	32	2	1
8	Montane Grassland			104	148
9	Montane Grassland (Rabbitbrush)			51	100
10	Montane Grassland (Bonito Park)			1	101
11	Pinyon Pine – Utah Juniper / Blue Grama Woodland	5	2	51	361
12	Pinyon Pine – Utah Juniper / Blue Grama Woodland (Sparse)			8	33
13	Limber Pine Woodland			9	13
14	Ponderosa Pine / Cinder Woodland	26	93	61	1038
15	Ponderosa Pine / Montane Grass Mosaic	1	3	69	1223
16	Ponderosa Pine Invasive Herbaceous Vegetation			19	309
17	Ponderosa Pine / Apache Plume Woodland (Sparse)	51	115	127	224
18	Ponderosa Pine / Apache Plume Woodland	18	238	41	1649
19	Ponderosa Pine / Apache Plume Woodland (Pinyon)	1	1	19	66
20	Ponderosa Pine / Sand Bluestem Woodland	4	15	3	5
21	Douglas-fir Forest			7	29
22	Transportation, Communications, and Utilities	1	7	2	56
23	Facilities	1	1	3	7
24	Residential Land			10	3
25	Reservoirs and Trick Tanks			2	1
26	Strip Mines, Quarries, and Gravel Pits			9	65
27	Croplands and Pastures			3	57
	Total	275	1,227	1,008	6,361

Accuracy assessment

In the 2001 sampling season, 204 accuracy assessment observations were included in the reference data out of the total 334 accuracy assessment observations that were collected. One hundred and thirty-one accuracy assessment observations were eliminated since they represented duplicate observations in polygons in the final vegetation map. In these duplicate cases, the field observation that assessed the largest area of the polygon was selected as the field observation data to be used in the accuracy assessment analysis. For 2002, 130 additional field observations were added to the accuracy assessment reference data making a combined total of 334 reference points for the final accuracy assessment analysis (Figure 13). The final number of reference points analyzed for each map class was representative of the total area of each map class except for map classes with high percentage of occurrence on private land (i.e. land use classes). In these cases, the number of reference points sampled was less than the number suggested for the accuracy assessment analysis.

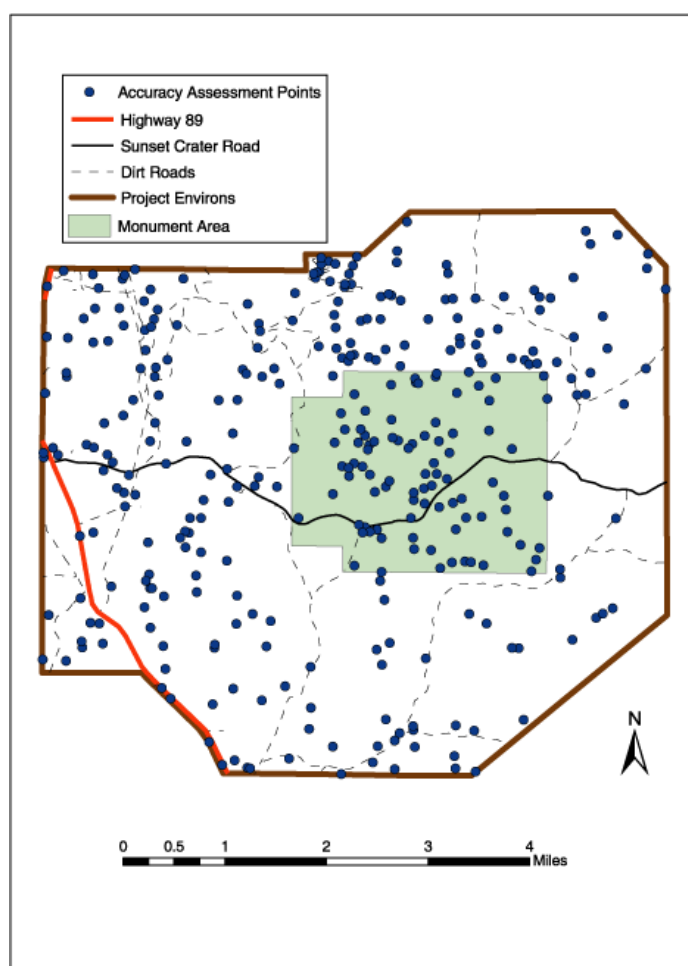


Figure 13. Location of accuracy assessment field observations for the 2001 and 2002 combined reference data set.

Evaluation of the performance of each map class can provide insight on map error. For each map class we report the criteria at which the class was assessed to meet the standard of 80% or greater for commission and omission accuracy (Table 6).

Standard analysis of map accuracy (criteria 5, exact criteria) suggested that overall accuracy was low, 53.9% (90% confidence interval of 43.7% to 64.1% and a Kappa index of 50.1%, Table 7). For criteria 4, acceptable error, accuracy of the map is 70.3% (90% confidence interval of 69.0% and 84.0%) and Kappa index of 68.0% (Table 8). Criteria 3, understandable error, accuracy is 86.8% (90% confidence interval of 84.1% and 95.4%) and a Kappa index of 85.8% (Table 9). Omission and commission accuracies for each individual map class, including two-tailed, 90% confidence intervals, are also shown for each criteria in each contingency table.

Table 6. Map class performance.

Map Code	Map Class	Commission Accuracy (Criteria and %)	Omission Accuracy (Criteria and %)	Comments
1	Cinder Sparse Mosaic	Acceptable 80%	Understandable 87%	This type is considered adequate as mapped.
2	Lava Beds	Exact 90%	Exact 100%	This type is considered adequate as mapped.
3	Rock Outcrop and Scree Shrubland	Acceptable 100%	Understandable 38%	Omission accuracy remained below the standard even with the least restrictive criteria, indicating that incidences of this type were often omitted from the map. This map class is often less than the minimum map unit in size (84% of all polygons were <.5 ha. in size) so omissions might be expected. Merging this map class into adjacent polygons would increase the accuracy of the overall map, however there is value in having known occurrences mapped.
4	Wild Buckwheat-Sand Bluestem Sparse Vegetation	Understandable 62%	Understandable 76%	36% of this map class occurs below the MMU. When misclassified it was shown on the map as Cinder Sparse Mosaic or Apache Plume / Cinder Sparse Vegetation. Sparse shrub and tall grassland communities (Map classes 4 & 5) may need to be considered as a single map class due to the constraints in photointerpreting them.
5	Apache Plume/Cinder Sparse Vegetation	Acceptable 83%	Understandable 70%	This map class was sometimes misclassified as Wild Buckwheat – Sand Bluestem Sparse Vegetation (omission error), which typically occurs in cinders and has a similar formation type.
6	Lava Bed Sparse Vegetation	Acceptable 83%	Exact 91%	This type is considered adequate as mapped.
7	Sand Bluestem Herbaceous Vegetation	Understandable 83%	Understandable 100%	This type is considered adequate as mapped.
8-10	Montane Grassland	Understandable 71%	Understandable 80%	On the map this class was misclassified as Ponderosa Pine Invasive Vegetation, Ponderosa Pine Montane Grass Mosaic, and Ponderosa Pine Cinder Woodland (omission error). Many polygons of this class interfinger between ponderosa pine dominated canopies. This class was mapped as Rock Outcrop and Scree Shrubland and Wild Buckwheat-Sand Bluestem Sparse Vegetation (omission error) and misclassified as Ponderosa Pine Invasive Vegetation and Montane Grassland (commission error). Small patches of Montane Grassland adjacent to ponderosa pine dominated canopies could be combined into the large-scale ponderosa pine herbaceous understory map classes to increase accuracy.

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11-12	Pinyon Pine-Utah Juniper/Blue Grama Woodland	Exact 83%	Acceptable 83%	This type is considered adequate as mapped.
13	Limber Pine Woodland	Exact 83%	Understandable 86%	On the map this class was misclassified as Ponderosa Pine or Douglas-fir dominated class (omission error).
14	Ponderosa Pine/Cinder Woodland	Understandable 86%	Understandable 100%	The most common errors confused this type with Montane Grassland, Lava Bed Sparse Vegetation, or ponderosa pine dominated classes with Apache Plume or montane grassland understory.
15	Ponderosa Pine/Montane Grass Mosaic	Understandable 100%	Acceptable 89%	In the field areas where this class was found, it was mapped as Ponderosa Pine/Apache Plume Woodland (commission error).
16	Ponderosa Pine Invasive Herbaceous Vegetation	Understandable 82%	Understandable 82%	This class is most often confused with Montane Grassland.
17-19	Ponderosa Pine/Apache Plume Woodland	Understandable 74%	Understandable 96%	This class is often confused with Pinyon Pine-Utah Juniper/Blue Grama Woodland and Apache Plume / Cinder Sparse Vegetation (omission error) and as Ponderosa Pine / Montane Grass Mosaic (commission error).
20	Ponderosa Pine/Sand Bluestem Woodland	Understandable 80%	Understandable 96%	This class is often confused with Ponderosa Pine Cinder Woodland or Apache Plume/Cinder Sparse Vegetation.
21	Douglas-fir Forest	Acceptable 83%	Understandable 100%	This type is considered adequate as mapped.
22	Transportation, Communications, and Utilities	Acceptable 100%	Acceptable 100%	This type is considered adequate as mapped.
23	Facilities	Acceptable 100%	Acceptable 100%	This type is considered adequate as mapped.
24	Residential Land	N/A	N/A	This class was not accuracy assessed because private lands were not accessible.
25	Reservoirs and Trick Tanks	Acceptable 100%	Acceptable 100%	This type is considered adequate as mapped.
26	Strip Mines, Quarries, and Gravel Pits	Understandable 100%	Exact 100%	This class is sometimes misclassified as Cinder Sparse Vegetation.
27	Croplands and Pastures	Acceptable 100%	Acceptable 100%	This type is considered adequate as mapped.

Table 7. Accuracy assessment contingency table (criteria 5, exact match) and statistical analysis of reference data with map class data.

Map Class Data		Reference Data (Field Data for Accuracy Assessment Classes)																										Total	Commission Accuracy	90% Confidence Intervals	
	Map Code	1	2	3	4	5	6	7	8-10	11-12	13	14	15	16	17-19	20	21	22	23	24	25	26	27	N	(% Correct)	-	+				
	1	20		1	1	2	1					1			3				1					30	66.7	55.1	81.6				
	2	1	9																					10	90.0	65.3	97.7				
	3	1		3					1															5	60.0	27.3	85.7				
	4	5			7	8								1										21	33.3	20.0	53.4				
	5	4			2	2	19			1					1									29	65.5	48.3	76.1				
	6						6	19				4				1								30	63.3	48.3	76.1				
	7				1	3			1							1								6	NA	NA	NA				
	8-10				4	2				16				1	4					1				28	57.1	6.4	27.4				
	11-12				1		2			1	25					1								30	83.3	69.5	91.6				
	13									1		5												6	83.3	43.5	95.4				
	14	2			1					3		1	13	2		5	1	1						29	44.8	32.6	61.3				
	15									7		1	2	14	2	3		1						30	46.7	32.6	61.3				
	16					3	1			9	1		1	1	5							1		22	22.7	14.2	47.1				
	17-19	2			2		5	1	1		4		3	2	1	9		1						31	29.0	15.6	39.3				
	20						2						1				2							5	40.0	14.3	72.8				
	21											2	1	1				2						6	33.3	11.7	65.3				
	22										1									1				2	50.0	12.1	87.9				
	23												1								3			4	75.0	35.6	94.2				
	24																					0		0	NA	NA	NA				
	25	2																					0	2	0.0	27.0	100.0				
	26																							6	100.0	46.0	91.4				
	27																				1		0	1	NA	27.0	100.0				
	Total	N	37	9	14	16	48	21	2	37	32	10	27	21	15	22	3	5	2	4	1	0	7	0	Total Sampling Points: 334 Total Correct: 179 Overall Accuracy: 53.92% Kappa Index: 50.09% 90% Confidence Intervals: 43.72%, 64.06%						
	Omission Accuracy	(% Correct)	54.1	100.0	21.4	43.8	39.6	90.5	50.0	43.2	78.1	50.0	48.1	66.7	33.3	40.9	66.7	40.0	50.0	75.0	NA	NA	85.7	NA							
	90% Confidence Intervals	-	42.1	76.9	8.9	32.5	27.0	74.9	27.0	31.4	64.2	21.8	35.2	48.7	18.6	24.4	25.4	14.3	12.1	52.6	NA	NA	54.8	NA							
	+	67.7	100.0	43.2	73.9	48.8	96.8	100.0	56.6	87.7	69.7	64.8	80.1	57.5	56.2	92.2	72.8	87.9	100.0	NA	NA	96.8	NA								

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Table 8. Accuracy assessment contingency table (criteria 4, acceptable accuracy) and statistical analysis of reference data with map class data.

Map Class Data		Reference Data (Field Data for Accuracy Assessment Class)																					Total	Commission Accuracy	90% Confidence Intervals		
	Map Code	1	2	3	4	5	6	7	8-10	11-12	13	14	15	16	17-19	20	21	22	23	25	26	27	N	(% Correct)	-	+	
	1	24		1	1	2	1								1								30	80.0	65.7	89.3	
	2		10																				10	100.0	78.7	100.0	
	3			5																			5	100.0	64.9	100.0	
	4	1			12	8																	21	57.1	39.6	73.1	
	5	1		1	2	24								1									29	82.8	68.6	91.3	
	6					2	25					3											30	83.3	69.5	91.6	
	7				1	3		2															6	33.3	11.7	65.3	
	8-10			3	2				19					4									28	67.9	52.3	80.2	
	11-12			1		2			1	25				1									30	83.3	69.5	91.6	
	13										6												6	100.0	68.9	100.0	
	14	2		1					3		1	17	2		1	1	1						29	58.6	43.5	72.3	
	15								1		1		23	1	3		1						30	76.7	62.1	86.8	
	16				3	1			9	1		1	1	5							1		22	22.7	11.5	39.9	
	17-19	2		2		5		1		4		1			16								31	51.6	37.3	65.6	
	20					1						1				3							5	60.0	27.2	85.7	
	21											1					5						6	83.3	49.8	96.2	
	22																	2					2	100.0	42.5	100.0	
	23																		4				4	100.0	59.7	100.0	
	25																			1			1	100.0	27.0	100.0	
	26	2																				6	8	75.0	46.0	91.3	
	27																						1	1	100.0	27.0	100.0
	Total	N	32	10	14	21	48	26	3	33	30	8	24	26	12	21	4	7	2	4	1	7	1	Total Sampling Points: 334 Total Correct: 235 Overall Accuracy: 70.3% Kappa Index: 68.02% 90% Confidence Intervals: 69.0%, 84.0%			
Omission Accuracy	(% Correct)	75.0	100.0	35.7	57.1	50.0	96.2	66.7	57.6	83.3	75.0	70.8	88.5	41.7	76.2	75.0	71.4	100.0	100.0	100.0	85.7	100.0					
90% Confidence Intervals	-	65.7	78.7	64.9	39.6	68.6	69.5	11.7	52.3	69.5	68.9	43.5	62.1	11.5	37.3	27.2	49.8	42.5	59.6	27.0	46.0	27.0					
	+	89.2	100.0	100.0	73.1	91.3	91.6	65.3	80.2	91.6	100.0	72.3	86.8	39.9	65.6	85.7	96.2	100.0	100.0	100.0	91.3	100.0					

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Table 9. Accuracy assessment contingency table (criteria 3, understandable accuracy) and statistical analysis of reference data with map class data.

Map Class Data		Reference Data (Field Data for Accuracy Assessment Class)																					Total	Commission Accuracy	90% Confidence Intervals		
	Map Code	1	2	3	4	5	6	7	8-10	11-12	13	14	15	16	17-19	20	21	22	23	25	26	27	N	(% Correct)	-	+	
	1	27		1			1								1								30	90.0	77.4	95.9	
	2		10																				10	100.0	78.7	100.0	
	3			5																			5	100.0	64.9	100.0	
	4				13	8																	21	61.9	44.1	77.0	
	5				2	26								1									29	89.7	76.8	95.8	
	6						30																30	100.0	91.7	100.0	
	7					1		5															6	83.3	49.8	96.2	
	8-10			3	2				20						3								28	71.4	56.0	83.1	
	11-12			1					1	28													30	93.3	81.7	97.8	
	13										6												6	100.0	68.9	100.0	
	14			1					2		1	25											29	86.2	72.6	93.7	
	15												30										30	100.0	91.7	100.0	
	16					1			2					18								1	22	81.8	65.1	91.6	
	17-19	2		2						4						23							31	74.2	59.7	84.8	
	20					1											4						5	80.0	43.5	95.4	
	21																	6					6	100.0	68.9	100.0	
	22																		2				2	100.0	42.5	100.0	
	23																			4			4	100.0	59.7	100.0	
	25																				1		1	100.0	27.0	100.0	
	26	2																				6	8	75.0	46.0	91.3	
	27																						1	1	100.0	27.0	100.0
	Total	N	31	10	13	17	37	31	5	25	32	7	25	30	22	24	4	6	2	4	1	7	1	Total Sampling Points: 334 Total Correct: 290 Overall Accuracy: 86.8% Kappa Index: 85.8% 90% Confidence Interval: 84.1%, 95.4%			
	Omission Accuracy	(% Correct)	87.1	100.0	38.5	76.5	70.3	96.8	100.0	80.0	87.5	85.7	100.0	100.0	81.8	95.8	100.0	100.0	100.0	100.0	100.0	85.7	100.0				
	90% Confidence Intervals	-	74.2	78.7	20.2	56.7	56.9	86.8	64.9	64.2	74.9	54.8	90.2	91.7	65.1	83.3	60.0	68.9	42.5	59.6	27.0	54.8	27.0				
+		84.1	100.0	60.7	90.0	80.9	99.3	100.0	89.9	57.4	96.7	100.0	100.0	91.6	99.1	100.0	100.0	100.0	100.0	100.0	96.7	100.0					

5. DISCUSSION

The vegetation at SUCR represents the results of primary succession 800 years after the volcanic reshaping of the landscape. This unique environment provided several challenges to vegetation mapping and can be summarized below:

- 1) Sparse vegetation is difficult to photointerpret and classify, especially if the substrate has a strong spectral signal, such as in cinder and lava. A strong spectral signature appears to have reduced the accuracy of mapped ponderosa pine classes with sparse understory communities (i.e. Ponderosa Pine / Apache Plume Woodland was often misclassified as Ponderosa Pine / Cinder Woodland and Ponderosa Pine / Montane Grass Mosaic).
- 2) Many new associations were described in the course of this project. NatureServe usually considered field relevés with less than five occurrences as local assemblages or provisional associations due to no previous data collection. With more extensive vegetation sampling and classification in northern Arizona, some of the types currently described as local assemblages or provisional associations may be assigned association status. Associations were not always the best mapping classes and some associations were aggregated into mosaics (i.e. Ponderosa Pine / Montane Grass Mosaic contains both the *Pinus ponderosa* / *Muhlenbergia montana* Woodland and *Pinus ponderosa* / *Bouteloua gracilis* Woodland association).
- 3) Scale changes between the preliminary map in 2001 and the final map in 2002 influenced the accuracy assessment results. Polygons that were assessed in 2001 when overlaid with the 2002 final vegetation map were found to be significantly different in size and shape. There were more preliminary polygons drawn at less than the MMU on the 2001 map. Project resources did not allow re-sampling of all 2001 data points in order to eliminate all these errors; although we did review each point and eliminated those that were suspected of representing that type of error. These changes resulted in differences in scale assessments of the polygons and probably reduced our overall map accuracy. Two-thirds of the accuracy assessment reference data were obtained in 2001 and showed a total accuracy of 48% using only these points. In 2002 the overall accuracy was 63% (exact criteria) using just 2002 collected reference data. For instance, Apache Plume Cinder Sparse Shrubland often occurred in small openings in ponderosa pine woodlands and was often interpreted as Ponderosa Pine / Apache Plume Woodland depending on the scale of the assessment.
- 4) The field key used for the accuracy assessment was not reviewed by the photointerpreters before accuracy assessment in 2001. It is recommended that all field keys be reviewed by the photointerpreters prior to accuracy assessment.
- 5) The field data collection, 1999, and accuracy assessment, 2001 and 2002, may be measuring land cover characteristics that are different from those shown on the 1996 photography used for map creation. Land surface changes since the 1996 aerial photography may be significant from the 1999 field sampling and the 2001/2002 accuracy assessment. Changes include land use, which caused alteration and development, recreational activities, fire and non-native

plant invasion composition. Seasonal vegetation changes from the time the aerial photographs were acquired (October 1996) to the time classification relevés and accuracy assessment observation points were sampled (summer 1999, 2000, 2001, and 2002) complicated the interpretation, since the dormant vegetation that was evident in the fall presents a different ecological aspect than summer vegetation. The difficulty of this task was increased because of the long shadows in October when both sets of photos were flown. New aerial photography flown near the summer solstice (June 21) would have minimized the shadow problem. Other problems with interpretation and digital transfer arose because the aerial photos and the DOQQs were flown in different years and exhibit different ground conditions. If new photography were used at the start of this project, at the time of this report the database's ground condition would only be three years old, not six years old. During the course of the SUCR vegetation mapping project, the Arizona Department of Transportation began widening U.S. Highway 89, which runs north and south along the western edge of the mapping area. The resulting changes in vegetation were not documented in the October 1996 photography. The highway was being expanded from a narrow two-lane highway to a four-lane highway with turning lanes and acceleration and deceleration lanes (Figure 14). In addition, the highway was widened so that "islands" of native vegetation, typically stands of ponderosa pine with a graminoid understory, remained in the median strip between the northbound and southbound travel lanes.



Figure 14. Photos illustrating reconstruction of portions of U.S. Highway 89.

At the southern end of this highway reconstruction project, the affected plant association is mapped as predominantly ponderosa pine woodlands with a mix of grasses and cinder in the understory. At the northernmost end of the highway reconstruction project the vegetation is montane grasslands and pinyon-juniper woodlands. Given the width of the reconstruction project, it is possible that nearly the entire stand of ponderosa pine was removed, or only a small portion may remain isolated in the median strip. Digital data showing the extent and location of the highway reconstruction was not available at the time we mapped SUCR. Once the highway data become available, the vegetation database should be revised to account for the new road cut and to re-calculate vegetation acreages. These map class changes may occur frequently enough to have caused misclassified polygons and therefore decrease the measured total accuracy assessment.

- 6) Twenty-eight percent of the total number of polygons were mapped at below the MMU. Accuracy assessment of these polygons is problematic due to the high amount of resources needed to correctly locate and assess these polygons. This not only increased the number of required polygons for accuracy assessment but also caused problems in interpretation of some classes. For example, Montane Grassland routinely occurs in small patches

interspersed among ponderosa pine and depending upon the scale of photointerpretation and field evaluation could often be confused with Ponderosa Pine / Montane Grass Mosaic. In addition, under a tree canopy GPS accuracy was often insufficient to conclusively place the field technician within polygons less than 0.5 hectares, particularly when the polygon may have had convoluted shapes.

- 7) The number and variability of vegetation signatures sometimes made them difficult to distinguish and interpret consistently. Environmental factors such as moisture gradients, slope exposure, presence and density of exotic grasses and forbs, and soil diversity result in several photographic signatures for each grassland and some shrub and woodland classes. Aerial photograph signatures in the ponderosa pine types were challenging to interpret because of dense mats of ponderosa pine litter and heavy layers of dust generated from pumice mining operations and recreation vehicle trails. Both conditions created a photosignature similar to that of dormant blue grama grass. Photography flown when the grass was green would have aided in distinguishing litter and dust from grass. Extensive ground reconnaissance and a number of accuracy assessment observation points were used to determine where the understory consisted of grasses or other herbaceous species versus mats of pine litter (Figures 15).



Figure 15. Typical ponderosa pine stands with pine litter and graminoid understories.

- 8) Color photography flown with more appropriate timing for this mapping project would have eliminated many of the problems and delays this project experienced. For example, RSGIG technicians spent a great deal of time trying to locate registration points on the aerial photos and the DOQQs.

Vegetation classification and map classes

Over 25% of the alliances and 35% of the associations were newly defined during the course of this project; the remainder was described as local assemblages described during the course of this project or incorporated into existing community classification. Most of the diversity of associations occurred within the woodland formation class. Ten of the 17 associations were directly translatable into map classes; the remaining associations were combined to form mosaics of vegetation as a map class. Additional detail in land use, canopy cover and associated species was photo-delineated for three of the associations and this additional detail was represented as map class modifiers. While the modifiers provided additional important information to the map, for accuracy assessment only map classes and not modifiers were analyzed.

Forests in the SUCR project area are not common. Although the term “ponderosa pine forest” is commonly used to describe the vegetation communities in the park, most of the ponderosa pine dominated areas have less than 75% canopy cover and contain a more open park-like canopy structure. Only in small patches at higher elevations on Darton Dome and O’Leary Peak does Douglas-fir and pinyon-pine forest canopy ever reach these cover values. Downslope these community types gradate quickly into a more open woodland-like formation. Therefore, most of our tree dominated vegetation communities fall within the sparser woodland communities.

Woodlands are represented mainly by ponderosa pine associations. The average tree cover for these associations is often a sparse 15% canopy cover. Although ponderosa pine associations throughout their range typically contain higher cover, at SUCR the primary successional environment limits tree establishment and growth rates. In fact, most of the ponderosa pine trees at SUCR have bent, distorted and exposed roots suggesting high environmental stress with deep cinder limiting seedling development. The ponderosa pine communities tend to have a few large trees and a sparse understory. These sparse understory species were difficult to distinguish on the aerial photography.

Only one NVCS shrubland alliances was defined in this project; the remaining shrublands were described in the sparse lifeform or as local shrubland stands. Due to the sparse patchiness of the landscape, and the large scale 1,000m² relevés, true shrublands were a minor type sampled. A mosaic, Rock Outcrop and Scree Shrubland, map class was developed to describe many of the small sparse stands of shrubs. As well, a sparse Apache Plume community often occurred in small patches in cinder barrens and in gaps of the ponderosa pine woodlands.

Five herbaceous associations were described and aggregated into three mappable classes. These were combined due to difficulty separating them in the photointerpretation. Most of the herbaceous associations were sampled using a small scale relevé (400m²), due to the density of the vegetation in these communities. Even after combining the communities, they were often misidentified on the map. Montane grasslands were often misclassified as invasive herbaceous types and vice versa. This problem not only stems from misinterpretation in the photo-delineation process, but from seasonal changes in herbaceous plant communities. It is likely that an area that had an invasive photosignature in 1996 no longer maintained the same species composition during the 2001 and 2002 field season. These errors represent a lapse of time between the photo acquisition and the project completion.

Although only two associations and one local assemblage were defined as sparse vegetation associations, many of the relevés placed in the woodland and herbaceous lifeforms contain less than 25% total vegetation cover. In order to not artificially proliferate associations based solely on their cover values they were combined based on similarities of their species composition and the cover ranges described for each association. The distinction between sparse communities and alternate placement in a woodland, shrub or herbaceous class is still under general review in the NVCS. At the time of classification only seven sparse alliances were represented in the NVCS classification. Further park classification work may have different standards and recommendations and may result in an altered placement of relevés than was determined in the course of this study.

The USGS-NPS vegetation mapping projects are designed to produce both a vegetation classification and a set of map classes. Typically the systems are very similar, but sometimes there is not a strict one-to-one correspondence between the two. Photographic interpretation is based on the ability to accurately and consistently delineate map classes based on complex signatures. Vegetation characteristics that can be seen on aerial photography are not necessarily the same as those apparent on the ground and vice versa. Field reconnaissance and map verification work by the photointerpreters aided enormously in developing the map classes and discerning the inherent variability of each photographic signature. Close collaboration between the mappers and the ecologists doing the classification was critical to each understanding the concepts behind the plant associations and map classes.

Accuracy assessment

The USGS-NPS park mapping program has the standard of 80% overall map accuracy and for each class. The map did not meet this accuracy using the exact (53.9%) or acceptable (70.3%) accuracy criteria, but it did using the understandable criteria (86.8%). The acceptable accuracy best describe the functional map accuracy and while it is lower than the standard, we believe the map is usable as long as the assessments for each individual map class are reviewed and are kept in mind when the map is being used for management purposes. Most of the error in the map can be directly attributed to known sources and not to gross error in photointerpretation.

Applications

The vegetation map is ready for use with the knowledge that some of the map classes are below the desired 80% accuracy. These map classes may need to be aggregated depending on the desired accuracy needed for a particular project. Map classes can be aggregated to the NVCS alliance level or to the lifeform.

This map will provide the baseline vegetation data that will allow for better resource management of the park. As with other USGS-NPS park management programs, it is possible that this map will assist with many different aspects of planning activities, including fire management planning, habitat modeling, field sampling for threatened and endangered species, research of particular species and their habitats, education and interpretation, and trail maintenance. This study will also help to compare habitats across management boundaries and hopefully to assist in the joint-agency management of the lands studied in the project environs. Ultimately, the vegetation map will help to monitor impacts on vegetation health as well as the overall ecosystem health of the area.

6. BIBLIOGRAPHY

- Agresti, A. & Coull, B.A. 1998. Approximate is better than exact for interval estimation of binomial proportions. *The American Statistician*. 52: 119-126.
- Anderson, J., E. Hardy, J. Roach, and R. Witmer. 1976. A Land Use and Land Cover Classification System for use with Remote Sensor Data. Geological Survey Professional Paper 964. U.S. Government Printing Office. Washington, D.C.
- Chronic, Halka. 1988. Pages of Stone -- Geology of Western National Parks and Monuments: Vol. 4, Grand Canyon & The Plateau Country. The Mountaineers Books.
- Cordasco, W. S., Thybony, and K. Thomas. 1998. Babbitt Ranches Biological Assessment of the Coconino Plateau. Babbitt Ranches. Flagstaff, AZ.
- ESRI. 2002. Internet Site: ESRI GIS and Mapping Software. www.esri.com. Accessed 2002-2003.
- Falzarano, S. and K. Thomas. In Press. Fuzzy set and Spatial Analyses of Thematic Accuracy of a land Cover Map. In R. Lunnetta and J.G. Lyon, editors, *Proceedings of the Remote Sensing and GIS Accuracy Assessment Symposium*, Las Vegas, NV, Dec 11-13, 2001.
- FEIS [Fire Effects Information System]. 2001. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2001, May). <http://www.fs.fed.us/database/feis/>. Accessed [11-17-03].
- FGDC [Federal Geographic Data Committee]. 1997. Vegetation classification standard, FGDC-STD-005 (<http://www.fgdc.gov/Standards/Documents/Standards/Vegetation>). United States Geological Survey, Reston, Virginia 22092 USA.
- Foody, G. M. 1992. On the Compensation for Chance Agreement. In *Image Classification Accuracy Assessment. Photogrammetric Engineering and Remote Sensing*, 58 (10): 1459-1460.
- Grossman, D. H., D. Faber-Langendoen, A.S. Weakley, M. Anderson, P. Bourgeron, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K. Patterson, M. Pyne, M. Reid, and L. Sneddon. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Volume I. The National Vegetation Classification System: Development, Status, and Applications. The Nature Conservancy, Arlington Virginia, USA.
- Jennings M., O. Loucks, D. Glenn-Lewin, R. Peet, D. Faber-Langendoen, D. Grossman, A. Damman, M. Barbour, R. Pfister, M. Walker, S. Talbot, J. Walker, G. Hartshorn, G. Waggoner, M. Abrams, A. Hill, D. Roberts, and D. Tart. 2003. Guidelines for Describing Associations and Alliances of the U.S. National Vegetation Classification, version 2.0.

- The Ecological Society of America, Vegetation Classification Panel. Internet Site: http://vegbank.nceas.ucsb.edu/vegbank/panel/esa_guidelines_v2.pdf.
- Klopfer, S.D., A. Olivero, L. Sneddon, and J. Lundgren. 2002. Final Report of the NPS Vegetation Mapping Program Fire Island National Seashore. Conservation Management Institute, GIS & Remote Sensing Division. Virginia Tech. Blackburg, Virginia, 24061.
- McCune, B. and M.J. Mefford. 1999. Multivariate analysis of ecological data. Version 4.01. MjM Software. Gleneden Beach, Oregon.
- Miller, G., N. Ambos, P. Boness, D. Reyher, G. Robertson, K. Scalzone, R. Steinke, and T. Subirge. 1991. Terrestrial Ecosystems Survey of the Coconino National Forest. United States Forest Service, Coconino National Forest, Flagstaff, Arizona, USA.
- Muller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. New York, NY: Wiley & Sons.
- Ort, M.H., M.D. Elson, and D.E. Champion. 2002. A Paleomagnetic Dating Study of Sunset Crater Volcano. Technical Report No. 2002-16. Desert Archeology, Inc. Tucson, Arizona.
- NPS [National Park Service]. 1997. Wupatki/Sunset Crater Volcano Official Map and Guide. U. S. Government Printing Office. Washington, D.C.
- NOAA [National Oceanic Atmospheric Administration]. 1997. Internet Site: National Climatic Data Center weather data. <http://www.ncdc.noaa.gov/ol/climate/online/coop-precip.html>. Accessed 1997-2003.
- Priest, S.S., W.A. Duffield, K. Malis-Clark, J.W. Hendley II, and P.H. Stauffer. 2001. The San Francisco Volcanic Field, Arizona. U.S. Geological Survey Fact Sheet 017-01. Internet Site: <http://geopubs.wr.usgs.gov/fact-sheet/fs017-01/>.
- Reid, M.S., K.A. Schulz, P.J. Comer, M.H. Schindel, D.R. Culver, D.A. Sarr, and M.C. Damm. 1999. Descriptions of vegetation alliances of the coterminous western United States. The Nature Conservancy, Boulder, Colorado, USA.
- SAS Institute 1989-2000. JMP Statistical Discovery Software. Version 4. Cary, NC.
- Thomas, K., Keeler-Wolf, T., Franklin, J., Stine, P. Mojave Desert Ecosystem Program: Central Mojave Vegetation Database Final Report. 2003. USGS Western Ecological Research Center, Sacramento, CA.
- TNC and ERSI [The Nature Conservancy and Environmental Research Systems Institute]. 1994a. NBS/NPS Vegetation Mapping Program: Field Methods for Vegetation Mapping. Arlington, VA.

- _____. 1994b. NBS/NPS Vegetation Mapping Program: Standardized National Vegetation Classification System. Arlington, VA.
- _____. 1994c. NBS/NPS Vegetation Mapping Program: Accuracy Assessment Procedures. Arlington, VA.
- USDA NRCS [U.S. Department of Agriculture, National Resource Conservation Service]. 1999. Internet Site: The PLANTS database. National Plant Data Center, Baton Rouge, LA. <http://plants.usda.gov/plants>. Accessed 2003.
- USGS-NPS [U.S. Geological Survey – National Park Service]. 2000. Internet Site: USGS - NPS Vegetation Mapping Program. <http://biology.usgs.gov/npsveg/>. Accessed 1998-2003.
- Zion Natural History Association. 1985. Geologic Cross Section of the Grand Canyon - San Francisco Peaks - Verde Valley Region. ISBN 0-915630-02-8. NPS-Zion National Park. Springdale, UT.

7. GLOSSARY

The following people contributed to this glossary: Alan Bell, Jack Butler, Daniel Cogan, Janet Coles, Doug Crawford, Dave Eckhardt, Monica Hansen, and Tom Owens.

This glossary refers to terms as they are used in USGS-NPS vegetation mapping projects. Some terms may not appear in this report.

7.5-Minute Quadrangle. Informally known as a 'quad' map. A USGS paper map product at 1:24,000 scale covering 7.5 minutes of latitude and 7.5 minutes of longitude. Features shown include elevation contours, roads, railroads, water bodies, buildings, urban developments, wooded cover, permanent ice fields, and wetlands. This is a basic layer of information for many ecological and natural resource applications. A digital version of a 7.5-minute quad is called a Digital Raster Graphic (DRG).

Accuracy. The closeness of results of observations, computations, or estimates to the true values or to values that are accepted as being true (ASP 1984). See also Error.

Accuracy Assessment (AA). The process of determining the thematic accuracy of the vegetation map. An unaffiliated ecologist tests map accuracy after the vegetation mapping and classification are complete. (Stadelmann et al. 1994).

Accuracy Assessment Point. A location where accuracy assessment data are collected. See "Producing rigorous and consistent accuracy assessment procedures" at <http://biology.usgs.gov/npsveg/aa/aa.html> for more information.

Aerial Photography. Photography taken from an airplane (not satellite) mounted with

specially designed photographic equipment. Ideally, the lens and the film are parallel to the surface being photographed. A sequence of aerial photographs along a flight line will have a certain amount of overlap so that the photos can be viewed with a stereoscope. "Sidelap" refers to overlap between flight lines (ASP 1984). Print size is usually 9"x9" and are photos that may use true color or color infrared film.

Alliance. A physiognomically uniform group of associations sharing one or more diagnostic (dominant or indicator) species that usually occur in the uppermost stratum of the vegetation (FGDC 1997). This is the second finest level in the NVCS hierarchy.

Anderson Classification System.

A classification system developed for use with remote sensing systems in the 1970s adopted for the National Vegetation Classification Standard to map cultural and water features (Anderson et al. 1976).

Level I	Level II
Urban or Built-up Land	Residential
	Commercial and Services
	Industrial
	Transportation, Communications, and Utilities
	Industrial and Commercial Complexes
	Mixed Urban or Built-up Land
	Other Urban or Built-up Land
Agricultural Land	Cropland and Pasture
	Orchards, Vineyards, and Ornamental Horticultural Areas
	Confined Feeding Operations
	Other Agricultural Lands
Water (non-vegetated portion)	
	Streams and Canals
	Lakes

	Reservoirs
	Bays and Estuaries
Barren Land	
	Dry Salt Flats
	Beaches
	Sandy Areas other than Beaches
	Strip Mines, Quarries, and Gravel Pits
	Transitional Areas
	Mixed Barren Lands

ArcInfo. A geographic information software used to view and analyze data.

Association. The finest level of the NVCS classification hierarchies. A physiognomically uniform group of stands of vegetation that share one or more diagnostic overstory and understory species. These elements occur as repeated patterns of assemblages across the landscape, and are generally found under similar habitat conditions (FGDC 1997).

Attribute (digital data). A numeric, text, or image data field in a relational database table (such as a GIS) that describes a spatial feature such as a point, line, polygon, or cell (ESRI 1994).

Automation. The process of entering data into a computer (see also Digitize).

Base map. The control to which all spatial data is georeferenced. Interpreted photo data are transferred to a base map to rectify and register the data. In this project the base maps are USGS DOQQs.

Bureau of Reclamation (USBR, BOR).

A U.S. Department of Interior agency created in 1902 and charged with developing environmentally and economically sound irrigation and hydropower projects in 17 Western States. The Remote Sensing and

GIS Group of the BOR manages a number of park projects for the USGS-NPS Vegetation Mapping Program.

Biological Resources Discipline (BRD). A USGS discipline housing the Center for Biological Informatics. The BRD's mission is to work with others to provide the scientific understanding and technologies needed to support the sound management and conservation of our Nation's biological resources. Formerly, the National Biological Service (NBS).

Center for Biological Informatics (CBI). A USGS Science Center. CBI serves as the operating agent for the National Biological Information Infrastructure. In addition, CBI manages the USGS-NPS Vegetation Mapping Program along with other national data collection programs that complement and strengthen its role within the NBII.

Class. The level in the NVCS hierarchies based on the structure of the vegetation. Class is determined by the relative percentage of cover and the height of the dominant, uppermost life forms (Grossman et al. 1998).

Classification Accuracy. How closely the map classes match the vegetation found on the landscape. This is determined by accuracy assessment protocols. See "Producing rigorous and consistent accuracy assessment procedures" at <http://biology.usgs.gov/npsveg/aa/aa.html> for more information.

Color Infrared (CIR) Film. A three-layer color film sensitized to green, red, and near-infrared portions of the spectrum. CIR films emphasize differences in infrared reflectance from surfaces and are some of the most useful aerial films currently available for use in agricultural and vegetation surveys. The images are sharper and have better contrast

than conventional color photos because they are less susceptible to atmospheric light scattering. Furthermore, CIR has a high transmission component through green leaves, meaning that it can detect layers of leaves lower in the canopy. In true-color photography, the photosynthetic pigments within leaves quickly absorb visible light, and the film records information about nothing below the uppermost leaf layer. Color differences recorded on CIR film are used to differentiate among vegetation types. Generally, in spring and summer, healthy deciduous trees and other vegetation photographs as magenta or red, while healthy evergreens photograph more as a brownish red. CIR film can only be used in daylight.

Commission Accuracy. See Producer's Accuracy.

Community. An assemblage of species that co-occur in defined areas at certain times and have the potential to interact with one another (Grossman et al. 1998). In the NVCS, Association and Community are synonyms.

Community Element Global (CEGL). NatureServe's unique plant association coding system in their central biodiversity database; also known as Elcode.

Community Type. See Association or Type.

Complex. A group of associations that are not distinguishable from one another on aerial photography and so are grouped into a map class. Compare with Mosaic.

Confusion Matrix. See Contingency Table.

Contingency Table. A table that is used in accuracy assessment to determine the degree of misclassification that has occurred. The

table compares the classes derived from accuracy assessment relevés to the classes derived from photointerpretation. Also referred to as Error Matrix, Confusion Matrix, or Misclassification Matrix.

Coordinate System. A reference system that represents horizontal and/or vertical locations and distances on a map. A geographic coordinate system is the latitude and longitude with respect to a reference spheroid. A local coordinate system is one that is not aligned with the Earth's surface. Most coordinate systems are based on projections of the earth's surface onto a plane. All spatial data in this project uses the Universal Transverse Mercator (UTM) coordinate system.

Cover. The area of ground covered by the vertical projection of the aerial parts of vegetation (FGDC 1997).

Cover Type. A designation based upon the plant species forming a plurality of composition within a given area (e.g., Oak-Hickory) (FGDC 1997). It is roughly equivalent to an Alliance in the NVCS classification hierarchy.

Coverage. A data theme in a geographic information system with vector and polygon topology and attribute data related to that topic. Also, the file format used by Arc/Info software for vector spatial data.

Cowardin Classification. A wetland classification system used as the FGDC standard for wetland classification (Cowardin et al. 1979).

Crosswalk. The relationship between the elements of two classification systems. For example, this project includes a crosswalk between Map Classes and units of the

NVCS. In a database, the crosswalk is in a Lookup Table (LUT).

Cultural Vegetation. Vegetation planted or actively maintained by humans such as annual croplands, orchards, and vineyards. Contrast with Natural Vegetation.

Datum. A mathematical model that describes the shape of the earth. The earth is not a sphere but is rather an ellipsoid distorted by rotation about its axis, bulging at the equator and flattened at the poles. Because of the distribution of continents and seas, the distortion is not uniform around the globe and there are datums for different parts of the earth based on different measurements (Snyder 1982). The datum used by this project is NAD83.

Datum (horizontal-control). The position on the spheroid of reference assigned to the horizontal control of an area. A datum may extend over an entire continent or be limited to a small area (referred to as 'local datum'). This project used the North American Datum of 1983 (NAD83) (ASP 1984).

Density. Density is the relationship between the area covered by the vegetation and the total area of a polygon in which the community is found. The USGS-NPS Vegetation Mapping Program uses a series of arbitrarily defined density classes to separate vegetation units: Closed/Continuous > 60 %, Discontinuous 40-60%, Dispersed 25-40%, Sparse 10-25%, Rare 2-10%. Compare with Pattern and Height.

Diagnostic Species. A species generally considered to indicate (i.e., diagnose) a specific set of environmental conditions. For example, the presence of *Vaccinium stamineum* var. *stamineum* (gooseberry) beneath a canopy of chestnut oak, black oak, and Virginia pine indicates that the site is

dry. The trees can inhabit a wide range of sites, wet to dry, but the gooseberry understory is the indicator of a drier habitat. Sometimes also called Indicator Species (FGDC 1997).

Dichotomous Field Key. A document that identifies plant associations or map classes on the basis of pairs of exclusive characteristics such as "forested" versus "non-forested". This key is an important product of each vegetation-mapping project. Also known as Vegetation Field Key and Vegetation Key.

Digital Orthophoto Quadrangle (DOQ). A USGS digital product derived from high altitude aerial photography. Each DOQ is rectified and registered to locations on the earth and covers the same area as a 7.5 minute quad. These are often used as base maps to register photointerpreted data. See also Quarter Quadrangle.

Digital Raster Graphic (DRG). A scanned image of a paper USGS topographic quadrangle map. The geographic information is georeferenced to the UTM projection with the same accuracy and datum as the original map. The minimum scanning resolution is 250 dots per inch.

Digitize. The process of converting lines on a map or image into a computer file. The basic technique involves tracing a line with a device connected to a computer that sends a stream of x-y coordinates corresponding to the traced line into a computer file. Synonymous with Automation.

Division. The highest level in the NVCS hierarchy, separating the earth's surface into vegetated and non-vegetated categories (FGDC 1997). (See NVCS).

Dominance. The extent to which a given species or life form dominates in a community because of its size, abundance or cover. The ecological assumption is that dominant species can affect the fitness of associated species (FGDC 1997).

Dominant Life Form. An organism, group of organisms, or taxon that by its size, abundance, or coverage exerts significant influence upon an association's biotic and abiotic conditions (FGDC 1997).

Ecological Groups. Non-NVCS categories of vegetation based on plant assemblages, physical environments, and dynamic processes useful for conservation planning. These groups are classified on total floristic composition, physiognomy (vertical structure), distribution (horizontal structure), physical environment (slope, rainfall), chemical variables (soil pH), and disturbance regimes. Some factors are difficult to measure directly, and must be inferred from knowledge of species ecology, spatial patterns, and ecological processes.

Edge Distortion. In reference to aerial photographs, lens distortion increases with distance from the center of the photograph. Because of this, photointerpreters work only with the center third of each aerial photograph.

Error. The numeric distance of results of observations, computations, or estimates from the values that are accepted as being true. Also refers to the misclassification of thematic data. Contrast with Accuracy.

Error Matrix. See Contingency Table.

Existing Vegetation. The plant species existing at a location at the present time. The USGS-NPS Vegetation Mapping Program

classifies and maps existing vegetation. Contrast with Potential Vegetation

Federal Geographic Data Committee (FGDC). Coordinates the development of the National Spatial Data Infrastructure (NSDI). The NSDI encompasses policies, standards, and procedures for agencies to produce and share geographic data. The 17 federal agencies that make up the FGDC are developing the NSDI in cooperation with state, local, and tribal governments, the academic community, and the private sector.

Field Reconnaissance. Preliminary field visits by photointerpreters and vegetation ecologists to gain an overview of the vegetation of the project area and how it relates to the NVCS.

Flight Line. A line connecting the principal points of sequential vertical aerial photographs. Designated on the film as 'flight line number – photo number' (ASP 1984).

Floristics. The kinds, number and distribution of plant species in a particular area.

Formation. A level in the NVCS hierarchies that represents vegetation types sharing a definite physiognomy or structure within broadly defined environmental factors, relative landscape positions, or hydrologic regimes (Grossman et al. 1998).

Frequency. The number of occurrences of an item of interest.

Georeference. The process of converting a map or image into real-world coordinates. A non-georeferenced map or image is said to be in 'digitizer-inches' or 'scanner-inches', i.e., it has no real-world coordinates.

Geographic Information System (GIS).

An organized database of geographically referenced information (ESRI 1994).

Global Positioning System (GPS). A system of satellites, ground receiving stations and handheld receivers that allow accurate location of features on the earth's surface. GPS receivers are used to locate field relevés, reconnaissance points, and accuracy assessment points.

Gradsect. Gradient directed transect sampling. The gradsect sampling design is intended to provide a description of the full range of biotic variability (e.g., vegetation) in a region by sampling along the full range of environmental variability. This approach is based on the distribution of vegetation along environmental gradients. Transects that contain the strongest environmental gradients in a region are selected in order to optimize the amount of information gained in proportion to the time and effort spent during the vegetation survey (Grossman et al. 1994).

Ground photograph. An image recorded with the photographer standing on the ground (See Aerial Photography).

Ground truth. The process of taking aerial photographs into the field to see how particular photographic signatures compare with the vegetation on the ground.

Group. The level in the NVCS hierarchies based on leaf characters and identified and named in conjunction with broadly defined macroclimatic types to provide a structural-geographic orientation (Grossman et al. 1998).

Habitat. The combination of environmental or site conditions and ecological processes influencing a plant community.

Habitat Type. 1. A collective term for all parts of the land surface supporting, or capable of supporting, the same kind of climax plant association (Daubenmire 1978). 2. An aggregation of land areas having a narrow range of environmental variation and capable of supporting a given plant association (Gabriel and Talbot 1984).

Hectare. A metric unit of measure equal to 10,000 m² or approximately 2.471 acres.

Height. Height of the overstory of a plant community. One of the physiognomic modifiers classified in the USGS-NPS Vegetation Mapping Program. Vegetation polygons are attributed by height class: < 0.5 m, 0.5-2 m, 2-5 m, 5-15 m, 15-35 m, 35-50 m, >50 m. Compare with Density and Pattern.

Indicator Species. See Diagnostic Species.

Infrastructure. Human-built systems that include structures such as roads and bridges, water supply systems, and electric, gas or telephone lines.

Integrated Taxonomic Information System (ITIS). A comprehensive, standardized reference for the scientific names, synonyms and common names for all the plants and animals of North America and the surrounding oceans. This database is accessible over the Internet (<http://www.itis.usda.gov/>). The PLANTS database is an important ITIS partner providing plant taxonomic information to ITIS.

Land Cover Classification.

A classification of the cultural, physical, and vegetation features that cover the earth, commonly used with remote sensing technology. The Anderson Classification System is a land cover/land use classification.

Vegetation classification is a subset of land cover classification.

Land Use Classification. A classification of the earth's surface that defines the human use the land is providing. Commonly used with remote sensing technology, and usually combined with land cover classification. Natural vegetation may be classified as "vacant", "forest", or "grazing".

Large-scale. Refers to a map or image with a large-scale denominator (e.g., 1:100,000). Large-scale maps cover a broad area, are usually low in detail, and images usually have low resolution (e.g., 30m per pixel).

Look-Up Table (LUT). A computer file that is a list of standard elements that may be entered in a field in the database. In the context of these vegetation-mapping projects, LUT relates the elements of one classification to another in a crosswalk. The values of a map classification could be related to the associations of the NVCS in a park project.

Map Accuracy. A measure of the maximum error allowed in horizontal location and elevation on maps. For example, the USGS map accuracy standards for 1:24,000-scale maps are that 90% of well-defined objects should appear within 40 feet (12.2 meters) of their true location. See United States National Map Accuracy Standards.

Map Attribute. See Attribute.

Map Class. Plant communities and non-vegetated elements that can be discerned on an aerial photograph. If individual plant associations cannot be distinguished on an aerial photograph, map classes lumping related plant associations must be developed. For example, at Devils Tower National Monument there were five associations in the

Ponderosa Pine Woodland Alliance, but it was necessary to create two ponderosa pine map classes because the associations could not be distinguished on the photography. Also known as Map Unit.

Map Code. The map class code number related to the map class. For example, map class Cinder Sparse Mosaic has a map code of 1.

Map Scale. The relationship between a distance portrayed on a map and the same distance on the earth's surface (Dana 1999). A scale of 1 inch = 1000 feet can also be expressed as 1:12,000 (i.e., 1 inch on the map equals 12,000 inches on the earth). When a map is reproduced in a different size, the scale reference (1:12,000) is no longer valid but the scale bar on the map is still valid.

Map Projection. A systematic conversion of locations on the Earth's surface from spherical coordinates to planar coordinates (ESRI 1994).

Map Unit. See Map Class.

Map Validation. The process of field checking photointerpretation. This step is completed prior to accuracy assessment.

Metadata. A text file describing how a spatial database was created. Metadata files document how the data were created, their content, quality, condition, and other characteristics. Metadata's purpose is to help organize and maintain an organization's internal investment in spatial data, provide information about an organization's data holdings to data catalogues, clearing-houses, and brokerages, and provide information to process and interpret data received through a transfer from an external source (FGDC 1997). The FGDC sets the content standards for metadata. The NBII has developed

software to aid in creating metadata and commercial software programs are also available.

Minimum Mapping Unit (MMU). The smallest area that is consistently delineated during photointerpretation. The MMU for the USGS-NPS Vegetation Mapping Program is 0.5 hectares.

Mosaic (Biology). An intermixing of plant associations in an area that has a unique photosignature but is too intricate for individual associations to be delineated. Compare with Complex.

Mosaic (Image). An image composed of an assemblage of edge-matched, overlapping aerial photographs.

National Biological Information Infrastructure (NBII). A broad, collaborative program to provide access to data and information relating to the Nation's biological resources. The NBII links diverse, high-quality biological databases, and analytical tools maintained by NBII partners in government agencies, academic institutions, nongovernmental organizations, and private industries.

National Biological Service (NBS). See Biological Resources Discipline.

National Map Accuracy Standards. See US National Map Accuracy Standards.

National Park Service (NPS). A U.S. Department of Interior agency created in 1916 and charged with preserving the natural and cultural resources of the national park system for the enjoyment, education, and inspiration of this and future generations. NPS manages the National Parks and the Inventory and Monitoring Program and works

closely with USGS to coordinate the USGS-NPS Vegetation Mapping Program.

National Vegetation Classification Standard (NVCS). The Federal Geographic Data Committee's vegetation classification model. It has been adapted to the formation level (as of June 2001); adoption of standards for finer levels is expected in the spring of 2004 with the adoption of the Ecological Society of America's 'Guidelines For Describing Associations and Alliances of the U.S. National Vegetation Classification'. Currently the U.S. National Vegetation Classification (NVC) is maintained by NatureServe and can be examined on their on-line NatureServe Explorer database (<http://www.natureserve.org/explorer/>).

Natural Heritage Programs. Operate throughout much of the western hemisphere gathering, managing, and distributing detailed information about the biological diversity found within their jurisdiction. Most programs are part of government agencies such as fish and wildlife departments, although some are run by universities or nongovernmental organizations.

Natural Resources Conservation Service (NRCS). A USDA agency that is the lead federal agency for conservation on private land and is a partner in land conservation with private land managers, conservation districts; resource conservation and development (RC&D) councils; state and local conservation agencies; state, local, and Tribal governments; rural communities; businesses; and others. The NRCS produces the nation's Soil Survey reports.

Natural Vegetation. Plant life of an area that appears to be substantially unaltered by human activities. Most existing vegetation has been subjected to some human modification, so a clear distinction between natural

and cultural vegetation may sometimes be difficult (Grossman et al. 1998).

NatureServe. A non-profit organization dedicated to developing and providing knowledge about the world's natural diversity. In cooperation with the Natural Heritage Network, NatureServe collects and develops authoritative information about the plants, animals, and ecological communities of the Western Hemisphere. NatureServe maintains databases to support the United States National Vegetation Classification Standard (NVCS) and the relevé data that it is based on. Nature-Serve's role in this project was to help develop the vegetation community classification. Formerly known as ABI (Association for Biodiversity Information).

North American Datum (NAD). The standard cartographic reference for map projections and coordinates throughout North America (see also Datum). Usually associated with a version, such as 1927 or 1983. This project used the 1983 North American datum (NAD83), which is consistent with satellite location systems. The 1983 datum uses the GRS 80 spheroid whereas the 1927 datum uses the Clarke 1866 spheroid (ESRI 1994).

Observation Point. Field data used to support map class and vegetation classification development. These points are collected during reconnaissance and verification field work.

Omission Errors. See Producer's Accuracy.

Order. The 2nd highest level in the NVCS hierarchy (FGDC 1997). An order is generally defined by dominant life form (tree, shrub, dwarf shrub, herbaceous, or non-vascular)

Ortho Image. An aerial photograph that has had the distortions common to aerial photography removed and has been registered to locations on the earth. A digital ortho image can be placed in a GIS and have other layers, such as vegetation, overlain on it. A DOQQ is an ortho image. Also sometimes called an ortho-photo.

Pattern. Describes the distribution of vegetation features across a landscape. Some examples include: Evenly Dispersed, Clumped/Bunched, Gradational/Transitional, or Alternating. Compare with Density and Height.

Photointerpretation. The art and science of identifying and delineating objects and conditions on an aerial photograph.

Photointerpretation Key. A description, often accompanied by pictures of examples, of the visual elements that make up the photographic signature of each map class.

Photointerpretation Modifiers. Codes used to describe special features that are not part of the NVCS. For example, an agency may be interested in eagle nests, beaver dams, prairie dog towns, and forest blow-down areas.

Photosignature. See Signature.

Physiognomic Modifiers. Modifiers used to describe the physiognomic structure of the vegetation found within a mapped polygon (e.g., cover, density, pattern, height).

Physiognomy. The structure and life form of a plant community (FGDC 1997).

Plant Association. See Association.

Plant Community. See Community.

PLANTS database. A database maintained by the Natural Resource Conservation Service. This database focuses on vascular plants, mosses, liverworts, hornworts, and lichens of the U.S. and its territories. The PLANTS Database includes names, checklists, automated tools, identification information, species abstracts, distributional data, crop information, plant symbols, plant growth data, plant materials information, links, references, and other information. This is the database that maintains the current list of accepted scientific names. See <http://plants.usda.gov/>.

Plot. A defined location of a certain size where the data necessary to classify the vegetation is collected. Plots are generally located non-randomly and plot size varies depending on the vegetation being sampled. See: <http://biology.usgs.gov/npsveg/fieldmethods>. Plot data are entered into a database for storage and analysis. Also referred to as Relevés.

Polygon. A multisided figure that represents area on a map. A polygon is defined by the lines that consist of the boundary and the label point within its boundary used for identification. Polygons have attributes that describe the geographic feature they represent.

Positional Accuracy. How close a point in a spatial database is to its actual location on the earth's surface. The National Map Accuracy Standard for horizontal positional accuracy at the 1:24,000 scale is 1/50 of an inch (40 feet/12.2 m) of an object's actual location.

Potential Vegetation. The vegetation that would become established if succession were completed without interference under the present climatic and edaphic conditions. Contrast with Existing Vegetation.

Precision Lightweight GPS Receiver (PLGR). A small handheld, global positioning system (GPS) receiver developed for the military and featuring anti-spoofing and anti-jamming capability.

Producer's Accuracy. The probability that a reference sample (the ground data) has been classified correctly, also known as error of omission. This quantity is computed by dividing the number of samples that have been classified correctly by the total number of reference samples in that class (Storey and Congalton 1986). Compare with User's Accuracy.

Projection. A two-dimensional representation of data located on a curved surface. Projections always involve distortion, so the cartographer must choose which characteristics (distance, direction, scale, area, or shape) will be emphasized at the expense of the other characteristics (Snyder 1982). In this project, all spatial data use the Universal Transverse Mercator (UTM) coordinate system that is based on the transverse mercator projection applied between 84 degrees north and 80 degrees south latitude.

Quadrangle. A USGS 7.5 minute topographic map.

Quarter Quad(rangle). A map or image that includes $\frac{1}{4}$ of a 7.5-minute quadrangle map. Quarter quadrangles are organized in geographic quadrants of the original map: northeast, northwest, southeast, and southwest.

Rectify. To remove distortions from aerial photographs in the process of transferring interpreted photographs into a spatial database. Distortions on photographs are due to topographic relief on the ground, radial distortion in the geometry of the aerial photog-

raphy, tip and tilt of the plane, and differences in elevation of the airplane from its nominal scale. This process may be separate or included in the registration process, depending on the technology used.

Reference Data. The field data that is collected for the accuracy assessment.

Register. The process of relating objects on an aerial photograph to the surface of the earth. This is necessary to be able to place vegetation data in a GIS with other spatial data such as roads, topography, or soils. This process may be separate or may be included in the rectification process, depending on the technology used. See also Transfer.

Relevé. See Plot.

Sample Data. Sample data are the map classes that were photo-delineated as occurring on the vegetation map. The sample data is compared to the reference data (see reference data) to compute map accuracy.

Scale. The relationship between a distance portrayed on a map and the same distance on the Earth (Dana 1999). A map scale can be defined by a fraction (e.g., 1 unit on map / 12,000 units on ground) or by a graphic scale bar.

Signature. The unique combination of color, texture, pattern, height, physiognomy, and position in the landscape used by photointerpreters to identify map classes on an aerial photograph. Or, characteristics of an item on a photograph by which the item may be identified (ASP 1984). Also referred to as Photosignature.

Small-scale. Refers to a map or image with a relatively small-scale denominator (e.g. 1:1,000). Small-scale maps cover a small

area, have fine detail, and the images have high resolution (e.g. 0.5m per pixel).

Spatial. Refers to features or phenomena distributed in geographic space and having physical, measurable dimensions.

Special Modifiers. See Photointerpretation Modifiers.

Stratum. A horizontal layer of vegetation. A stratum may be defined by the life form of the vegetation (tree, shrub, herbaceous), its relative position in the community (understory) or its actual height.

Structure (Vegetation). The spatial distribution pattern of life forms in a plant community, especially with regard to their height, abundance, or coverage within the individual layers. Synonymous with Physiognomy.

Subclass. The level in the NVCS hierarchies based on growth form characteristics (Grossman et al. 1998).

Subgroup. The level in the NVCS hierarchies that divides each group into either a "natural/semi-natural" or "cultural" (planted/cultivated) subgroup (Grossman et al. 1998).

The Nature Conservancy (TNC). A non-profit conservation organization founded in 1951. Working with communities, businesses and people, TNC protects millions of acres of valuable lands and waters worldwide. TNC was the original caretaker of the National Vegetation Classification (NVC), but those responsibilities have been spun off to NatureServe. TNC no longer has an active role with the USGS-NPS Vegetation Mapping Program.

Thematic Accuracy. The correctness of the map classes in relation to the vegetation on the ground. This is determined through standardized accuracy assessment procedures. The program standard is 80% accuracy for each map class within 90% confidence intervals. See Accuracy Assessment, Producer's Accuracy, and User's Accuracy.

Thematic Map. A map that displays the spatial distribution of a single attribute or a specific topic, such as land-cover and land-use classes.

Topology. The explicit definition of how map features represented by points, lines and areas are related. Specifically, accounting for issues of connectivity and adjacency of features.

Topographic Quads. USGS paper maps showing the topography of an area as well as roads, railroads, water bodies, buildings, urban developments, and wetlands. These come in a variety of scales, but commonly refer to 1:24,000-scale 7.5-minute quads. Informally referred to as topo quads.

Transfer. The process of entering data from interpreted aerial photo overlays into a digital database. The data is usually registered and rectified into real-world geographic coordinates. This process varies depending on the type of technology used. See also Transformation.

Transform(ation). The process of converting coordinates (map or image) from one coordinate system to another. This involves scaling, rotation, translation, and warping (images) (ESRI 1994).

Transition Zone. An area where the vegetation composition and structure is intermediate between two associations. The tran-

sition zone may be narrow as associations abruptly change due to a significant change in a major habitat factor, such as a cliff, or it may be broad when the physical environment changes gradually. Transition zones may be challenging to classify or map.

Type. A generic term that can mean any vegetation level in the NVCS, whether an association, alliance, formation, etc, or even a combination of levels. It is a vague but useful term. It is correctly used when the focus is not on a specific unit of vegetation, but rather when used loosely to explain some other point (e.g., "We do not have a good grasp of how vegetation types at Acadia link to the map classes."). Also known as Vegetation Type.

United States Geological Survey (USGS). Established in 1879, the USGS is the natural science agency for the Department of the Interior. The USGS is one of the host agencies, along with the National Park Service, for the USGS-NPS Vegetation Mapping Program.

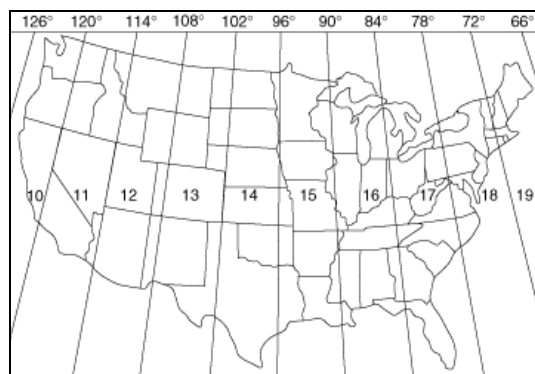
United States National Map Accuracy Standards. Defines accuracy standards for published maps, including horizontal and vertical accuracy, accuracy testing method, accuracy labeling on published maps, labeling when a map is an enlargement of another map, and basic information for map construction as to latitude and longitude boundaries. The table below shows the standard for some common map scales. Note that the conversion of paper maps into digital data usually creates additional error.

Scale	Engineering Scale	Accuracy Standard
1:1,200	1"=100'	+/- 3.33 feet
1:2,400	1"=200'	+/- 6.67 feet
1:4,800	1"=400'	+/- 13.33 feet
1:9,600	1"=800'	+/- 26.67 feet

1:10,000		+/- 27.78 feet
1:12,000	1"=1000'	+/- 33.33 feet
1:24,000	1"=2000'	+/- 40.00 feet
1:63,360	1"=one mile	+/- 105.60 feet
1:100,000		+/- 166.67 feet

Universal Transverse Mercator (UTM).

A map coordinate system (not a map projection) that is defined by the Transverse Mercator projection which has a set of zones defined by a central meridian as shown in the figure below for the United States (ESRI 1994):



User's Accuracy. In assessing the thematic accuracy of a vegetation map, the probability that a sample from the mapped data actually represents that category on the ground, also known as error of commission. This quantity is computed by dividing the number of correctly classified samples by the total number of samples that were classified as belonging to that category (Story and Congalton 1986). Compare with Producer's Accuracy.

Vector Data. Spatial (usually digital) data that consists of using coordinate pairs (x, y) to represent locations on the earth. Features can take the form of single points, lines, arcs or closed lines (polygons).

Vegetation. The plant cover over an area (FGDC 1997).

Vegetation Characterization. The detailed description of a plant association's diagnostic and dominant species, structure, and/or ecological processes. See: <http://biology.usgs.gov/npsveg/agfo/descript.pdf>

Vegetation Classification. The process of categorizing vegetation into recognizable and consistent elements. Also a document that lists and organizes the vegetation communities in an area. An example of a vegetation classification can be found at <http://biology.usgs.gov/npsveg/agfo/methods.pdf> classification.

Vegetation Community.

See Community.

Vegetation Description.

See Vegetation Characterization.

Vegetation (Field) Key.

See Dichotomous Field Key.

Vegetation Mapping. The process of identifying, classifying, and locating vegetation communities using real world coordinates.

Vegetation Structure. See Structure.

Vegetation Type. See Type.

Vertical Aerial Photography.

See Aerial Photography.

Wetland. A community or landscape type that is characterized by either hydric soils or hydrophytic plants or both. A wetland may be vegetated or non-vegetated.

Glossary Literature Cited

- ASP [American Society of Photogrammetry]. 1984. Multilingual Dictionary of Remote Sensing and Photogrammetry. Rabchevsky, G.A. (Editor). Falls Church, VA.
- Anderson, J.R., E.E. Hardy, and J.T. Roach. 1976. "Land Use and Land Cover Classification System for Use with Remote Sensing Data." Geological Survey Professional Paper 964. A revision of the land use classification system as presented in US. Geological Circular 671. Washington, D.C: U. S. Government Printing Office.
- Cowardin, L. W., V. Carter, F.C. Golet, and E. T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. Biological Service Program, U.S. Fish and Wildlife Service, FWS/OBS 79/31. Office of Biological Services, Fish and Wildlife Service, U.S. Department of Interior, Washington, D.C., USA.
- Dana, P.H. 1999. Map Projection Overview.
http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj_f.html.
- Daubenmire, R.F. 1978. Plant Geography, with Special Reference to North America. New York, New York.
- ESRI [Environmental Systems Research Institute, Inc.]. 1994. Understanding GIS: The Arc/Info Method. Redlands, CA.
- FGDC [Federal Geographic Data Committee]. 1997. Vegetation Classification Standard.
<http://biology.usgs.gov/fgdc/veg/standards/vegstd.html>.
- Gabriel, H.W. and S.S. Talbot. 1984. "Glossary of Landscape and Vegetation Ecology for Alaska." Alaska Technical Report 10. Washington, D.C.: Bureau of Land Management, U.S. Department of the Interior.
- Grossman, D.H., D. Faber-Langendoen, A.S. Weakley, M. Anderson, P. Bourgeron, R. Crawford, K. Goodin, S. Landal, K. Metzler, K. Patterson, M. Pyne, M. Reid, and L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. Arlington, VA. The Nature Conservancy.
- Grossman, D.H., K.L. Goodin, X. Li, D. Faber-Langendoen, M. Anderson, and R. Vaughan. 1994. Establishing standards for field methods and mapping procedures. Prepared for the USGS-NPS Vegetation Mapping Program by The Nature Conservancy, Arlington VA, and Environmental Science Research Institute, Redlands, CA.
- Snyder, John P. 1982. Map Projections Used by the U.S. Geological Survey. 2nd Edition. Washington, D.C.: United States Government Printing Office.

Stadelmann, M., A. Curtis, R. Vaughan, and M. Goodchild. 1994. Producing rigorous and consistent accuracy assessment procedures. Prepared for the USGS-NPS Vegetation Mapping Program by The Nature Conservancy, Arlington VA, and Environmental Science Research Institute, Redlands, CA.

Storey, M. and R. G. Congalton. 1986. Accuracy assessment: A user's perspective, *Photogrammetric Engineering and Remote Sensing*.

APPENDIX A

A. CD-Rom Readme Text and CD-Rom

The following is the text of the Readme.doc document for the CD-Rom that accompanies this report. This CD-Rom contains all coverages and GIS data developed for the SUCR vegetation map, databases for vegetation classification relevés and accuracy assessment observations, field photos, report files, and associated metadata. The associated metadata describes the attributes in all of the coverages and databases. We also include a list of appropriate citations below each of the coverages or databases to be used when citing these sources.

The files are arranged on the CD-Rom as follows:

Readme.doc – This file

1. Ancillary_Data Folder - This folder contains 4 subfolders with information on the park, project, and imagery boundary files. Each subfolder contains a coverage in Arc/Info export format (.e00), a shape file, a coverage, and associated metadata:
 - a. Flightline_bndry- Flightline boundaries used to develop the aerial photography
Citation:
U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Flight Line Coverage: Sunset Crater Volcano National Monument. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - b. Park_bndry- Boundary of Sunset Crater Volcano National Monument
Citation:
Flagstaff Area National Monuments. 2004. Boundary: Sunset Crater Volcano National Monument, AZ. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - c. Proj_bndry- Boundary for vegetation map for Sunset Crater Volcano National Monument
Citation:
U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Project Boundary: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - d. Quad_Doqq_bndry-Boundary of the USGS topographic quadrant maps for Sunset Crater Volcano National Monument
Citation:
U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Boundary: Flagstaff Area National Monuments USGS Quadrangles and DOQQs. A digital spatial database (ArcInfo). U.S. Geological Survey.
2. Basemap folder – This folder contains the MrSid compressed mosaic of the DOQQs and associated metadata for Sunset Crater National Monument. The MrSid images can be viewed as images in ArcView using the MrSid extension.
Citation:
U.S. Geological Survey. 2004. DOQQ Basemap: Sunset Crater Volcano National Monument. Digital orthophotoquads. U.S. Geological Survey.

3. Ground Photos (.tif/.jpeg) - This folder contains photos for each relevé collected for the vegetation classification. Each photo is listed as “SC-***a/b/c” where the SC stands for Sunset Crater, the *** indicates the relevé number, and either a, b, or c is listed after the prefix corresponding sequentially to the number of photos taken at each relevé point. For example, at relevé number SC-032 two photos were taken and are listed as SC-032a and SC-032b. For additional information on the aspect and time of the photo taken at each relevé refer to the Vegetation Relevé Database described below.
4. Map_Demo – This folder contains an ArcView project file (.apr), associated data that was used to create the final vegetation map, graphics associated with printing the vegetation map, and a readme.txt file. To open the project, a copy of this folder must be placed on your hard drive. You will also need the ArcPress extension. Start ArcView and then navigate to the project file (Sucr_demo.apr). Further information can be found in the included readme.txt. To print the vegetation map, a graphic of the map can be found under the Vegetation_Map folder, under the Graphics folder, and in the Map_Demo folder. In the HP_RTL folder an ArcPress extension (sucr_veg.rtl) will allow you to directly print the map layout to a plotter. In the MS_Bitmap folder a graphic (sucr_veg.bmp) will also allow you to print out the map.
5. Project_Report – This folder contains the entire final project report (SUCR_Final_Report.pdf) in an Adobe Acrobat format.
6. Vegetation_Data – This folder contains all the spatial data (final vegetation GIS cover including a vegetation map clipped to the park boundary, observation points, aspen cover, accuracy assessment points, classification relevé points, and off road vehicle cover) and databases (Vegetation Relevé Database and Accuracy Assessment Database) used to create the final vegetation map as well as associated metadata.
 - a. Accuracy Assessment
 1. Database- Microsoft access database named SUCR_AAdatabase.mdb with accuracy assessment data
Citation:
Hansen, M. and K. Thomas. 2004. Sunset Crater Volcano National Monument: Accuracy Assessment. A MS Access database. U.S. Geological Survey.
 2. Metadata-All associated metadata for the spatial data and database
 3. Spatial data- A coverage and shapefile of the accuracy assessment points used in the accuracy assessment analysis
 4. sucr_aa_pts.e00-An Arc/Info export format (.e00) of the accuracy assessment points
Citation:
Dale, B., M. Hansen, and K. Thomas. 2004. Accuracy Assessment Points: Sunset Crater Volcano National Monument. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - b. Aspen_Map
 1. Metadata-Associated metadata for the spatial data

2. Spatial data- A coverage and shapefile of the occurrence of aspen in the Sunset Crater Vegetation Mapping Project
3. sucr_aspen.e00-An Arc/Info export format (.e00) of the cover of aspen in the project boundary

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Aspen Coverage: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

c. Clip_Veg

1. Metadata- Associated metadata for the spatial data
2. Spatial data- A coverage and shapefile of the vegetation map clipped to the Sunset Crater Volcano National Monument boundary
3. sucr_clip_veg.e00-An Arc/Info export format (.e00) of the cover of vegetation map clipped to the Sunset Crater Volcano National Monument boundary

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Clipped Vegetation Coverage: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

d. Observation_Points

1. Metadata- Associated metadata for the spatial data
2. Spatial data- A point coverage and shapefile of the observation points used to help with the photointerpretative work
3. sucr_obs.e00- An Arc/Info export format (.e00) of the observation points collected in the field to help with the photointerpretative work

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Observation Point Coverage: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

e. OHV_Map

1. Metadata- Associated metadata for the spatial data
2. Spatial data- A point coverage and shapefile of the off highway vehicle tracks are embedded within and can be identified in the coverage or shapefile relational table.
3. sucr_obs.e00- An Arc/Info export format (.e00) of the area where off highway vehicle tracks were evident in the project area. Areas with no evident tracks are embedded within and can be identified in the coverage or shapefile relational table

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Off Highway Vehicle Use: Sunset Crater Volcano National Monument. A digital spatial database (ArcInfo). U.S. Geological Survey.

f. Releve_Plots

1. Database- Microsoft access database named SUCR_FieldReleve_data-base.mdb with all the information collected in the field at each classification relevé

Citation:

Hansen, M. and K. Thomas. 2004. Field Relevé Plots: Sunset Crater Volcano National Monument. A MS Access database. U.S. Geological Survey.

2. Metadata- Associated metadata for the database and spatial data
3. Spatial data- A coverage and shapefile of the classification relevés
4. sucr_releve.e00-An Arc/Info export format (.e00) of the cover of classification relevé points sampled in the Sunset Crater project boundary

Citation:

Hansen, M. and K. Thomas. 2004. Field Relevé Plots: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

g. Vegetation_Map

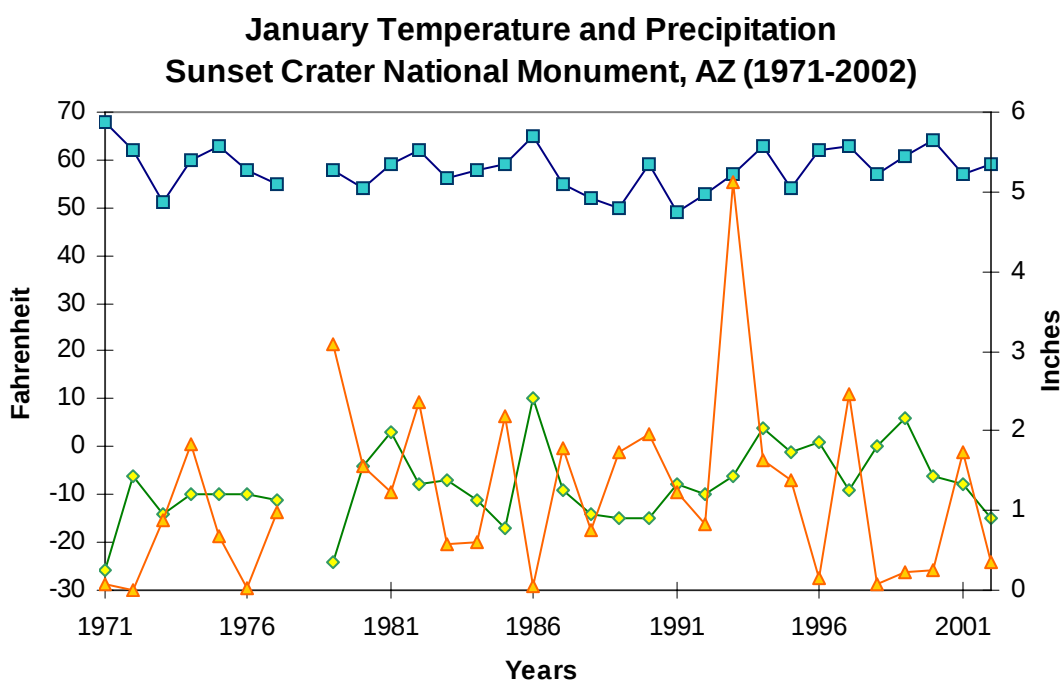
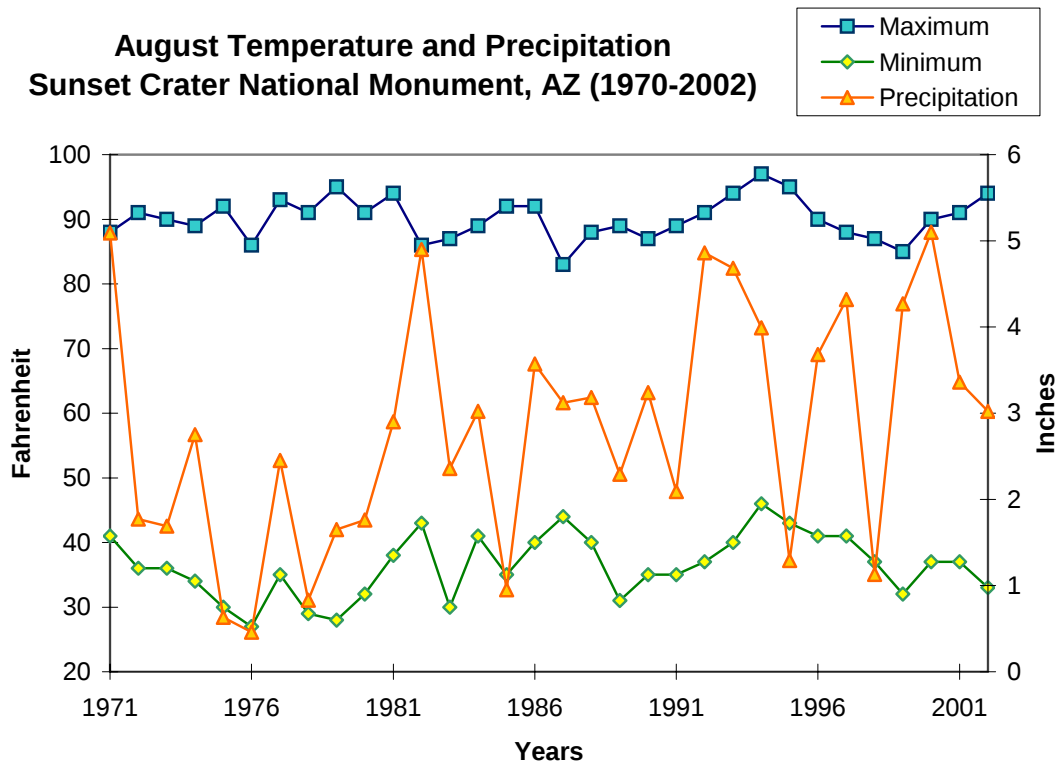
1. Metadata- Associated metadata for the spatial data
2. Spatial data- A coverage and shapefile of the vegetation map for the Sunset Crater Volcano National Monument and the project environs
3. sucr_veg.e00-An Arc/Info export format (.e00) of the cover of the vegetation map coverage

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Sunset Crater Volcano National Monument Vegetation Map. A digital spatial database (ArcInfo). U.S. Geological Survey.

APPENDIX B

B. Precipitation and Temperature Averages for Sunset Crater Volcano National Monument (August and January 1971-2002)



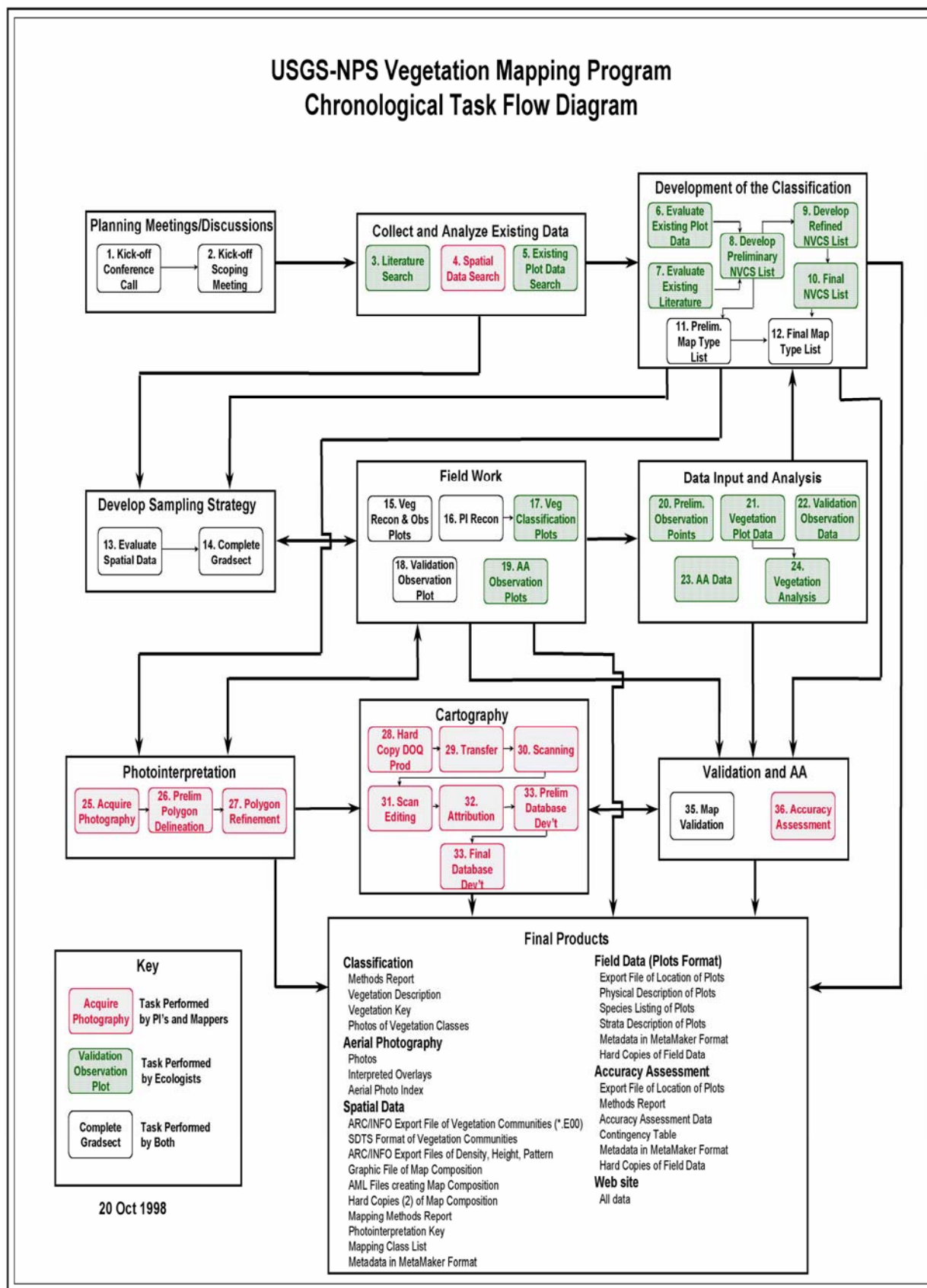
Precipitation data from www.ncdc.noaa.gov/ol/climate/online/coop-precip.html
for the Sunset Crater reporting station. (Internet Access January 2002)

Temperature data from www.ncdc.noaa.gov/ol/climate/climatedata.html for the Flagstaff area.
(Internet Access January 2002)

APPENDIX C

C. Flowchart of USGS-NPS National Parks Vegetation Mapping Program

(Created by Tom Owens)



APPENDIX D

D. Photointerpretation Observations, Classification Relevés, and Accuracy Assessment Observations Forms

NATIONAL PARK VEGETATION MAPPING PROGRAM: PHOTOINTERPRETATION OBSERVATION FORM

IDENTIFIERS/LOCATORS

Plot Code _____	Polygon Code _____
Provisional Community Name _____	
State ____	Park Name _____ Park Site Name _____
Quad Name _____	Quad Code _____
GPS file name _____ Field UTM X _____ m E Field UTM Y _____ m N	
<i>please do not complete the following information when in the field</i>	
Corrected UTM X _____ m E Corrected UTM Y _____ m N UTM Zone _____	
Survey Date _____ Surveyors _____	

ENVIRONMENTAL DESCRIPTION

Elevation _____	Slope _____	Aspect _____
Topographic Position _____		
Landform _____		

Cowardian System	Hydrologic Regime	<u>Salinity/Halinity Modifiers</u>
___ Upland	<u>Non-Tidal</u>	___ Saltwater
___ Riverine	___ Permanently Flooded	___ Brackish
___ Palustrine	___ Saturated	___ Freshwater
___ Lacustrine	___ Semipermanently Flooded	
	___ Temporarily Flooded/Saturated	
	___ Intermittently Flooded	
	___ Seasonally Flooded	

Environmental Comments:	Unvegetated Surface: <i>(please use the cover scale below)</i> ___ Bedrock ___ Litter, duff ___ Wood (> 1 cm) ___ Large rocks (cobbles, boulders > 10 cm) ___ Small rocks (gravel, 0.2-10 cm) ___ Sand (0.1-2 mm) ___ Bare soil ___ Other: _____
-------------------------	--

VEGETATION DESCRIPTION

Leaf phenology (of dominant stratum)	Leaf Type (of dominant stratum)	Physiognomic class	Cover Scale for Strata & Unvegetated Surface	Height Scale for Strata
<u>Trees and Shrubs</u> ___ Evergreen ___ Cold-deciduous ___ Drought-deciduous ___ Mixed evergreen - cold-deciduous ___ Mixed evergreen - drought-deciduous <u>Herbs</u> ___ Annual ___ Perennial	___ Broad-leaved ___ Needle-leaved ___ Mixed broad-leaved/Needle leaved ___ Microphyllous ___ Graminoid ___ Forb ___ Pteridophyte	___ Forest ___ Woodland ___ Shrubland ___ Dwarf Shrubland ___ Herbaceous ___ Nonvascular ___ Sparsely Vegetated	01 5% 02 10% 03 20% 04 30% 05 40% 06 50% 07 60% 08 70% 09 80% 10 90% 11 100%	01 <0.5 m 02 0.5-1m 03 1-2 m 04 2-5 m 05 5-10 m 06 10-15 m 07 15-20 m 08 20-35 m 09 35 - 50 m 10 >50 m

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Strata	Height	Cover Class	Dominant species (mark any known diagnostic species with a *)	Cover Class
T1 Emergent	_____	_____	_____	

T2 Canopy	_____	_____	_____	

T3 Sub-canopy	_____	_____	_____	

S1 Tall shrub	_____	_____	_____	

S2 Short Shrub	_____	_____	_____	

S3 Dwarf-shrub	_____	_____	_____	

H Herbaceous	_____	_____	_____	

N Non-vascular	_____	_____	_____	

V Vine/liana	_____	_____	_____	

E Epiphyte	_____	_____	_____	

<i>please see the table on the previous page for height and cover scales for strata</i>				
Other Comments				Cover Scale for Species
				01 <1%
				02 1-5%
				03 5-25%
				04 25-50%
				05 50-75%
				06 75-100%

CLASSIFICATION RELEVÉ FORM

SURVEY AND SITE INFORMATION

Park Name: _____		Date: _____	
Surveyors _____			
Plot Code _____			
Provisional Alliance/Association Name _____			
Zone 12		Datum NAD 83	
USGS Quad _____	7.5 or 15'	Environ-Code _____	
Air Photo # _____	Polygon Code _____		
UTM E _____m	UTM N _____m	Way Point _____	
Error =+/- _____			
Landowner(check one):NPS _____ Forest Service _____ Private(owner if known) _____ State Lands: Game and Fish _____			
Plot length _____ m		Plot width _____ m	
		Plot Shape: (square, rectangle, triangle, circle)	
for 400m ²		Circle Diameter=35.6m for 1000m ² , Diameter=22.6	
Directions to Plot _____			

Plot Photos (Y/N) _____		Roll # _____	Frame # _____
Date _____		Time _____	
Direction _____			

ENVIRONMENTAL DESCRIPTION

Elevation _____ (m.)	Slope _____ %	Aspect _____	
Topographic position: _____ Landform: _____ (enter number from Code Sheet)			
Community Type: _____ (Wetland(W) or Upland(U)) (if W then)			
☐ Estuarine	☐ Semipermanently Flooded	☐ Permanently Flooded	<u>Salinity/Halinity</u>
☐ Riverine	☐ Seasonally Flooded	☐ Permanently Flooded-tidal	<u>Modifiers:</u>
☐ Palustrine	☐ Saturated	☐ Tidally Flooded	☐ Saltwater
☐ Laustrine	☐ Temporarily Flooded	☐ Artificially Flooded	☐ Brackish
	☐ Intermittently Flooded		☐ Freshwater

VEGETATION DESCRIPTION

Vegetation Group: _____ (from the three columns below)

Leaf phenology:	Leaf Type:	Physiognomic class:
<u>Trees and Shrubs</u>	1_Broad-leaved	1_Forest
1_Evergreen	2_Needle-leaved	2_Woodland
2_Cold-deciduous	3_Microphyllous	3_Shrubland
3_Drought-deciduous	4_Graminoid	4_Dwarf shrubland
4_Mixed evergreen-cold-deciduous	5_Broad-leaved herbaceous	5_Herbaceous (grassland and forb)
5_Mixed evergreen drought-deciduous	6_Pteridophyte	6_Nonvascular
<u>Herbs</u>	7_Mixed broad and needle-leaved	7_Sparsely vegetated
6_Annual	8_Extremely xeromorphic	
7_Perennial	9_Hydromorphic	

Additional Comments:

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Plot # _____ Date: _____

Cover Class Intervals: 1(<1%), 2(1-5%), 3(>5-10%), 4(>10-25%), 5(>25-50%), 6(50-75%), 7(>75%)

G=Ground(<0.5m), S-Shrub(0.5-3.0m), T-Tree(>3.0m)

Layer

[illegible]

(Fill data only once per field plot!)

Total Vegetation Cover(Class):	_____	Total Tree	_____	Total Shrub	_____	Total Ground	_____	Total Non-native	_____
%	_____		_____		_____		_____		_____

Cover Scale for Strata, Sensitive Species, Exotics, Biotic Surfaces and Unvegetated Surface:

01	<1%	03	>5-10%	05	>25-50%	07	>75%
----	-----	----	--------	----	---------	----	------

02	>1-5%	04	>10-25%	06	>50-75
----	-------	----	---------	----	--------

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Unvegetated Surface	Bare Soil	Sand (0.1-2mm)	Gravel (2mm-6.4cm)	Cobble (6.4-19cm)	Stone (>19-61cm)	Boulder (>61 cm)	Bedrock	Litter, duff	Biotic Crust (cryptograms, moss, lichens)
Cover Class									

Environmental Comments:	Soil Taxon/Description:

Strata	Moss/Lichen	0-25cm	25-50cm	0.5-1m	1-3m	3-5m	5-10m	10-20m	20-30m	>30m
Cover Class										

Sensitive Species:

Genus	Species	% Cover	Cover Class

Exotic Species:

Genus	Species	% Cover	Cover Class

DBH Table:

Species	Diameter	Species	Diameter

3-Flagstaff Park's Code Sheet for Classification Relevés

MACRO TOPOGRAPHY

- 00 INTERFLUVE(crest, summit, ridge): linear top of ridge, hill, or mountain; elevated area between two fluves
- 01 HIGH SLOPE(shoulder slope, upper slope, convex creep slope): the top of a slope, convex
- 02 HIGH LEVEL(mesa): top of plateau
- 03 MIDSLOPE(transportational midslope, middle slope): intermediate slope
- 04 BACKSLOPE(dipslope): subset of midslopes which are steep, linear, and cliff segments
- 05 STEP IN SLOPE(ledge, terracette): nearly level shelf interrupting a steep slope, rock wall, or cliff face
- 06 LOWSLOPE(lower slope, foot slope, colluvial footslope): inner gently inclined surface at the base of a slope, concave
- 07 TOESLOPE(alluvial toeslope): outermost gently inclined surface at base of slope, commonly gentle and linear
- 08 LOW LEVEL(terrace): valley floor or shoreline representing the former position of an alluvial plain, lake or shore
- 09 CHANNEL WALL(bank): sloping side of a channel
- 10 CHANNEL BED(narrow valley bottom, gully arroyo): bed of single or braided watercourse commonly barren of vegetation
- 11 BASIN FLOOR(depression): nearly level to gently sloping, bottom surface of a basin

LANDFORM

- 20 **Rockpile**=uplands composed primarily of jointed and exfoliating granitic outcrops
- 21 **Bajada**=alluvial slopes of fans that accumulate at the base of a desert mountain or mountain canyons that are interrupted by the trenching of minor water sources
- 22 **Drainage Channel**=bottom not side slope of a drainage confined by banks or a canyon
- 23 **Valley Bottom Fill**=usually level places
- 24 **Playa**=Pleistocene dried lakebed often with some surface water
- 25 **Side Slope**=side of drainage channels
- 26 **Lower Slope**=lower better watered portion of a slope
- 27 **Mid Slope**=central portion of a slope
- 28 **Upper Slope**=the upper driest portion of a slope
- 29 **Interfluvium**=the area between small drainage channels
- 30 **Ridge**=high ground between two opposing slopes
- 31 **Slick Rock**=large exposed expanses of bedrock
- 32 **Terrace**=level or gently sloping shelf perched on a slope, often caused by down-cutting rivers
- 33 **Mesa**=level or gently sloping ground surrounded on 3 or more sides by steep down slopes and capped
- 34 **Butte**=similar to a mesa, except with a top that does not have a flat configuration
- 35 **Cliff**=very steep rock slopes
- 36 **Talus**=unsorted material resulting from mass wasting of steep mountain slopes
- 37 **Sand Dune/Sand Sheet**=large accumulations of sand, may be stable or unstable (moving)

ACCURACY ASSESSMENT OBSERVATION FORM

SURVEY AND SITE INFORMATION

Park Name: <u>Sunset Crater National Monument</u>		Date: _____
Surveyors _____		
Plot Code _____		
Zone 12	Datum NAD 83	
USGS Quad _____	7.5	
UTM E _____ m	UTM N _____ m	
Error = +/- _____		
Elevation _____ (m)		

PLEASE CIRCLE CLOSEST MAP CLASS REPRESENTING SITE:

Vegetation Apache Plume / Cinder Sparse Vegetation Douglas-fir Forest Lava Bed Sparse Vegetation Limber Pine Woodland Montane Grassland (also circle if appropriate: Rabbitbrush, Bonito Park) Pinyon – Utah Juniper / Blue Grama Woodland (also circle if appropriate: Sparse) Ponderosa Pine / Apache Plume Woodland (also circle if appropriate: Sparse, Pinyon) Ponderosa Pine / Cinder Woodland Ponderosa Pine / Montane Grass Mosaic Ponderosa Pine / Sand Bluestem Woodland Ponderosa Pine Invasive Herbaceous Vegetation Rock Outcrop and Scree Shrubland Wild Buckwheat – Sand Bluestem Sparse Vegetation	Land Use Cropland or pasture Facilities Recreational trails and sites Residential land Strip Mines, Quarries, Gravel Pits Transportation, communications and utility corridors Geomorphology Cinder Sparse Mosaic Lava Beds
---	--

CONFIDENCE: Exact Good (Some problems) Poor None that fit

Please explain all reasons for Good, Poor or None Confidence

PLEASE CIRCLE CLOSEST ASSOCIATION/ALLIANCE REPRESENTING SITE:

<i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation <i>Bouteloua gracilis</i> Herbaceous Vegetation Cinder Sparse Mosaic <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage) <i>Eriogonum corymbosum</i> Cinder Sparse Vegetation <i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation <i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> - <i>Holodiscus dumosus</i> Scree Shrubland (Local Assemblage) <i>Muhlenbergia montana</i> Herbaceous Vegetation. <i>Pascopyrum smithii</i> Herbaceous Vegetation <i>Pinus edulis</i> – (<i>Juniperus osteosperma</i>) / (<i>Bouteloua gracilis</i>) Woodland <i>Pinus edulis</i> / Sparse Understory Forest <i>Pinus flexilis</i> Woodland Alliance <i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland	<i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland <i>Pinus ponderosa</i> / Cinder Woodland. <i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland <i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland <i>Pinus ponderosa</i> - (<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> - (<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation <i>Pinus ponderosa</i> / <i>Rhus trilobata</i> Shrubland (Local Assemblage) <i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage) <i>Populus tremuloides</i> / Cinder Woodland (Local Assemblage) <i>Pseudotsuga menziesii</i> Forest Alliance <i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest
--	--

CONFIDENCE: Exact Good (Some problems) Poor None that fit

Please explain all reasons for Good, Poor or None Confidence

APPENDIX E

E. Field Key for the Sunset Crater Volcano National Monument Vegetation Community Descriptions and Map Classes

1. Site characterized by sparsely vegetated substrate (<2%) or by infrastructure. (go to 23)
1. Site with greater than 2% vegetation, may be within lava bed, cinder, scree, or rock outcrop. (go to 2)
2. Site characterized by tree and/or shrub cover. (go to 3)
2. Site characterized by grasses and forbs, trees may be present. (go to 15)
3. Site characterized by trees. (go to 4)
3. Site characterized by shrubs. (go to 19)

TREES

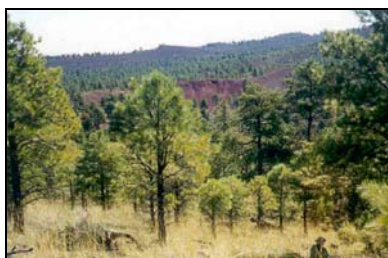
4. Site an island of vegetation within a lava bed or at the edge of lava beds. Map Class: **Lava Beds Sparse Vegetation**. Association is *Populus tremuloides* or *Pinus ponderosa* in the overstory and *Fallugia paradoxa* and/or *Holodiscus dumosus* in the understory. ***Pinus ponderosa* - (*Populus tremuloides*) / *Fallugia paradoxa* - (*Holodiscus dumosus*) Lava Bed Sparse Vegetation**. (see picture below)



4. Site not as above. (5)
5. Trees mostly evergreen. (6)
5. Trees mostly deciduous. Dominant tree is *Populus tremuloides*. This is often less than 0.5ha and is combined with adjacent vegetation communities in the vegetation map. Association is ***Populus tremuloides* / Cinder Woodland (Local Assemblage)**. (see picture below) However, a separate coverage, SUCR_aspen, shows some photointerpreted occurrences for this association.



6. Dominant tree is *Pinus ponderosa*. *Pinus edulis*, *Juniperus osteosperma* or *J. deppeana* may be present and with equal cover. *Pseudotsuga menziesii* may be present, but with less cover than *Pinus ponderosa*. (7)
6. Dominant tree species not *Pinus ponderosa* or if so, *Pseudotsuga menziesii* is co-dominant. (12)
7. Herbaceous cover greater than 5% and is the dominant understory lifeform. Shrub cover generally less than 10% and not dominated by *Fallugia paradoxa*. If shrub cover more than 10%, it is still less than the herbaceous cover. (8)
7. Shrub cover dominated by *Fallugia paradoxa* or all understory cover (shrubs and grasses combined) 5% or less. (11)
8. Herbaceous cover is dominated by *Andropogon hallii*.
Map Class: **Ponderosa Pine / Sand Bluestem Woodland**. (see picture below)
Association is ***Pinus ponderosa* / *Andropogon hallii* Woodland**.



8. Dominant grass not as above. (9)
9. Herbaceous cover is dominated by *Bouteloua gracilis*. *Muhlenbergia montana*, is not present or has very low cover (<2%). Map Class: **Ponderosa Pine/Montane Grass Mosaic**. (see picture below) Association is ***Pinus ponderosa* / *Bouteloua gracilis* Woodland**.



9. *Bouteloua gracilis* not dominant or if so, *Muhlenbergia montana* with equal or greater cover than *Bouteloua gracilis*. (10)
10. Herbaceous cover is often dominated by *Muhlenbergia montana*. *Bouteloua gracilis*, if present, can co-dominate, but often has less cover than *Muhlenbergia montana*. Map Class: **Ponderosa Pine/Montane Grass Mosaic**. (see picture below) Association is ***Pinus ponderosa* / *Muhlenbergia montana* Woodland**.



10. Herbaceous cover is dominated by non-native exotic species such as *Bromus tectorum* and/or *Linaria dalmatica* ssp. *dalmatica* and/or native disturbance following species such as *Artemisia dracunculus*. Map Class: **Ponderosa Pine Invasive Herbaceous Vegetation**. (see picture below) Association is *Pinus ponderosa* Wooded Invasive Herbaceous Vegetation (Local Assemblage).



11. Shrub cover greater than 5% and dominated by *Fallugia paradoxa*. Some areas may also contain high cover of *Ericameria nauseosa*. Map Class: **Ponderosa Pine / Apache Plume Woodland**. (see picture on left below) If *Pinus edulis* is greater than 10% then the modifier “pinyon” applies. If total cover is less than 25% then the modifier “sparse” applies. (see picture on right below) Association is *Pinus ponderosa* / *Fallugia paradoxa* Woodland.



11. Shrub and herbaceous cover generally less than 5% total. Map Class: **Ponderosa Pine / Cinder Woodland**. (see picture below) Association is *Pinus ponderosa* / Cinder Woodland.



12. Dominant tree species is *Pinus flexilis*. *Pseudotsuga menziesii*, if present, has less cover than *Pinus flexilis*. Map Class: **Limber Pine Woodland**. (see picture below) Association is ***Pinus flexilis* Woodland Alliance**.



12. Dominant tree species is not *Pinus flexilis* or is *Pinus flexilis* with *Pseudotsuga menziesii* co-dominating. (13)
13. Dominant or associated dominant tree species is *Pseudotsuga menziesii*. *Pinus flexilis* or *Pinus ponderosa* may be present and have equal cover to *Pseudotsuga menziesii*. Map Class: **Douglas-fir Forest**. (see picture below) Association has herbaceous understory dominated by *Muhlenbergia montana*: ***Pseudotsuga menziesii* / *Muhlenbergia montana* Forest**, otherwise ***Pseudotsuga menziesii* Forest Alliance**. (No picture available)
13. Dominant tree species is *Pinus edulis*. *Juniperus osteosperma* may be co-dominant but does not need to be present. *Juniperus deppeana* may be present. Map Class: **Pinyon Pine – Utah Juniper / Blue Grama Woodland**. (see picture below) If total cover is less than 25% then the modifier “sparse” applies. Continue key to vegetation association (14)



14. *Juniperus osteosperma* or *Juniperus deppeana* are present. Herbaceous cover, if present, characterized by *Bouteloua gracilis*. Association is ***Pinus edulis* – (*Juniperus osteosperma*) / (*Bouteloua gracilis*) Woodland**. (see picture below)



14. Neither *Juniperus osteosperma* or *Juniperus deppeana* are present. Association is ***Pinus edulis* / Sparse Understory Forest.** (see picture below)



GRASSES

15. Dominant grass is *Andropogon hallii*. Map Class: **Sand Bluestem Herbaceous Vegetation.** (see picture below) Association is ***Andropogon hallii* Colorado Plateau Herbaceous Vegetation.**



15. Dominant grass not as above. (16)
16. Herbaceous cover is dominated by *Bouteloua gracilis*. *Muhlenbergia montana*, if present, has less cover than *Bouteloua gracilis*. Map Class: **Montane Grassland.** (see picture below) If *Ericameria nauseosa* is greater than 10% then the modifier “rabbitbrush” applies. If the site is in Bonito Park then the modifier “Bonito Park” applies. Association: ***Bouteloua gracilis* Herbaceous Vegetation.**



16. Dominant grass not as above. (17)
17. Herbaceous cover is dominated by *Muhlenbergia montana*, *Bouteloua gracilis*, if present, has less cover than *Muhlenbergia montana*. Map Class: **Montane Grassland**. (see picture below) If *Ericameria nauseosa* is greater than 10%, then the modifier “rabbitbrush” applies. If the site is in Bonito Park then the modifier “Bonito Park” applies. Association is ***Muhlenbergia montana* Herbaceous Vegetation**.



17. Dominant grass not as above (18).
18. Herbaceous cover is dominated by *Pascopyrum smithii*. Map Class: **Ponderosa Pine Invasive Herbaceous Vegetation**. (see picture below) Association is ***Pascopyrum smithii* Herbaceous Vegetation**.



18. Herbaceous cover is dominated by non-native exotic species such as *Bromus tectorum* and/or *Linaria dalmatica* ssp. *dalmatica*. Native disturbance following species such as *Artemisia dracunculus* may also be present. *Pinus ponderosa* present but cover less than herbaceous cover. Map Class: **Ponderosa Pine Invasive Herbaceous Vegetation**. (see picture below) Association is ***Pinus ponderosa* Wooded Invasive Herbaceous Vegetation (Local Assemblage)**.



SHRUBS

19. *Eriogonum corymbosum* is the dominant shrub. *Andropogon hallii* also present. Map Class: **Wild Buckwheat – Sand Bluestem Sparse Vegetation**. (see picture below) Association is *Eriogonum corymbosum* Cinder Sparse Vegetation.



19. Dominant shrub not as above. (20)
20. *Fallugia paradoxa* is the dominant shrub. Map Class: **Apache Plume / Cinder Sparse Vegetation**. (see picture below) Association is *Fallugia paradoxa* (*Atriplex canescens*, *Ephedra torreyana*) Cinder Sparse Vegetation.



20. Dominant shrub not as above. (21)
21. *Rhus trilobata* is the dominant shrub. *Pinus ponderosa* is also present with low cover (up to 5%). This is often less than 0.5ha and was combined with adjacent vegetation communities for the vegetation map. Association is *Pinus ponderosa* / *Rhus trilobata* **Shrubland (Local Assemblage)**. (see picture below) (Continue key to surrounding vegetation community for map class)



21. Dominant shrub not as above and occurring on lava and basalt outcrops. Map Class: **Rock Outcrop and Scree Shrubland**. Continue key to get to vegetation association (22).
22. *Holodiscus dumosus* is the dominant shrub. Found on basaltic and cinder scree. Association is **Fallugia paradoxa – Brickellia grandiflora – (*Holodiscus dumosus*) Scree Shrubland (Local Assemblage)**. (see picture below)



22. *Ericameria nauseosa* and *Pericome caudata* are the dominant shrubs. Found on lava and basalt outcrops. Association is ***Ericameria nauseosa*-*Pericome caudata* Rock Outcrop Sparse Vegetation (Local Assemblage)**. (see picture below)



SPARSE VEGETATION

23. Site characterized by sparsely vegetated cinder or lava. (24)
23. Site characterized by land use. (25)
24. Substrate loose cinder. Map Class: **Cinder Barren Sparse Vegetation**. (see picture below)



24. Substrate lava. Map Class: **Lava Beds.** (see picture below)



25. Site characterized by land use. Map Classes below.
- a. **Croplands and pastures**
 - b. **Facilities**
 - c. **Recreational tracks:** This map class occurs often as linear polygons within many of the map classes on the vegetation map. These tracks are easily identified in the aerial photography and were included as a separate coverage, suc_r_OHV.
 - d. **Residential land**
 - e. **Strip Mines, Quarries, Gravel Pits**
 - f. **Transportation, communications and utilities**
 - g. **Reservoirs and Trick Tanks**

APPENDIX F

F. National Vegetation Classification Standard (NVCS) Local Descriptions for Sunset Crater Volcano National Monument

(Kathryn Thomas and Monica Hansen of the USGS Colorado Plateau Research Station collected, analyzed, and initially classified field relevé data. Marion Reid and Keith Schulz of NatureServe reviewed and finalized local classification and compiled global classification.)

The following vegetation descriptions are derived from the 114 vegetation relevés sampled throughout the course of this project. Global information, information based on reports throughout the distribution of the associations/alliances, was also compiled by NatureServe to augment the local descriptions. All of the vegetation association descriptions will include information on both the global and local descriptions, unless the associations have only been described from Sunset Crater Volcano National Monument.

The vegetation descriptions are separated into twelve sections. Many of the sections are subdivided into a ‘Sunset Crater Volcano National Monument’ and a ‘Globally’ section. After the Sunset Crater Volcano National Monument subheading information follows on the association/alliance as it appears in the park, the local information. After the Globally subheading information follows on the association/alliance as it appears throughout its range. Information about each of the sections is described in Table 1.

Table 1. Explanations on the vegetation descriptions sections.

Vegetation Description Sections	Explanation
Classification Confidence Level	The classification confidence level identified by NatureServe.
USFS Wetland System	The U.S. Department of Agriculture – Forest Service wetland classification system ranking crosswalked to NVCS associations, provided by NatureServe.
Range	The range describes where this association was mapped in the project area, information on where particular relevés were sampled, and where the association occurs throughout its entire range.
Environmental Description	Environmental description describes the abiotic conditions measured related to the association/alliance. In the local descriptions, all slopes are described as a range of elevation (lowest to highest elevation) as well as an average elevation across all of the relevés measured in meters (m).
Most Abundant Species	This section identifies the dominant and/or indicator species for Sunset Crater Volcano National Monument and globally throughout its range.
Associated Species	Associated species describes the most common species associated with all of the relevés locally and globally.
Vegetation Description	This section identifies the vegetation characteristics specific to the association/alliance. Locally, total vegetation cover is described as absolute percent cover and is given as a range (lowest to highest % cover) and average across all of the relevés. Diameter Base Height (DBH) is provided in centimeters (cm) if trees were present in the relevés.

Conservation Rank	The conservation rank is a ranking system used to identify and prioritize conservation areas applied to NVCS associations by NatureServe. The global conservation rank is described in Table 2.
Database Code	Database codes are a unique code that NatureServe developed to organize and identify the vegetation associations.
Map Classes	Map classes describes how the association is crosswalked to the map class, a general description of where the map class occurs, and the total number of hectares and polygons occurring inside and outside Sunset Crater Volcano National Monument.
Comments	Comments particular to the vegetation description locally at Sunset Crater Volcano National Monument and globally.
References	References identified in the vegetation description.

Table 2. Conservation ranking system for associations.

Global Conservation Rank	% of Associations
GX – Eliminated	0
GH – Presumed eliminated (historic)	<1
G1 – Critically imperiled	10
G2 – Imperiled	18
G3 – Vulnerable	22
G4 – Apparently secure	16
G5 – Secure	8
GU – Unrankable	3
G? – Unranked	22

List of vegetation community types (NVCS Associations) organized by NVCS structure.

NVCS Association	Page
<i>Pinus edulis</i> / Sparse Understory Forest	F-5
<i>Pseudotsuga menziesii</i> Forest Alliance	F-8
<i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest	F-12
<i>Pinus edulis</i> – (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland	F-15
<i>Pinus flexilis</i> Woodland Alliance	F-18
<i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland	F-21
<i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland	F-23
<i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland	F-26
<i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland	F-28
<i>Pinus ponderosa</i> / Cinder Woodland	F-31
<i>Populus tremuloides</i> / Cinder Woodland (Local Assemblage)	F-33
<i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Shrubland	F-35
<i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> – (<i>Holodiscus dumosus</i>) Scree Shrubland (Local Assemblage)	F-37
<i>Pinus ponderosa</i> / <i>Rhus trilobata</i> Shrubland (Local Assemblage)	F-38
<i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation	F-39
<i>Bouteloua gracilis</i> Herbaceous Vegetation	F-40
<i>Muhlenbergia montana</i> Herbaceous Vegetation	F-42
<i>Pascopyrum smithii</i> Herbaceous Vegetation	F-45
<i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage)	F-48
<i>Ericameria nauseosa</i> – <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage)	F-50
<i>Eriogonum corymbosum</i> Cinder Sparse Vegetation	F-51
<i>Pinus ponderosa</i> – (<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> – (<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation	F-53

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Pinus edulis / Sparse Understory Forest

COMMON NAME	Two-needle Pinyon / Sparse Understory Forest
PHYSIOGNOMIC CLASS	Forest (I.)
PHYSIOGNOMIC SUBCLASS	Evergreen forest (I.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen forest (I.A.8)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural Temperate or subpolar needle-leaved evergreen forest (I.A.8.N)
FORMATION	Rounded-crown temperate or subpolar needle-leaved evergreen forest (I.A.8.N.b)
ALLIANCE	<i>Pinus edulis</i> Forest Alliance

CLASSIFICATION CONFIDENCE LEVEL Strong

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Two-needle Pinyon / Sparse Understory Forest occurs on cinder cones in the park environs adjacent to the Sunset Crater Volcano NM boundaries. Within the environs of the project study boundary this vegetation type was mapped within the San Francisco volcanic field on the northern and eastern slopes of various unnamed cinder cones and also on Black Mountain. Only one representative stand was sampled in our study, on the northeastern slope of O'Leary peak.

Globally

These woodlands are found locally on the Colorado Plateau, but likely are more widespread and occur throughout the range of *Pinus edulis*.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association occurs mostly on the steep cooler slopes of the northern and eastern cinder cones. The one representative stand had 55% slope, an elevation of 2,200m, and occurred on fine cinder soils.

Globally

These forests and woodlands occur in foothills, mesas, plateaus and mountains of New Mexico, Arizona and Utah. Sites are flat to moderately sloping at elevations that range from 1,980-2,290 m (6,500-7,500 feet). Stands frequently occur on less xeric, northern and eastern exposures, but it can occur on all aspects. Substrates are variable but often include eroded, shallow or coarse-textured substrates such as cinder (but not rock outcrops) that limit the growth of understory shrubs and herbaceous plants. Cover of tree litter is dense in some stands (Kennedy 1983). The original concept of this association included stands on relatively mesic sites with high tree growth potential that produced a dense tree canopy, which shades out the understory vegetation. However, the association also includes fire-suppressed stands and woodlands growing on eroded or "badlands" substrates and/or over-grazed stands that lack understory vegetation (Baker et al. 1995, Stuever and Hayden 1997a and b).

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus edulis</i>

Globally

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus edulis</i> , <i>Juniperus monosperma</i> , <i>Juniperus osteosperma</i>

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Ageratina herbacea, *Fallugia paradoxa*

Globally

Juniperus scopulorum, *Juniperus deppeana*, *Ageratina herbacea*, *Cercocarpus montanus*, *Fallugia paradoxa*, *Rhus trilobata*, *Gutierrezia sarothrae*, *Achnatherum hymenoides*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Only one relevé was classified as *Pinus edulis* sparse understory forest, where the total vegetation cover is 70% with 63% within the tree layer, 6% within the shrub layer, and 11% within the herbaceous layer.

Within the one relevé, mature *Pinus edulis* had a cover of 62%. The DBH ranged from 17-50cm (average 32cm).

Twenty-one species of shrubs and herbs were measured within this association. The most common shrubs were *Ageratina herbacea* and *Fallugia paradoxa*, both with less than 4% of the total cover.

Globally

This plant association is characterized by a moderate (over 25% cover) to dense tree canopy with little or no understory. The tree canopy is dominated by *Pinus edulis*. Other trees may co-dominate especially one or more species of *Juniperus* that vary with geography, such as *J. monosperma*, *J. osteosperma*, *J. scopulorum* or *J. deppeana*. If other species of *Pinus* are present they do not co-dominate. The sparse understory (<10% cover and usually <2%) may include scattered shrubs, dwarf-shrubs, succulents, grasses and forbs such as *Ageratina herbacea*, *Cercocarpus montanus*, *Fallugia paradoxa*, *Rhus trilobata*, *Gutierrezia sarothrae*, *Achnatherum hymenoides* and species of *Opuntia*, *Yucca*, *Poa*, *Penstemon*, and *Phlox*.

CONSERVATION RANK G5

DATABASE CODE C EGL000795

MAP CLASSES

Two-needle Pinyon / Sparse Understory Forest is mapped as part of the Pinyon Pine – Utah Juniper / Blue Grama Woodland map class which corresponds to map codes 11 and 12

The map class Pinyon Pine - Utah Juniper / Blue Grama Woodland occurs mainly on the northern and eastern section of the project boundary. The total area mapped within Sunset Crater Volcano NM is 2 hectares within 5 polygons and the total area in the park environs is 394 hectares within 59 polygons.

COMMENTS

Sunset Crater Volcano National Monument

The Pinyon / Sparse Understory Forest is distinct with a high canopy cover of Pinyon, absence of Utah Juniper, and a sparse understory. This type grades into the Pinyon (Juniper) / Blue Grama Woodland association at lower elevations with less steep slopes; however, due to difficulty in photointerpretation, the two associations have been combined into one map class: Pinyon Pine – Utah Juniper / Blue Grama Woodland.

Global Comments

The original concept of this plant association had a nearly closed tree canopy with a sparse, shaded understory growing on relatively mesic sites. These forests may actually be a product of fire suppression, livestock grazing removal of fine fuels, and/or soil erosion, and may be present in degraded examples of other *Pinus edulis* associations (Stuever and Hayden 1997a and b). The association concept has been expanded to include more open-growing stands by Muldavin et al. (2000) who included stands under 20% tree cover

Global Dynamics

Pinus edulis is extremely drought-tolerant and slow-growing (Little 1987, Powell 1988, Muldavin et al. 1998a). It is also non-sprouting and may be killed by fire. However, fire frequency is relatively low because of the lack of continuous fine fuel needed to spread ground fire. When fire occurs, it will likely be severe, occurring under the extreme conditions (high winds) needed to carry a crown fire (Bradley et al. 1992, Wright et al. 1979). Active fire suppression and historic grazing by livestock (which has removed the fine fuels that carry fire) have likely altered natural fire regimes and may have contributed to the conversion of open woodlands to closed tree canopies with sparse understories. Subsequent erosion of bare soil can be expected to reduce site productivity (Baker et al. 1995).

REFERENCES

Baker et al. 1995, Bradley et al. 1992, Kennedy 1983, Muldavin et al. 2000, Stuever and Hayden 1997a and b, Wright et al. 1979

Pseudotsuga menziesii Forest Alliance

COMMON NAME	Douglas-fir Forest Alliance
PHYSIOGNOMIC CLASS	Forest (I.)
PHYSIOGNOMIC SUBCLASS	Evergreen forest (I.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen forest (I.A.8)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (I.A.8.N)
FORMATION	Conical-crowned temperate or subpolar needle-leaved evergreen forest (I.A.8.N.c)
ALLIANCE	<i>Pseudotsuga menziesii</i> Forest Alliance

CLASSIFICATION CONFIDENCE LEVEL Alliances are not ranked by NatureServe for classification confidence

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Douglas-fir Forest is mapped on the cooler northern slopes of O'Leary Peak and on the top of Darton Dome. Only one relevé was sampled and it occurred in a cold air-drainage on the western slope of O'Leary Peak.

Globally

This montane and coastal alliance includes evergreen forests dominated by *Pseudotsuga menziesii* occurring from Vancouver Island south through the Cascades and coastal ranges of northern California, through the Rocky Mountains, the Nevada-Utah mountains, the Arizona-New Mexico mountains, to extreme western Texas and northern Mexico.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Douglas-fir Forest was sampled at an elevation of 2,600m on a steep slope (40%).

Globally

Forest associations within this alliance occur in two major distributions. The first is along the northwest Pacific slope in low-elevation valleys of western Oregon and Washington, in scattered dry sites of the Olympics and western Cascades, and along the eastern slope of the Oregon and Washington Cascades. The second is in the Rocky Mountains, extending from the Okanogan Highlands and Blue Mountains of eastern Washington and Oregon south and east into the mountains of the Great Basin and into the Rocky Mountains from Montana south into northern Mexico.

The Pacific Northwest region has mild winter temperatures, cool to hot summers, and receives 75-250 cm of annual precipitation in a Mediterranean pattern of winter rain followed by summer drought. The majority of the precipitation falls as rain, but snowfall can be abundant at montane elevations. These forests occur along low- to moderate-elevation (0-1300 m) mountain slopes and valley margins, with an increasing affinity for moist topographic positions away from the coast and southward. They occupy sites where soil drought is induced by site features (shallow soils, sunny aspect) or local rainshadow effects that lessen precipitation. Generally these forests are in drier sites or zones than *Pseudotsuga menziesii* - *Abies grandis* forests but more moist sites or zones than *Pinus ponderosa* - *Pseudotsuga menziesii* woodlands. Contiguous vegetation is often *Quercus* spp. woodlands and savannas, chaparral, or annual grasslands at the xeric margin, and closed *Sequoia sempervirens* or *Tsuga heterophylla* forests at the mesic margin.

Pseudotsuga menziesii forests found in the Rocky Mountains occur under a comparatively drier and more continental climate regime, and at higher elevations than in the Pacific Northwest. Elevations range from less than 1000 m in the northern Rocky Mountains to nearly 2900 m in the southern Rockies and plateaus of the southwestern U.S. Lower elevation stands typically occupy protected northern exposures or mesic ravines and canyons, often on steep slopes. At higher elevations, these forests occur primarily on southerly aspects or ridgetops. Precipitation ranges from 50-100 cm with moderate snowfall and with a greater proportion falling during the growing season.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Monsoonal summer rains can contribute a significant proportion of the annual precipitation in Arizona, New Mexico, and Colorado. Adjacent vegetation is typically dominated by *Pinus ponderosa* or *Pinus flexilis* (in Idaho and Montana) on drier, warmer sites; *Picea* spp. on more moist sites; *Abies concolor* (in New Mexico and Arizona) or *Abies lasiocarpa* at higher, cooler sites. Montane grasslands and meadows may also occur in patches within these forests, or on adjacent dry slopes.

Soils are highly variable across the range of this alliance and derived from diverse parent materials. *Pseudotsuga menziesii* forests are reported by most studies (Lillybridge et al. 1995, Steele et al. 1981, Pfister et al. 1977, Mauk and Henderson 1984) to show no particular affinities to geologic substrates. Rock types can include marine sediments in northern California and Oregon, glacial deposits in the Puget Sound, extrusive volcanics in the Cascades and Columbia Basin, and sedimentary rocks in the central and southern Rockies and the Colorado Plateau. The soils are typically slightly acidic (pH 5.0-6.0), well-drained, and well-aerated. They can be derived from moderately deep colluvium or shallow jointed bedrock, and are usually gravelly or rocky.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pseudotsuga menziesii</i> , <i>Pinus flexilis</i>

Globally

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pseudotsuga menziesii</i> , <i>Pinus ponderosa</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Ribes cereum, *Holodiscus dumosus*

Globally

Arbutus menziesii, *Acer circinatum*, *Acer glabrum*, *Acer grandidentatum*, *Amelanchier alnifolia*, *Quercus arizonica*, *Quercus gambelii*, *Quercus hypoleucoides*, *Quercus rugosa*, *Arctostaphylos patula*, *Arctostaphylos uva-ursi*, *Arnica cordifolia*, *Bromus ciliatus*, *Calamagrostis rubescens*, *Carex geyeri*, *Festuca arizonica*, *Festuca occidentalis*, *Gaultheria shallon*, *Holodiscus discolor*, *Jamesia americana*, *Juniperus communis*, *Juniperus osteosperma*, *Linnaea borealis*, *Mahonia repens*, *Muhlenbergia montana*, *Muhlenbergia virescens*, *Osmorhiza berteroi*, *Paxistima myrsinites*, *Physocarpus malvaceus*, *Purshia tridentata*, *Spiraea betulifolia*, *Symphoricarpos albus*, *Symphoricarpos occidentalis*, *Symphoricarpos oreophilus*, *Thalictrum occidentale*, *Vaccinium caespitosum*, *Vaccinium membranaceum*, *Viola adunca*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Only one relevé was sampled within the Douglas-fir Forest alliance. The total vegetation cover was 70% with 65% in the tree layer, 4% in the shrub layer, and 1% in the herbaceous layer. Fifteen species were found on the relevé, most with low cover.

Tree canopy was co-dominated by *Pseudotsuga menziesii* (35%) and *Pinus flexilis* (30%). *Pseudotsuga menziesii* DBH ranged from 12-65 cm (average 35 cm) and *Pinus flexilis* ranged from 11.5-31 cm (average 16.2 cm). Fifty to sixty-five percent of the trees in the relevé were 10-30 meters tall, with the remainder 10 meters or shorter.

The shrub layer was characterized by *Ribes cereum* and *Holodiscus dumosus*. The herbaceous layer was nearly absent (~1% total cover).

Globally

This alliance includes evergreen forests dominated by *Pseudotsuga menziesii* occurring in mountain ranges of western U.S., as well as northern Mexico, and western Texas. In the Pacific ranges the dominant species is *Pseudotsuga menziesii* var. *menziesii*, while *Pseudotsuga menziesii* var. *glauca* is the dominant in forests of the Rocky Mountains, south to Mexico.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

On the eastside of the Cascades and east into the northern and southern Rocky Mountains, these forests are dominated by *Pseudotsuga menziesii* in the canopy and almost always in the tree regeneration layer. *Pinus ponderosa* is an important seral species occurring in many associations, either as older seral remnants or codominating in the canopy. Other trees that can be present to abundant (but which are typically seral) include *Larix occidentalis* in the northern Rockies, *Populus tremuloides*, (in the southern Rockies and south into New Mexico and Arizona), *Pinus strobiformis* or *P. flexilis* (in New Mexico and Arizona), and *Pinus contorta* (throughout much of the alliance's range). Species of *Abies* and *Picea* do not commonly occur in this alliance, but are present in some stands.

Understories in *Pseudotsuga menziesii* forests are varied; many associations have well-developed shrub layers, varying in height from <2 m (typically), up to 5 m. Dominant species in some associations in the northern Rockies include *Acer glabrum*, *Linnaea borealis*, *Paxistima myrsinites*, *Physocarpus malvaceus*, *Symphoricarpos albus*, *Symphoricarpos oreophilus*, *Spiraea betulifolia*, *Vaccinium caespitosum*, and *Vaccinium membranaceum*. Further south other shrubs become the dominant or diagnostic species, such as *Acer grandidentatum*, *Amelanchier alnifolia*, *Arctostaphylos patula*, *Jamesia americana*, *Physocarpus monogynus*, *Quercus arizonica*, *Quercus gambelii*, *Quercus rugosa*, *Quercus X pauciloba*, and *Quercus hypoleucoides*. *Arctostaphylos uva-ursi* and *Mahonia repens* are present to important throughout the range.

The herbaceous layer can be sparse, or if the shrub layer is not abundant, can be relatively species-rich, usually graminoid-dominated. Important or dominant species include the graminoids *Bromus ciliatus*, *Calamagrostis rubescens*, *Carex geyeri*, *Carex rossii*, *Festuca arizonica*, *Festuca occidentalis*, *Bromus ciliatus*, *Luzula parviflora*, *Muhlenbergia montana*, and *Muhlenbergia virescens* and the forbs *Arnica cordifolia*, *Osmorhiza berteroi*, *Thalictrum occidentale*, *Viola adunca*, and species of many other genera, including *Lathyrus*, *Penstemon*, *Erigeron*, *Lupinus*, *Fragaria*, *Vicia*, *Arenaria*, *Galium*, and others.

In the low elevation forests of western Washington and Oregon (west of the Cascade crest) the canopy is semi-open to closed. *Pseudotsuga menziesii* dominates with little or no *Tsuga heterophylla* or *Thuja plicata*. *Abies grandis* is codominant on some sites, and *Pinus contorta* can also codominate. *Salix scouleriana* and *Arbutus menziesii* are common but subordinate. There is a well-developed understory of deciduous or evergreen shrubs, or graminoids. *Holodiscus discolor*, *Symphoricarpos albus*, or *Rosa gymnocarpa* are typical dominant species and diagnostic. Other shrubs that may be important include *Gaultheria shallon*, *Rhododendron macrophyllum*, *Vaccinium ovatum*, *Mahonia aquifolium* (= *Mahonia piperiana*), *Mahonia nervosa*, *Corylus cornuta*, and *Symphoricarpos mollis*. In the herbaceous layer *Festuca occidentalis*, and *Melica subulata* are diagnostic species which are often dominant or codominant. *Bromus vulgaris*, *Festuca subuliflora*, and *Elymus glaucus* are also very common.

DATABASE CODE A.157

MAP CLASSES

Pseudotsuga menziesii Forest Alliance is mapped as map class Douglas-fir Forest, map code 21. The map class Douglas-fir Forest includes both the *Pseudotsuga menziesii* Forest Alliance and *Pseudotsuga menziesii* / *Muhlenbergia montana* Forest association.

The map class Douglas-fir Forest occurs only at high elevation on Darton Dome and O'Leary Peak, mostly with eastern or northern aspects. Douglas-fir Forest does not occur in Sunset Crater Volcano NM and only occurs in the park environs; the total area mapped in the park environs is 29 hectares within 7 polygons.

COMMENTS

Sunset Crater Volcano National Monument

This relevé did not represent any previously described associations within the Douglas-fir Forest alliance. Therefore, it was placed at the courser level of classification in the Douglas-fir Forest alliance. The vegetation assemblage may represent a new association, but such designation will require additional relevé data from other locations.

Global Comments

This alliance is derived from a series concept, where the presence of *Pseudotsuga menziesii* is diagnostic if other more shade-tolerant conifers are absent (presumes dominance of *Pseudotsuga menziesii* if some form of disturbance or extreme edaphic conditions do not limit its regeneration). In the Pacific ranges, the dominant taxon is *Pseudotsuga menziesii* var. *menziesii*, while *Pseudotsuga menziesii* var. *glauca* is the dominant in forests of the Rocky Mountains south into Mexico.

Global Dynamics

Successional relationships in this alliance are complex. *Pseudotsuga menziesii* is less shade-tolerant than many northern or montane trees such as *Tsuga heterophylla*, *Abies concolor*, *Picea engelmannii*, or *Thuja plicata*, and seedlings compete poorly in deep shade. At drier locales, seedlings may be favored by moderate shading, such as by a canopy of *Pinus ponderosa*, which helps to minimize drought stress. In some locations, much of these forests have been logged or burned during European settlement, and present-day stands are second-growth forests dating from fire, logging, or other stand replacing disturbances (Mauk and Henderson 1984, Chappell et al. 1997). *Pseudotsuga menziesii* forests were probably subject to a moderate severity fire regime in pre-settlement times, with fire-return intervals of 30-100 years. Many of the important tree species in these forests are fire-adapted (*Populus tremuloides*, *Pinus ponderosa*, *Pinus contorta*, *Larix occidentalis*) (Pfister et al. 1977), and fire-induced reproduction of *Pinus ponderosa* can result in its continued codominance in *Pseudotsuga menziesii* forests (Steele et al. 1981). Seeds of the shrub *Ceanothus velutinus* can remain dormant in forest stands for 200 years (Steele et al. 1981) and germinate abundantly after fire, competitively suppressing conifer seedlings. Some stands may have higher tree-stem density now than historically, due largely to fire suppression. Fire suppression has also lead to the succession of *Pinus ponderosa* woodlands or *Quercus* spp. woodlands to *Pseudotsuga menziesii* forests.

REFERENCES

Chappell et al. 1997, Lillybridge et al. 1995, Mauk and Henderson 1984, Pfister et al. 1977, Steele et al. 1981

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Pseudotsuga menziesii / *Muhlenbergia montana* Forest

COMMON NAME	Douglas-fir / Mountain Muhly Forest
PHYSIOGNOMIC CLASS	Forest (I.)
PHYSIOGNOMIC SUBCLASS	Evergreen forest (I.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen forest (I.A.8)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (I.A.8.N)
FORMATION	Conical-crowned temperate or subpolar needle-leaved evergreen forest (I.A.8.N.c)
ALLIANCE	<i>Pseudotsuga menziesii</i> Forest Alliance

CLASSIFICATION CONFIDENCE LEVEL Strong

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

The Douglas-fir / Mountain Muhly Forest occurs on higher elevation cinder cones in the project environs. Only one relevé was sampled, at the top of Darton Dome.

Globally

This forest association occurs on mountains and plateaus in Trans-Pecos Texas, New Mexico, Arizona, and possibly Colorado.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association occurs on the northern and eastern slopes of cinder cones in cinder gravel within the project environs at high elevations. The one relevé sampled occurred at an elevation of 2,250m and in a flat location (~8% slope).

Globally

This forested plant association occurs on mountains and plateaus in Trans-Pecos Texas, New Mexico, Arizona, and possibly Colorado. Sites are variable and include rocky ridge tops, gentle to steep slopes, stream sides and cinder cones. Elevation ranges from 2,650–2,970 m (8,700–9,750 feet) on steep south and west facing slopes, and down to 2245 m (7500 feet) on cool, northerly slopes. Substrates are generally dry, shallow, well-drained, gravelly or cobbly, coarse-textured soils. Lower elevation soils may be deep sands or cinder.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pseudotsuga menziesii</i> , <i>Pinus ponderosa</i>
Herbaceous	<i>Muhlenbergia montana</i>

Globally

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pseudotsuga menziesii</i> , <i>Pinus ponderosa</i>
Herbaceous	<i>Muhlenbergia montana</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Oxytropis lambertii

Globally

Pinus ponderosa, *Pinus strobiformis*, *Pinus flexilis*, *Pinus edulis*, *Juniperus deppeana*, *Juniperus scopulorum*, *Ceanothus fendleri*, *Cercocarpus montanus*, *Holodiscus dumosus*, *Mahonia repens*, *Quercus grisea*, *Ribes cereum*

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

In the one relevé of Douglas-fir / Mountain Muhly Forest sampled total vegetation cover was 50%, with 45% relative cover in the tree layer, 1% in the shrub layer, and 13% in the ground layer. Ten species were recorded.

Pseudotsuga menziesii and *Pinus ponderosa* were the dominant trees with *Pseudotsuga menziesii* having 25% cover and *Pinus ponderosa* with 20% cover. The DBH for *Pseudotsuga menziesii* ranged from 11-95cm (average 23cm) and the DBH for *Pinus ponderosa*, mostly young trees, ranged from 11.5-21.5cm (average 14.5). Tree heights ranged from 3-20 m.

The shrub layer was virtually absent (<0.5%). The herbaceous layer was characterized by *Muhlenbergia montana* (12% cover).

Globally

This plant association is characterized by a moderately dense evergreen tree canopy dominated or co-dominated by *Pseudotsuga menziesii* with a *Muhlenbergia montana* dominated graminoid layer. Other tree species may include large *Pinus ponderosa* (often co-dominant), and scattered *Pinus flexilis* (northern stands), *Pinus strobiformis*, *Pinus edulis*, *Juniperus deppeana* or, *J. scopulorum* (especially on dryer sites and southern stands). *Abies concolor* is not present or accidental. *Quercus gambelii* may be present in the subcanopy (tree form) or tall-shrub layer, but with less than 5% cover. Shrub cover is typically sparse (< 10% cover) and consists of scattered *Ceanothus fendleri*, *Cercocarpus montanus*, *Holodiscus dumosus*, *Mahonia repens*, *Quercus grisea* or *Ribes cereum*. The herbaceous layer is dominated by graminoids and is moderately dense and diverse. *Muhlenbergia montana* is the most consistent graminoid species and typically dominates. Other graminoids include *Blepharoneuron tricholepis*, *Bromus* spp., *Carex rossii*, *Elymus elymoides*, *Koeleria macrantha*, and *Poa fendleriana* but not *Festuca arizonica* or *Muhlenbergia virescens*. The forb cover is sparse. Common species are *Artemisia ludoviciana*, *Geranium caespitosum*, *Lithosperma multiflorum*, *Packera neomexicana*, *Pseudocymopterus montanus*, and *Thalictrum fendleri* (Alexander et al. 1987, Fitzhugh et al. 1987, Muldavin et al. 1996, Stuever and Hayden 1997a or b). The graminoid layer has greater than or equal shrub cover.

CONSERVATION RANK G4

DATABASE CODE Cegl000443

MAP CLASSES

Douglas-fir / Mountain Muhly Forest association was mapped as map class Douglas-fir Forest corresponding to map code 21. The map class Douglas-fir Forest includes both the *Pseudotsuga menziesii* Forest Alliance and *Pseudotsuga menziesii* / *Muhlenbergia montana* Forest association.

This map class only occurs within the environs of the study boundary and does not occur within Sunset Crater Volcano NM. Map class Douglas-fir Forest occurs on the northern side of Darton Dome and along the southeastern side of O'Leary Peak. The total hectares mapped are 29 and these occur within 7 polygons.

COMMENTS

Sunset Crater Volcano National Monument

The Douglas-fir / Mountain Muhly Forest association differs from the global description due to having <60% tree cover and with *Pinus ponderosa* co-dominating the association. This association needs to be further sampled within the Colorado Plateau to determine if this relevé would be better classified as a woodland rather than a forest type. Due to this type occurring in the environs of the project boundary, additional relevés were not sampled within this project boundary.

Global Comments

Two phases of this association are described by Stuever and Hayden (1997a or b). The limber pine (*Pinus flexilis*) phase is described from higher elevation stands in northern New Mexico (Muldavin et al. 1996) and the two-needle pinyon (*Pinus edulis*) phase from more southern latitudes where *Pinus edulis*, *P. strobiformis*, *Juniperus deppeana*, and *J. scopulorum* are common seral species (Stuever and Hayden 1997a or b).

Global Dynamics

Both diagnostic species are tolerant of ground fire. *Pseudotsuga menziesii* develops thick fire-resistant bark with age, and *Muhlenbergia montana* resprouts after burning although it may take a few years to recover to pre-burn density (Fischer and Bradley 1987, Wright et al. 1979). Fire-return interval can be low in areas in dry, rocky stands where ground fire is limited by lack of continuous fine fuels. The sparse shrub layer reduces the risk of crown fire by limited ladder fuel to the crown of overstory trees. If fire frequency is high, the more fire-resistant tree *Pinus ponderosa* will be favored and may become dominant (Stuever and Hayden 1997b). Disturbance of tree canopy favors graminoids (Alexander et al. 1987). Improper livestock grazing (where accessible) can result in converting the herbaceous layer from graminoids to unpalatable forbs (Fitzhugh et al. 1987). Drier sites tend to have more graminoids and more mesic stands have more shrubs (Alexander et al. 1987).

REFERENCES

Alexander et al. 1987, Fischer and Bradley 1987, Fitzhugh et al. 1987, Muldavin et al. 1996, Stuever and Hayden 1997b, Wright et al. 1979

Pinus edulis – (*Juniperus osteosperma*) / *Bouteloua gracilis* Woodland

COMMON NAME	Two-needle Pinyon – (Utah Juniper) / Blue Grama Woodland
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus edulis</i> – (<i>Juniperus</i> spp.) Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Moderate

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Two-needle Pinyon - Utah Juniper / Blue Grama Woodland occurs within Sunset Crater Volcano NM on the eastern side of Sunset Crater. This association is also common within the environs at the bases of cinder cones. This association is found on Black Mountain, Darton Dome, O' Leary Peak, Robinson Mountain, and Robinson Crater in the study environs.

Globally

This woodland association occurs in the cinder fields, mountains and mesas in the southern Colorado Plateau and Mogollon Rim, and may extend into southern Utah and western Colorado.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association occurs at 2,100-2,300m. It occurs at the base of cinder cones and in flat lower elevation areas. It is frequently on the southern exposure of cinder cones and occasionally climbs towards the top of the cinder cones. Slope ranges from 10-40%. The typical substrate consists of cinder gravel with a smaller percentage of cinder sand and lava cobbles.

Globally

This woodland association is known from the mountains and mesas in the southern Colorado Plateau, Mogollon Rim and extends into southern Utah and western Colorado. Elevations normally range from 2,100-2,300m (6,885-7,540 feet). Sites are variable, but generally are relatively dry and rocky. Stands occur on flat to moderate slopes along drainages and on mesa tops, on gentle to moderate 10-40% rocky slopes of foothills, and at the base of cinder cones. The substrates are variable and range from deep, coarse textured soil derived from cinder, to sandy loams derived from sandstone or fine-textured soils derived from limestone.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus edulis</i> , <i>Juniperus osteosperma</i> , <i>Juniperus deppeana</i>
Herbaceous	<i>Bouteloua gracilis</i>

Globally

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus edulis</i> , <i>Juniperus osteosperma</i> , <i>Juniperus deppeana</i> , <i>Juniperus scopulorum</i>
Herbaceous	<i>Bouteloua gracilis</i>

USGS-NPS Vegetation Mapping Program

Sunset Crater Volcano National Monument

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Ageratina herbacea, *Aristida divaricata*, *Artemisia carruthii*, *Artemisia dracunculus*, *Bouteloua curtipendula*, *Brickellia californica*, *Cercocarpus montanus*, *Ericameria nauseosa*, *Eriogonum corymbosum*, *Fallugia paradoxa*, *Ipomopsis aggregata*, *Oxytropis lambertii*, *Mahonia fremontii*, *Purshia stansburiana*, *Ribes cereum*, *Rhus trilobata*, *Yucca baccata*, *Verbascum thapsus*

Globally

Juniperus deppeana, *Juniperus scopulorum*, *Cercocarpus montanus*, *Ericameria nauseosa*, *Rhus trilobata*, *Yucca* spp., *Achnatherum hymenoides*, *Bouteloua curtipendula*, *Elymus elymoides*, *Koeleria macrantha*, *Hesperostipa comata*, *Hesperostipa neomexicana*, *Pleuraphis jamesii*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Two-needle Pinyon - Utah Juniper / Blue Grama Woodland was sampled in seven relevés with a total vegetation cover ranging from 23-62% (average 42%). Absolute cover in the tree layer ranges from 20-55% (average 30%), in the shrub layer 2-10% (average 5%), and in the herbaceous layer 2-20% (average 5%). The total number of species ranged from 12-29 species (average 21).

Within the tree layer *Pinus edulis* ranged from 11-54% absolute cover (average 19%) and *Juniperus osteosperma* 2-26% (average 9%). *Juniperus deppeana* occurred in 43% of the total relevés with 6-16.5% absolute cover (average 11%). *Pinus edulis* DBH ranged from 11-92cm (average 29cm), *Juniperus osteosperma* 11.5-59.5cm (average 26cm), and *Juniperus deppeana* 10.5-75cm (average 32cm). One to five percent of all trees within this association had a height of 3-5 m, 5-10% were 5-10 m, and less than 1% were 10-20m tall.

The shrub layer had 2-10% absolute cover with the dominant shrubs consisting of *Fallugia paradoxa* and *Rhus trilobata*. The herbaceous layer had 2-20% absolute cover with the characteristic species being *Bouteloua gracilis* and *Artemisia dracunculus*.

Globally

This plant association is characterized by an open to moderately dense tree canopy (10-65% cover) co-dominated by *Pinus edulis* and *Juniperus osteosperma*. *Pinus edulis* may be present with relatively small cover in some stands. *Juniperus deppeana* may replace *Juniperus osteosperma* in southern stands. Other species of *Juniperus* such as *J. scopulorum* may be present in higher elevation stands. Shrub cover is sparse (<10% cover). If *Quercus gambelii* is present, it has less than 5% cover. Other associated shrubs may be present such as scattered *Brickellia californica*, *Cercocarpus montanus*, *Ericameria nauseosa*, *Eriogonum corymbosum*, *Fallugia paradoxa*, *Gutierrezia sarothrae*, *Opuntia* spp., *Purshia stansburiana*, *Rhus trilobata*, *Ribes cereum* or *Yucca* spp. The herbaceous layer is typically moderately dense and is dominated by the warm-season, perennial short grass, *Bouteloua gracilis*. Associated graminoids include *Aristida* spp., *Achnatherum hymenoides* (= *Oryzopsis hymenoides*), *Bouteloua curtipendula*, *Elymus elymoides*, *Koeleria macrantha*, *Hesperostipa comata* (= *Stipa comata*), *H. neomexicana* (= *Stipa neomexicana*), and *Pleuraphis jamesii* (= *Hilaria jamesii*). *Muhlenbergia montana* is absent or scarce (<1% cover). Forb cover is typically low, but may be moderately diverse. Species such as *Artemisia dracunculus*, *Eriogonum* spp., and *Oxytropis lambertii* are common.

CONSERVATION RANK G5

DATABASE CODE Cegl000778

MAP CLASSES

Two-needle Pinyon - Utah Juniper / Blue Grama Woodland corresponds to the map class Pinyon Pine –Utah Juniper / Blue Grama Woodland (map code 11) and vegetation cover modifier Pinyon Pine – Utah Juniper / Blue Grama Woodland (Sparse) (map code 12). The sparse modifier refers to association occurrences with less than 25% trees and greater than 15% herbaceous cover. Map class Pinyon Pine –Utah Juniper / Blue Grama Woodland includes the Pinyon Pine –Utah Juniper / Blue Grama Woodland association and the Two-needle Pinyon / Sparse Understory Forest association.

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Sunset Crater Volcano National Monument

Pinyon Pine –Utah Juniper / Blue Grama Woodland occurs primarily within the environs of the study boundary and does not occur on Sunset Crater. It occurs mainly on the northern and eastern section of the project boundary. The total area mapped for map class 11 within Sunset Crater Volcano NM is 2 hectares within 5 polygons and the total area in the park environs is 361 hectares within 51 polygons. Map code 12 does not occur within Sunset Crater Volcano NM; however, the total area in the park environs is 33 hectares within 8 polygons.

COMMENTS

Sunset Crater Volcano National Monument

Two-needle Pinyon - Utah Juniper / Blue Grama Woodland association may have a sparse understory layer or be dominated by herbaceous species other than *Bouteloua gracilis*. If *Bouteloua gracilis* is present it is an indicator species for this association as currently classified. Further sampling within the Colorado Plateau is needed to determine if *Bouteloua gracilis* is a true indicator for this association.

Global Comments

The two *Pinus edulis* / *Bouteloua gracilis* plant associations are treated as phases in Stuever and Hayden (1997a). In the NVCS we are including stands with southern Great Plains, Chihuahua Desert floristic affinities in the *Pinus edulis* – (*Juniperus monosperma*) / *Bouteloua gracilis* Woodland (CEGL002151) and stands with the Colorado Plateau and Great Basin floristic affinities in the *Pinus edulis* – (*Juniperus osteosperma*) / *Bouteloua gracilis* Woodland (CEGL000778). Both of these associations may include stands codominated by *Juniperus deppeana* in their southern extent. Stuever and Hayden (1997a) also described *Juniperus deppeana* phase (recognized by its dominance in the stand) and hillslope phase, which occurs on slopes > 15% and may have low cover of grasses (<5% cover). More survey is needed to fully understand the distribution and ecological relationships between these 3 species of *Juniperus* and *Pinus edulis*.

REFERENCES

Stuever and Hayden 1997a

Pinus flexilis Woodland Alliance

COMMON NAME	Limber Pine Woodland Alliance
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus flexilis</i> Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Alliances are not ranked by NatureServe for classification confidence

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

This alliance is found at high elevations on O’Leary Peak in the project environs.

Globally

Stands included in this widespread woodland alliance occur intermittently throughout the Rocky Mountains and on mountains and plateaus in the Great Basin and Colorado Plateau, and on breaks in the northwestern Great Plains. The alliance ranges from Montana to New Mexico and from western North Dakota to southern California. It also likely occurs in southern Alberta and southeastern British Columbia, Canada.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

The one relevé sampled was found at an elevation of 2,725m on the southeastern side of O’Leary peak on a steep slope of 40%. The substrate was mainly cinder gravel and basaltic derived soils.

Globally

Woodlands included in this alliance occur intermittently from timberline to lower montane and foothill zones throughout much of the Rocky Mountains, on escarpments and other geographic breaks in the northwestern Great Plains, and in mountains in the Great Basin and southern California. Elevations range from 850-3500 m. Climate is semiarid, cold temperate. Annual precipitation patterns and amounts are variable, but locally the sites are typically xeric on exposed, windswept rocky slopes and ridges from subalpine to foothills and prairie breaks. Some stands are on eroded substrates and resemble 'badlands' while others may occur on lava flows. These open woodlands occur on all aspects, but are most common on dry south- and west-facing slopes. Soils are typically shallow, skeletal and coarse-textured such as gravelly, sandy loams or loams, but may include alkaline clays. Stands grow best on calcareous soils derived from limestone or sandstone, but parent material is variable and includes a variety of igneous, sedimentary, and metamorphic rocks. Depending on the stand, bedrock may include a mixture of andesite, basalt, cinder, lava, limestone, dolomite, granite, gneiss, quartzite, rhyolite, schist, sandstone, serpentine, or shale. Exposed bedrock is common and many stands have over 50% bare soil. Soil pH is typically neutral or slightly alkaline, but can range from acid to alkaline.

Adjacent vegetation at high elevations includes alpine meadows and shrublands and subalpine forests dominated by *Picea*, *Abies* or *Pseudotsuga*. Adjacent montane stands are dominated by *Pinus ponderosa*, *Pinus contorta* or *Pseudotsuga menziesii*. At lower elevations adjacent vegetation may include *Juniperus*-dominated woodland and savannas; shrublands dominated by species of *Artemisia*, *Cercocarpus*, or *Purshia tridentata*; dry prairie; or riparian woodland dominated by *Pseudotsuga menziesii*. The transition can be abrupt or an extended ecotone where the woodlands grade into a savanna.

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Sunset Crater Volcano National Monument

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

Stratum

Tree canopy

Species

Pinus flexilis, *Pseudotsuga menziesii*, *Populus tremuloides*

Globally

Stratum

Tree canopy

Species

Pinus flexilis, *Pseudotsuga menziesii*

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Brickellia grandiflora, *Holodiscus dumosus*, *Ribes cereum*

Globally

Abies concolor, *Juniperus osteosperma*, *Juniperus scopulorum*, *Picea engelmannii*, *Pinus albicaulis*, *Pinus balfouriana*, *Pinus contorta*, *Pinus jeffreyi*, *Pinus longaeva*, *Pinus ponderosa*, *Arctostaphylos uva-ursi*, *Artemisia arbuscula*, *Artemisia nova*, *Artemisia tridentata*, *Cercocarpus ledifolius*, *Juniperus communis*, *Mahonia repens*, *Purshia tridentata*, *Rhus trilobata*, *Shepherdia canadensis*, *Symphoricarpos oreophilus*, *Yucca glauca*, *Achnatherum hymenoides*, *Bouteloua gracilis*, *Calamagrostis purpurascens*, *Carex rossii*, *Festuca idahoensis*, *Festuca campestris*, *Leucopoa kingii*, *Koeleria macrantha*, *Pseudoroegneria spicata*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

The one Limber Pine Woodland relevé had a total vegetation cover of 40%, with 35% absolute cover in the tree layer, 2% in the shrub layer, and 5% in the herbaceous layer. Sixteen species occurred in this relevé.

The dominant species within the tree layer were *Pinus flexilis* (12% absolute cover), *Pseudotsuga menziesii* (8% absolute cover), and *Populus tremuloides* (7% absolute cover). The DBH for *Pinus flexilis* ranged from 13-19cm (average 15cm), *Pseudotsuga menziesii* ranged from 30-93cm (average 36cm), and *Populus tremuloides* ranged from 13-77.6cm (average 59cm). Tree height was distributed between 3-20m.

The shrub and herbaceous layer were sparse (7% absolute cover) with the dominant species being *Brickellia californica*, *Holodiscus dumosus*, and *Ribes cereum*.

Globally

Stands included in this widespread woodland alliance occur locally on warm, dry, rocky, exposed sites in the Rocky Mountain west, northwestern Great Plains, and desert mountains in the Great Basin and in southern and eastern California. Stands have an open canopy typically 3-10 m tall, but individuals may reach 15 m. The stands are solely dominated or codominated by the evergreen needle-leaved tree *Pinus flexilis*. Other trees species that may be present to codominant vary by geography and elevation zones throughout the woodland's range. In the subalpine, *Pinus albicaulis*, *Picea engelmannii* or *Pseudotsuga menziesii* may be present. In the montane zone, *Pinus contorta*, *Pinus ponderosa* or *Pseudotsuga menziesii* are frequently present, and in the lower montane transition zone from woodlands to grasslands or shrublands, *Juniperus osteosperma* or *Juniperus scopulorum* may co-occur with *Pinus flexilis*. In California, associates may include *Abies concolor*, *Pinus albicaulis*, *Pinus balfouriana*, *Pinus contorta*, *Pinus jeffreyi*, and *Pinus longaeva* (Sawyer and Keeler-Wolf 1995).

The understory vegetation is typically sparse because sites are dry and have a large cover of rock. On stands occurring in the breaks in the plains, Johnston (1987) reported 18% exposed rock and 25% bare soil. A sparse shrub layer may be present. The taller shrubs may include *Artemisia tridentata*, *Cercocarpus ledifolius*, *Jamesia americana*, *Rhus trilobata*, *Shepherdia canadensis*, *Symphoricarpos oreophilus* and immature tree species. The most frequent low shrubs are *Arctostaphylos uva-ursi*, *Artemisia arbuscula*, *Artemisia nova*, *Juniperus communis*, *Mahonia repens*, *Purshia tridentata*, and *Yucca glauca*. The herbaceous layer often dominates the understory. The most common species are graminoids such as *Bouteloua gracilis*, *Calamagrostis purpurascens*, *Carex rossii*, *Festuca idahoensis*, *Festuca campestris*, *Leucopoa kingii* (= *Festuca kingii*), *Koeleria macrantha*, *Achnatherum hymenoides* (= *Oryzopsis hymenoides*), and *Pseudoroegneria spicata*. Scattered forbs may include species of *Achillea*, *Antennaria*, *Arenaria*, *Arnica*, *Astragalus*, *Erigeron*, *Eriogonum*, *Hymenopappus*, *Hymenoxys*, *Liatris*,

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Sedum, *Solidago*, and *Thermopsis*. In six relevés in the Little Missouri National Grassland in western North Dakota, the average cover for each of the strata was trees 38%, shrubs 21%, graminoids 20%, and forbs 9% (USFS 1992).

DATABASE CODE A.540

MAP CLASSES

Limber Pine Woodland Alliance is mapped as map class Limber Pine Woodland, map code 13.

Limber Pine Woodland Alliance occurs only in the environs of the study boundary on O'Leary Peak. The total area mapped within the park environs is 13 hectares within 9 polygons.

COMMENTS

Sunset Crater Volcano National Monument

The one relevé sampled did not represent any of the previously described associations within the Limber Pine Woodland alliance. In order to classify this relevé it was placed at a coarser classification level within the Limber Pine Woodland alliance. This relevé may represent a new vegetation association, however sampling at additional locations is needed to verify this.

Global Comments

It may be difficult to determine which tree species are dominant in a mixed, montane or subalpine forest stand, especially when *Pinus flexilis* is seral on *Pseudotsuga menziesii* habitat type sites. Some stands included in this alliance are too sparse to be classified as woodlands, especially those growing on lava (Eggler 1941).

Global Dynamics

Although some of the conifers that are typically codominant in *Pinus flexilis* stands are late successional species, they are not likely to displace *Pinus flexilis*. This is because most of these stands occur on harsh sites where *Pinus flexilis* is more competitive than most other conifer species. These stands are generally considered to be topographic or edaphic 'climax' stands (Cooper 1975, Eyre 1980). Even in stands at lower elevations, such as prairie breaks, it is unlikely that other coniferous species will become dominant (Eyre 1980). Because *Pinus flexilis* occurs over a broad range of elevations, it can also be important as a post-fire seral species on drier sites in the Rocky Mountains (Cooper 1975, Peet 1988). Peet (1978) reported apparent competitive displacement with *Pinus flexilis* in Colorado. He noted that *Pinus flexilis* may dominate xeric sites from low to high elevations, except where *Pinus aristata* or *Pinus albicaulis* occur. There, *Pinus flexilis* is largely restricted to lower elevation, rocky sites. Peet (1978) also reported that *Pinus flexilis* occurs in the less xeric *Pinus contorta* and *Pinus ponderosa* habitats.

Birds and small mammals often eat and cache the large, wingless pine seeds. Most important is the Clark's nutcracker, which can transport the seeds long distances and cache them on exposed windswept sites (Lanner and Vander Wall 1980). This results in the regeneration of pines in clumps from forgotten caches (Eyre 1980, Steele et al. 1983).

REFERENCES

Cooper 1975, Eggler 1941, Eyre 1980, Lanner and Vander Wall 1980, Peet 1978, Peet 1988, Sawyer and Keeler-Wolf 1995, Steele et al. 1983, USFS 1992

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Pinus ponderosa / *Andropogon hallii* Woodland

COMMON NAME	Ponderosa Pine / Sand Bluestem Woodland
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus ponderosa</i> Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Low Confidence. This association has been newly described at Sunset Crater Volcano NM. No global descriptions or conservation ranks have currently been assigned.

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine / Sand Bluestem Woodland occurs on cinder cones in Sunset Crater Volcano NM. It is found on the west side of Sunset Crater Volcano NM and on a cinder cone southeast of Sunset Crater Volcano NM. This association also occurs in the park environs in patches within the OHV area.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Only one relevé was sampled at an elevation of 2,200m with a slope of 42% and on cinder gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Herbaceous	<i>Andropogon hallii</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia campestris, *Ericameria nauseosa*, *Oenothera* sp.

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

The total vegetation cover for the one relevé sampled was 25% with 15% absolute cover in the tree layer, 5% in the shrub layer, and 15% in the herbaceous layer. Nine species were recorded.

The tree layer was characterized by *Pinus ponderosa* with DBH ranging from 13-63cm (average 30cm). The tree heights were between 3-10m. The most abundant grass was *Andropogon hallii* (12% absolute cover). The shrub cover was sparse.

CONSERVATION RANK G?

DATABASE CODE Cegl005808

MAP CLASSES

Ponderosa Pine / Sand Bluestem Woodland is represented by map class Ponderosa Pine / Sand Bluestem Woodland (map code 20).

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Ponderosa Pine / Sand Bluestem Woodland is mapped on Sunset Crater and in the southeastern corner of the project boundary in USDA-FS lands. The total area mapped in Sunset Crater Volcano NM is 15 hectares within 4 polygons and in the park environs 5 hectares within 3 map polygons.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Pinus ponderosa / *Bouteloua gracilis* Woodland

COMMON NAME	Ponderosa Pine / Blue Grama Woodland
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus ponderosa</i> Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Strong

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine / Blue Grama Woodland commonly occurs in the park environs and in the southeast corner of Sunset Crater Volcano NM. It is commonly found in the flat areas adjacent to Hwy 89 and FS road 776. It is also located at the base of cinder cones including Darton Dome, Robinson Mountain, and O'Leary Peak.

Globally

This ponderosa pine woodland occurs in the southern Rocky Mountains, extending east on southern Great Plains escarpments as far as Oklahoma, south to the mountains of West Texas, west to the Colorado Plateau and Mogollon Rim of New Mexico, Arizona, and southern Utah.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association's elevation ranged from 2,050-2,250m (average 2,120m) and the slope ranged from 4-25% (average 12%).

Globally

This widespread woodland occurs at foothill and lower montane elevations from the southern Rocky Mountains, extending east on southern Great Plains escarpments, south to the mountains of West Texas, west to the Colorado Plateau and Mogollon Rim of New Mexico, Arizona and Utah. Elevation ranges from 1,740-2,610 m (5,700-8,550). Sites occur on dry, gentle to steep slopes on all aspects, but are more common on southern and western aspects, especially at higher elevations. Substrates are quite variable and include shallow sandy loam soils derive from granitic parent materials, coarse cinder soils and clayey soil with or without high coarse fragment content.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Shrub	<i>Ericameria nauseosa</i>
Herbaceous	<i>Bouteloua gracilis</i>

Globally

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Herbaceous	<i>Bouteloua gracilis</i>

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia carruthii, *Artemisia dracunculus*, *Bromus tectorum*, *Elymus elymoides*, *Festuca arizonica*, *Muhlenbergia montana*, *Tetradymia canescens*

Globally

Pinus edulis, *Juniperus monosperma*, *J. osteosperma*, *J. deppeana*, *J. scopulorum*, *Artemisia tridentata*, *Ceanothus fendleri*, *Cercocarpus montanus*, *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, *Fallugia paradoxa*, *Purshia tridentata*, *Quercus grisea*, *Rhus trilobata*, *Tetradymia canescens*, *Bouteloua hirsuta*, *Carex geophila*, *Elymus elymoides*, *Hesperostipa comata*, *Koeleria macrantha*, *Muhlenbergia montana*, *Poa fendleriana*, *Schizachyrium scoparium*, *Artemisia ludoviciana*, *Eriogonum racemosum*, *Chaetopappa ericoides*, *Packera neomexicana*.

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

The Ponderosa Pine / Blue Grama Woodland has a total vegetation cover that ranges from 40-75% absolute cover (average 61%). The average cover for the tree layer ranged from 5-30% (average 15%), shrub layer 2-25% (average 8%), and herbaceous layer 30-50% (average 39%). Species richness ranged from 15-39 (average 24) in the three relevés measured.

The tree layer is dominated by *Pinus ponderosa*, with DBH ranging from 16-58cm (average 30cm). The shrub layer was often characterized by *Ericameria nauseosa* (1-35% absolute cover). The herbaceous layer is dominated by *Bouteloua gracilis* with 3-25% absolute cover (average 20%).

Globally

This plant association is characterized by an open to moderately dense, evergreen, needleleaf tree canopy 10-30 m tall that is either dominated by *Pinus ponderosa* or codominated by *Pinus ponderosa* and *Pinus edulis*. *Juniperus monosperma*, *J. osteosperma*, *J. deppeana* or *J. scopulorum* may be important subdominants. The typically moderately dense herbaceous layer has greater cover than the shrub layer, and is dominated by graminoids. *Bouteloua gracilis*, the warm-season, sod-forming, shortgrass dominates the herbaceous layer. Common graminoid associates include *Aristida* spp., *Bouteloua hirsuta*, *Carex geophila*, *Elymus elymoides*, *Hesperostipa comata*, *Koeleria macrantha*, *Muhlenbergia montana*, *Poa fendleriana*, or *Schizachyrium scoparium*. *Muhlenbergia montana* may be present, but only with low cover (<2%) and does not co-dominate. *Quercus gambelii* may be present in the sparse shrub layer (<10% cover) with low cover (<5%). Other shrubs may include scattered *Artemisia tridentata*, *Ceanothus fendleri*, *Cercocarpus montanus*, *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, *Fallugia paradoxa*, *Purshia tridentata*, *Quercus grisea*, *Rhus trilobata*, and *Tetradymia canescens*. Forb cover is typically sparse and may include species such as *Antennaria* spp., *Artemisia ludoviciana*, *Erigeron* spp., *Eriogonum racemosum*, *Chaetopappa ericoides*, *Packera neomexicana*, and *Penstemon* spp.

CONSERVATION RANK G4

DATABASE CODE Cegl000848

MAP CLASSES

The association Ponderosa Pine / Blue Grama Woodland is represented by map class Ponderosa Pine / Montane Grass Mosaic (map code 15). Ponderosa Pine / Montane Grass Mosaic is a combined map class of Ponderosa Pine / Blue Grama Woodland and Ponderosa Pine / Mountain Muhly Woodland. These two associations were combined in one map class due to difficulties in photointerpreting the different grass understories under ponderosa pine canopy cover.

Ponderosa Pine / Montane Grass Mosaic is mapped as the dominant map class in the western section of the project boundary. This map class also occurs in a small patch on Darton Dome and in the southeastern section on Forest Service lands. The total area mapped in Sunset Crater Volcano NM is 3 hectares within 1 polygon and in the park environs 1223 hectares within 69 map polygons.

COMMENTS

Sunset Crater Volcano National Monument

This association has high variability in the shrub, tree, and herbaceous layer. With more relevés collected within the Colorado Plateau this association may be subdivided into additional associations.

Global Comments

This ponderosa pine woodland is a broadly defined plant association. Stuever and Hayden (1997b) report 6 phases: the *Bouteloua gracilis*, *Schizachyrium scoparium*, *Andropogon hallii*, *Artemisia tridentata*, *Quercus grisea*, and *Q. gambelii* phases. Hanks et al. 1983 described 4 phase of the *Pinus ponderosa*/*Bouteloua gracilis* Habitat Type from northern Arizona. More classification review is needed to further define the relationships between these phases and other similar plant associations. Alexander et al. (1987), DeVelice et al. (1986), and Muldavin et al. (1996) also described phases of this Habitat Type that need further review and cross-walking to NVCS. Youngblood and Mauk (1985) included stands of this association in their broadly defined *Pinus ponderosa*/*Muhlenbergia montana* Habitat Type.

Global Dynamics

Both diagnostic species are tolerant of ground fire. *Pinus ponderosa* develops thick fire-resistant bark that protects it from ground fires (Bradley et al. 1992). *Bouteloua gracilis* resprouts after burning and is unharmed by fires in years with above normal winter and spring precipitation, but can be severely damaged during drought years (Wright and Bailey 1980). Most *Pinus ponderosa* stands have relatively frequent fires (every 3-20 years), but fire are less frequent in dry, rocky stands where ground fire is limited by lack of continuous fine fuels (Stuever and Hayden 1997b). Fire-return interval has generally increased because of active fire suppression and historic livestock grazing, which has reduced the fine-fuels needed to carry ground fires (Madany and West 1980, Savage and Swetnam 1990). Absence of fire has led to large accumulations of ground fuel and has likely resulted in denser stands and invasion of less fire-adapted, shade tolerant species species such as *Pseudotsuga menziesii*. This has likely increased risk of severe, stand replacing crown fires.

REFERENCES

Alexander et al. 1987, Bradley et al. 1992, , DeVelice et al. 1986, Hanks et al. 1983, Madany and West 1980, Stuever and Hayden 1997b, Savage and Swetnam 1990, Wright and Bailey 1980, Youngblood and Mauk 1985

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Pinus ponderosa / *Fallugia paradoxa* Woodland

COMMON NAME	Ponderosa Pine / Apache Plume Woodland
SYNONYM	N/A
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus ponderosa</i> Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Low Confidence, Newly described at Sunset Crater Volcano NM. No additional global description data available.

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine / Apache Plume Woodland is one of the most common associations in Sunset Crater Volcano NM and also occurs frequently in the park environs. This association is found on level cinder areas and steeper cinder slopes in the eastern section of the park. It is also the most common association in the eastern half of the park environs.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa Pine / Apache Plume Woodland was found on cinder gravel with a range of slopes (0-45%, average 11%). Elevation ranged from 1,975-2,450m (average 2,120m).

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Shrub	<i>Fallugia paradoxa</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Alhagi maurorum, *Andropogon hallii*, *Bouteloua gracilis*, *Bromus tectorum*, *Eriogonum corymbosum*, *Ericameria nauseosa*, *Forestiera pubescens*, *Linum lewisii*, *Juniperus osteosperma*, *Pinus edulis*, *Pseudotsuga menziesii*, *Ribes cereum*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa Pine / Apache Plume Woodland total vegetation cover ranged from 9-55% cover (average 24%). The tree layer ranged in absolute cover from 9-55% (average 24%), shrub layer ranged from 1-43% (average 6%), and herbaceous layer ranged from 1-20% (average 4%). The average total number of species per relevé ranged from 2-25 (average 11) as seen in 27 relevés.

Fallugia paradoxa dominated the shrub layer (1-45% absolute cover, average 9%). The tree layer is dominated by *Pinus ponderosa* (5-36% absolute cover, average 16%) with DBH ranging from 11-85cm (average 34cm). The herbaceous layer was sparse.

CONSERVATION RANK G?

DATABASE CODE Cegl002999

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

MAP CLASSES

Ponderosa Pine / Apache Plume Woodland is mapped as Ponderosa Pine / Apache Plume Woodland, Ponderosa Pine / Apache Plume Woodland (Sparse), and Ponderosa Pine / Apache Plume Woodland (Pinyon), represented respectively by map codes 17, 18, and 19.

The map class Ponderosa Pine / Apache Plume Woodland (Sparse) refers to relevés with less than 20% total vegetation cover and the map class Ponderosa Pine / Apache Plume Woodland (Pinyon) contains greater than 10% *Pinus edulis*.

Ponderosa Pine / Apache Plume Woodland and its modifiers are mapped as the predominant association in the eastern half of the project area. The total hectares mapped of Ponderosa Pine / Apache Plume Woodland in Sunset Crater Volcano NM is 354 and these occur within 70 polygons and in the park environs 1940 hectares within 187 polygons. This consists of map code 18 with 238 hectares and 18 polygons in Sunset Crater Volcano NM and 1650 hectares and 41 polygons in the park environs, map code 17 with 115 hectares and 51 polygons in Sunset Crater Volcano NM and 224 hectares and 127 polygons in the park environs, and map code 19 with 1 hectare and 1 polygon in Sunset Crater Volcano NM and 66 hectares and 19 polygons in the park environs.

COMMENTS

Sunset Crater Volcano National Monument

Depending on the spacing of trees, this map class may represent a mosaic of Ponderosa Pine / Apache Plume Woodland and Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland with Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland occurring in patches of 1,000m² or larger.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Pinus ponderosa / *Muhlenbergia montana* Woodland

COMMON NAME	Ponderosa Pine / Mountain Muhly Woodland
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus ponderosa</i> Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Strong

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine / Mountain Muhly Woodland occurs frequently in the park environs around Sunset Crater Volcano NM. It occurs most frequently in the northwestern section of the environs around Robinson Crater, Robinson Mountain, and O'Leary Peak. Also in the environs it occurs south of Bonito Park at the base of unnamed cinder cones.

Globally

This widespread woodland occurs at foothill and lower montane elevations in the southern Rocky Mountains, extending south to the mountains of West Texas, and west to the Mogollon Rim and Colorado Plateau of New Mexico, Arizona and Utah.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa Pine / Mountain Muhly Woodlands occurs between an elevational range of 2,150-2,270m (average 2,200m). Slope is low to moderate and ranges from 1-35% (average 9%). Typically it is on cinder gravel.

Globally

This widespread woodland occurs at foothill and lower montane elevations in the southern Rocky Mountains, extending south to the mountains of West Texas, and west to the Mogollon Rim and Colorado Plateau. Elevation ranges from 2,150-2,870 m (7,050-9,400 feet). Stands occur on bottomlands, elevated plains, cinder cones, piedmont slopes, mesas, foothills, and mountains. Sites include gentle to steep slopes on all aspects, but are more common on southern and western aspects, especially at higher elevations. Substrates are variable, but are typically shallow, rocky, coarse-textured soils derived from granitic or cinder parent materials. There is considerable cover of bare soil and exposed bedrock.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Herbaceous	<i>Muhlenbergia montana</i>

Globally

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i> <i>Pinus edulis</i> , <i>Pinus discolor</i> , <i>Juniperus monosperma</i> , <i>Juniperus osteosperma</i> , <i>Juniperus deppeana</i> , <i>Juniperus scopulorum</i>
Herbaceous	<i>Muhlenbergia montana</i>

USGS-NPS Vegetation Mapping Program

Sunset Crater Volcano National Monument

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia carruthii, *Bouteloua gracilis*, *Brickellia californica*, *Cercocarpus montanus*, *Cirsium wheeleri*, *Elymus elymoides*, *Ericameria nauseosa*, *Fallugia paradoxa*, *Festuca arizonica*, *Juniperus deppeana*, *Juniperus osteosperma*, *Mahonia fremontii*, *Muhlenbergia minutissima*, *Pinus edulis*, *Tetradymia canescens*, *Oxytropis lambertii*, *Schizachyrium scoparium*, *Quercus gambelii*

Globally

Pinus edulis, *Pinus discolor*, *Juniperus monosperma*, *J. osteosperma*, *J. deppeana*, *J. scopulorum*, *Artemisia tridentata*, *Brickellia californica*, *Ceanothus fendleri*, *Cercocarpus montanus*, *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, *Fallugia paradoxa*, *Quercus gambelii*, *Purshia tridentata*, *Quercus grisea*, *Rhus trilobata*, *Tetradymia canescens*, *Yucca baccata*, *Blepharoneuron tricholepis*, *Bouteloua gracilis*, *Carex geophila*, *C. rossii*, *Elymus elymoides*, *Koeleria macrantha*, *Poa fendleriana*, *Schizachyrium scoparium*, *Artemisia ludoviciana*, *Eriogonum racemosum*, *Chaetopappa ericoides*, *Lotus wrightii*, *Oxytropis lambertii*, *Packera neomexicana*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

The total vegetation cover ranged from 22-50% (average 37%). The tree layer absolute cover ranged from 12-35% (average 22%), shrub layer ranged 0-9% (average 2%), and the herbaceous strata ranged from 7-35% (average 16%). The total species richness ranged from 12-37 species (average 24) as found on 12 relevés.

The tree layer was dominated by *Pinus ponderosa* with cover ranging from 5-36% (average 33%). DBH ranged from 11-99cm (average 31cm) and tree height ranged from 5-20m. The herbaceous layer was dominated by *Muhlenbergia montana* with 2-20% cover (average 9%). The shrub layer was sparse.

Globally

This association is characterized by an open to moderately dense, evergreen, needleleaf tree canopy to 10-30 m tall that is dominated or codominated by *Pinus ponderosa*. Associated tree species vary geographically. *Pinus edulis*, *Pinus discolor*, *Juniperus monosperma*, *J. osteosperma*, *J. deppeana* and *J. scopulorum* may be important in the tree canopy. *Pseudotsuga menziesii*, *Pinus flexilis*, and *Populus tremuloides* may also be present, but are considered accidental. The typically moderately dense herbaceous layer has greater cover than the shrub layer, and is dominated by graminoids. *Muhlenbergia montana*, a warm-season, medium-tall perennial typically dominates the herbaceous layer and is diagnostic of this association. *Bouteloua gracilis* may co-dominate. Common graminoid associates include *Aristida* spp., *Blepharoneuron tricholepis*, *Carex geophila*, *C. rossii*, *Elymus elymoides*, *Koeleria macrantha*, *Poa fendleriana* and *Schizachyrium scoparium*. *Festuca arizonica*, *Muhlenbergia virescens*, *M. dubia*, *M. emersleyi* and *Hesperostipa* spp. are typically absent. *Quercus gambelii* may be present with low cover (to 5%) in the sparse shrub layer (<10% cover). Other scattered shrubs may include *Artemisia tridentata*, *Brickellia californica*, *Ceanothus fendleri*, *Cercocarpus montanus*, *Chrysothamnus viscidiflorus*, *Ericameria nauseosa*, *Fallugia paradoxa*, *Mahonia* spp., *Purshia tridentata*, *Quercus grisea*, *Rhus trilobata*, *Tetradymia canescens* or *Yucca baccata*. Forb cover is typically sparse and may include species such as *Antennaria* spp., *Artemisia ludoviciana*, *Erigeron* spp., *Eriogonum racemosa*, *Chaetopappa ericoides*, *Lotus wrightii*, *Oxytropis lambertii*, *Packera neomexicana*, and *Penstemon* spp.

CONSERVATION RANK G4G5

DATABASE CODE CEGL000862

MAP CLASSES

The association Ponderosa Pine / Mountain Muhly Woodland is represented by Ponderosa Pine / Montane Grass Mosaic (map code 15). Ponderosa Pine / Montane Grass Mosaic is a combined map class of Ponderosa Pine / Blue Grama Woodland and Ponderosa Pine / Mountain Muhly Woodland. These two associations were combined in one map class due to difficulties in photointerpreting the different grass understories under ponderosa pine canopy cover.

Ponderosa Pine / Montane Grass Mosaic is mapped as the dominant map class in the western section of the project boundary. This map class also occurs in a small patch on Darton Dome and in the southeastern section on Forest

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Service lands. The total area mapped in Sunset Crater Volcano NM is 3 hectares within 1 polygon and in the park environs 1223 hectares within 69 map polygons.

COMMENTS

Global Comments

This ponderosa pine woodland is a broadly defined plant association. Stuever and Hayden (1997b) suggested the xeric upland and mesic bottomland stands be put into different phases. Fitzhugh et al. (1987) suggested it be divided into regional phases.

Global Dynamics

Both diagnostic species are tolerant of ground fire. *Pinus ponderosa* develops thick fire-resistant bark and *Muhlenbergia montana* resprouts after burning, although it may take a few years to recover to pre-burn density (Fischer and Bradley 1987, Bradley et al. 1992). This association had frequent fires (every 3-10 years on average) in pre-settlement times, but fires are less frequent in dry, rocky stands where ground fire is limited by lack of continuous fine fuels (Stuever and Hayden 1997a or b). Fire-return interval has generally increased because of active fire suppression and historic livestock grazing, which has reduced the fine-fuels needed to carry ground fires (Madany and West 1980, Savage and Swetnam 1990). Absence of fire has led to large accumulations of ground fuel and has likely resulted in denser stands and invasion of less fire-adapted, shade tolerant species such as *Pseudotsuga menziesii*. This has likely increased risk of stand replacing crown fires

Improper livestock grazing will favor the more grazing-tolerant species such as *Bouteloua gracilis*, and over time can may eliminate *Muhlenbergia montana* and convert the stand into a *Pinus ponderosa* / *Bouteloua gracilis* Woodland (CEGL000848).

REFERENCES

Bradley et al. 1992, Fischer and Bradley 1987, Fitzhugh et al. 1987, Madany and West 1980, Savage and Swetnam 1990, Stuever and Hayden 1997b

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Sunset Crater Volcano National Monument

Pinus ponderosa / Cinder Woodland

COMMON NAME	Ponderosa Pine / Cinder Woodland
PHYSIOGNOMIC CLASS	Woodland (II.)
PHYSIOGNOMIC SUBCLASS	Evergreen woodland (II.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar needle-leaved evergreen woodland (II.A.4.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (II.A.4.N.)
FORMATION	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland (II.A.4.N.a.)
ALLIANCE	<i>Pinus ponderosa</i> Woodland Alliance

CLASSIFICATION CONFIDENCE LEVEL Low Confidence, Newly described at Sunset Crater Volcano NM. No additional global description data available.

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine / Cinder Woodland is one of the most common associations in the mapping project and is found on level and on steep slopped cinder. Within Sunset Crater Volcano NM it occurs in lower elevations on the north side of Sunset Crater. It predominates the central area of the park environs and occurs on O'Leary peak and in the surrounding lower elevation areas.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa Pine / Cinder Woodlands elevation ranges from 2,020-2,300m (average 2,060m). The association occurs on steep slopes on cinder cones and flatter areas (0-45% slope, average 14%).

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Andropogon hallii, *Bouteloua gracilis*, *Brickellia californica*, *Elymus elymoides*, *Ericameria nauseosa*, *Fallugia paradoxa*, *Festuca arizonica*, *Monardella odoratissima*, *Muhlenbergia montana*, *Oxytropis lambertii*, *Pinus edulis*, *Rhus trilobata*, *Ribes cereum*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

The total vegetation cover ranged from 21-70% (average 36%). The tree layer absolute cover ranged from 19-55% (average 32%), the shrub layer 0.5-10% (average 3%), and the herbaceous strata 0.5-20% (average 3%). The total species richness ranged from 5-20 species (average 11) as measured on 22 relevés.

The tree layer was dominated by *Pinus ponderosa* (15-56% absolute cover, average 33%). DBH ranged from 11-99cm (average 31cm) with heights ranging 5-30m. The shrub layer was sparse and the herbaceous cover was low to sparse.

CONSERVATION RANK G?

DATABASE CODE Cegl002998

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Sunset Crater Volcano National Monument

MAP CLASSES

The map class Ponderosa Pine / Cinder Woodland is mapped as Ponderosa Pine / Cinder Woodland and occurs as map code 14.

Ponderosa Pine / Cinder Woodland is mapped as a predominant map class in the central part of the project boundary. In Sunset Crater Volcano NM 93 hectares were mapped within 26 polygons; in the park environs 1038 hectares within 61 polygons.

COMMENTS

Sunset Crater Volcano National Monument

Ponderosa Pine / Cinder Woodland can be distinguished from Ponderosa Pine / Apache Plume Woodland by the understory shrub cover. Ponderosa Pine / Cinder Woodlands shrub layer absolute cover is <5% and Ponderosa Pine / Apache Plume Woodland shrub layer average absolute cover is >5%. This type is similar to *Pinus ponderosa* / *Bouteloua gracilis* Habitat Type, *Andropogon hallii* phase, previously described in Hanks et al. 1983.

REFERENCES

Hanks et al. 1983

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Populus tremuloides / Cinder Woodland (Local Assemblage)

COMMON NAME Quaking Aspen / Cinder Woodland

CLASSIFICATION CONFIDENCE LEVEL Not Rated, Unique to Monument

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Quaking Aspen / Cinder Woodland is rare within Sunset Crater Volcano NM and in the environs. This association occurs in flat areas as well as on steep cinder slopes. It is found along the edge of the park roadside in the western section of Sunset Crater Volcano NM. It was also found on an unnamed cinder cone east of HWY 89. Only one relevé was sampled of this association and it occurred on the eastern slope of O'Leary Peak.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

The one relevé that was sampled occurred at an elevation of 2,180m. This association can occur on steep slopes and flat areas. The slope of the sampled relevé was steep (68%). It is found on cinder sand and gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Populus tremuloides</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Holodiscus dumosus, *Juniperus osteosperma*, *Pinus ponderosa*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Only one relevé was sampled; it had a total vegetation cover of 35% with 29% absolute cover in the tree layer, 6% in the shrub layer, and 4% in the herbaceous layer. Twenty-three species occurred in the relevé.

The tree layer was characterized by *Populus tremuloides* (22% cover). The DBH ranged from 12-71cm (average 22cm). The shrub layer and the herbaceous layer were sparse.

MAP CLASSES

Quaking Aspen / Cinder Woodland was mapped as an inclusion in the surrounding vegetation classes due to mainly occurring in patches less than 0.5 hectares (minimum mapping unit) and being indistinguishable from the surrounding vegetation. However, a separate coverage (sucr_aspen) was developed to illustrate the few patches of this association.

COMMENTS

Sunset Crater Volcano National Monument

Populus tremuloides is a clonal species that grows in the cinder soils and the lava beds within Sunset Crater Volcano NM and in the environs. This species is of particular interest to park staff due to it typically occurring only in mountainous areas (McDougall 1973).

This monument-specific community must be further sampled on the Colorado Plateau to determine if it is unique to Sunset Crater Volcano NM or if it is found across the landscape. Currently it has no global information, conservation rank or database code. Observations and descriptions of additional occurrences are required to confirm it as an association within the NVCS.

REFERENCES
McDougall 1973

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Fallugia paradoxa (*Atriplex canescens*, *Ephedra torreyana*) Cinder Shrubland

COMMON NAME	Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland
PHYSIOGNOMIC CLASS	Shrubland
PHYSIOGNOMIC SUBCLASS	Deciduous shrubland
PHYSIOGNOMIC GROUP	Cold-deciduous shrubland
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural Cold-deciduous shrubland
FORMATION	Broad-leaved and microphyllous evergreen extremely xeromorphic subdesert shrubland
ALLIANCE	<i>Fallugia paradoxa</i> Shrubland Alliance

CLASSIFICATION CONFIDENCE LEVEL Low Confidence, this association has only been described from Sunset Crater Volcano NM and Wupatki NM. No additional global description data available.

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland is a common association within the mapping area for Sunset Crater Volcano NM. It is found within Sunset Crater Volcano NM on cinder cones and in flat areas specifically on Sunset Crater and Lenox Crater. In the project environs this association is also seen on cinder cones and lower elevations areas. It was mapped on Darton Dome, Robinson Crater, Black Mountain, and in the surrounding more level areas.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland has an elevation that ranges from 2,130-2,440m (average 2,254m). The slope ranged from 7-50% (average 20%). It is generally found on cinder gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Shrub	<i>Fallugia paradoxa</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Andropogon hallii, *Eriogonum corymbosum*, *Pinus edulis*, *Pinus ponderosa*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland total vegetation cover ranged from 6-20% (average 14%). The tree layer was sparse (1-2% absolute cover), the shrub layer ranged from 3-15% absolute cover (average 8%), and herbaceous layer 1-8% (average 4%). Species richness among the four relevés measured ranged from 3-14 species (average 10 species).

The tree layer is sparse with scattered *Pinus ponderosa* and *Pinus edulis*. The shrub layer is the most defining stratum with *Fallugia paradoxa* cover ranging from 3-15% cover (average 10%). The herbaceous layer was sparse with no defining species.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Globally

This plant association also occurs at Wupatki NM. At Wupatki NM four wing saltbush (*Atriplex canescens*) and Torrey's joint-fir (*Ephedra torreyana*) commonly co-occur in this association. However, at Sunset Crater Volcano NM four wing saltbush and Torrey's joint-fir were never found to occur within the association.

CONSERVATION RANK G?

DATABASE CODE C EGL005806

MAP CLASSES

The association Apache Plume (Four Wing Saltbush, Torrey's Joint Fir) Cinder Shrubland is represented as Apache Plume / Cinder Sparse Vegetation (map code 5).

Apache Plume / Cinder Sparse Vegetation is mapped as occurring in small patches throughout the entire project area. The total area of Apache Plume / Cinder Sparse Vegetation mapped in Sunset Crater Volcano NM is 27 hectares within 33 polygons and in the park environs is 202 hectares within 159 polygons.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

Fallugia paradoxa – *Brickellia grandiflora* – (*Holodiscus dumosus*) Scree Shrubland (Local Assemblage)

COMMON NAME Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland

CLASSIFICATION CONFIDENCE LEVEL Not Rated, Unique to Monument

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

The proposed association Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland occurs on steep scree cinder slopes. This map class is unique within the Sunset Crater Volcano NM environs. The map class occurs on the slopes of Darton Dome, Roden Crater, and O’Leary Peak.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland occurred at 2,380-2,750m (average 2,540) and on steep slopes (25-37%, average 29%). The substrate was basaltic boulders and cinder scree.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Shrub	<i>Holodiscus dumosus</i> , <i>Fallugia paradoxa</i> , <i>Brickellia grandiflora</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia dracuncululus, *Chamaebatiaria millefolium*, *Echinocereus* sp., *Ericameria nauseosa*, *Penstemon barbatus*, *Pinus edulis*, *Populus tremuloides*, *Ribes cereum*, *Verbascum thapsus*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland had a total vegetation cover that ranged from 30-50% cover (average 43%). The tree layer was sparse 0-12% (average 4%). The shrub layer was dominant and ranged from 17-45% (average 32%). The herbaceous layer ranged from 3-15% (average 8%). Species richness was 16-24 (average 20%) among the three relevés sampled.

The shrub layer was dominant and consisted of a suite of species including *Holodiscus dumosus* (1-15% absolute cover), *Fallugia paradoxa* (2-17% absolute cover), and *Brickellia grandiflora* (0.5-10% absolute cover). The herbaceous layer was sparse.

MAP CLASSES

The proposed association Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland is represented by map class Rock Outcrop and Scree Shrubland (Map Code 3). Rock Outcrop and Scree Shrubland combines both Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland and Rubber Rabbitbrush - Mountain Tail-leaf Rock Outcrop Sparse Vegetation local vegetation assemblages. These two assemblages were combined into one map class due to occurring in very small patches in similar habits throughout the entire project area.

Rock Outcrop and Scree Shrubland was mapped as very small polygons throughout the entire project area. The total area of Rock Outcrop and Scree Shrubland mapped in Sunset Crater Volcano NM is less than 0.5 hectares within 2 polygons and in the park environs is 4 hectares within 11 polygons.

Pinus ponderosa / *Rhus trilobata* Shrubland (Local Assemblage)

COMMON NAME Ponderosa Pine / Three-leaved Sumac Shrubland

CLASSIFICATION CONFIDENCE LEVEL Not Rated, Unique to Monument

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine / Three-leaved Sumac occurs on steep cinder slopes. This map class is unique and occurs within the project environs. It occurs on cinder cones east of HWY 89 and east of Lenox Park.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Only one relevé was sampled within the Ponderosa Pine / Three-leaved Sumac. It occurred at an elevation of 2,200m on steep slopes (27%) and cinder gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Shrub	<i>Rhus trilobata</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia dracunculus, *Ribes cereum*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa Pine / Three-leaved Sumac had a total vegetation cover of 30%. The tree layer absolute cover was 5%, shrub layer 20%, and herbaceous layer 10%. Species richness was 24 species on one relevé.

The tree layer was sparse and consisted of a low cover (5%) of *Pinus ponderosa*. The shrub layer was the dominant layer with 17% cover of *Rhus trilobata*. The herbaceous layer was sparse.

MAP CLASSES

The proposed association Ponderosa Pine / Three-leaved Sumac is mapped as an inclusion of other surrounding map classes. This proposed association occurred mainly in areas less than 0.5 hectares (less than the minimum mapping unit) and therefore was not mapped as a unique map class.

COMMENTS

Sunset Crater Volcano National Monument

This vegetation type is known only from Sunset Crater NM. More inventory is needed to determine if it is more widespread and possibly develop a new NVC association.

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Sunset Crater Volcano National Monument

Andropogon hallii Colorado Plateau Herbaceous Vegetation

COMMON NAME	Sand Bluestem Colorado Plateau Herbaceous Vegetation
PHYSIOGNOMIC CLASS	Herbaceous Vegetation (V.)
PHYSIOGNOMIC SUBCLASS	Perennial graminoid vegetation (V.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar grassland (V.A.5.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (V.A.5.N.)
FORMATION	Tall sod temperate or subpolar grassland (V.A.5.N.d.)
ALLIANCE	<i>Andropogon hallii</i> Herbaceous Alliance

CLASSIFICATION CONFIDENCE LEVEL Low Confidence, Newly described at Sunset Crater and Wupatki NM.
No additional global description data available.

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Sand Bluestem / Herbaceous Vegetation occurs on cinder cones and on flat areas within Sunset Crater Volcano NM and in the environs. This association occurs around the base of and on Sunset Crater. Within the environs it occurs in only small patches in the project environs.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Only two relevés were sampled within the Sand Bluestem / Herbaceous Vegetation, both on Sunset Crater. The elevation ranged from 2,300-2,250m. This association occurred on steep slopes (35 and 40%) in cinder gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Andropogon hallii</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Eriogonum corymbosum, *Monardella odoratissima*, *Pinus ponderosa*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Two relevés were sampled within this association and had a total vegetation cover of 16 and 43%. The tree layer was sparse (0-4%) the shrub layer was also sparse (0.5%) and the herbaceous layer (12-40%). The total species richness consisted of 12 and 13 species.

Occasional *Pinus ponderosa* and *Eriogonum corymbosum* were found in the sparse tree and shrub layers. The herbaceous cover was dominated by *Andropogon hallii* (10-40%).

CONSERVATION RANK G?

DATABASE CODE Cegl002785

MAP CLASSES

Sand Bluestem Herbaceous Vegetation was mapped as map code 7.

Sand Bluestem Herbaceous Vegetation was mapped as one of the dominant vegetation types on Sunset Crater Volcano NM and in a small patch in the western half of the project boundary. In Sunset Crater Volcano NM 32 hectares were mapped within 10 polygons; in the park environs only 1 hectare within 2 polygons was mapped.

Bouteloua gracilis Herbaceous Vegetation

COMMON NAME	Blue Grama Herbaceous Vegetation
PHYSIOGNOMIC CLASS	Herbaceous Vegetation (V.)
PHYSIOGNOMIC SUBCLASS	Perennial graminoid vegetation (V.A.5.N.e.)
PHYSIOGNOMIC GROUP	Temperate or subpolar grassland (V.A.5.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (V.A.5.N.)
FORMATION	Short sod temperate or subpolar grassland (V.A.5.N.e.)
ALLIANCE	<i>Bouteloua gracilis</i> Herbaceous Alliance

CLASSIFICATION CONFIDENCE LEVEL Weak

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Blue Grama Herbaceous Vegetation is a common vegetation type that occurs in the western half of the project environs on level areas. It occurs in meadows and parks, such as in Bonito Park.

Globally

This plant association occurs in Arizona, New Mexico and Wyoming.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association was sampled at an elevational range from 2,070-2,120m (average 2,100m). It occurred mainly in the flat areas in meadows with slope ranging from 0-15% (average 7%). The typical substrate consists of cinder sand and gravel.

Globally

This minor plant association is reported from in Arizona, New Mexico and Wyoming. Elevation ranges from 1,830-2,200m (6,000-7,200 feet). Sites are flat to gently sloping and include plains, plateaus and montane meadows. Substrates are variable and range from coarse-textured soils derived from sand, gravel or cinder to silty clay loam prairie soils.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Bouteloua gracilis</i>
Shrub	<i>Ericameria nauseosa</i>

Globally

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Bouteloua gracilis</i>
Shrub	<i>Ericameria nauseosa</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia carruthii, *Artemisia dracunculus*, *Bromus tectorum*, *Ericameria nauseosa*, *Elymus elymoides*, *Muhlenbergia montana*, *Pinus ponderosa*

Globally

Bouteloua curtipendula, *Elymus elymoides*, *Muhlenbergia montana*, *M. richardsonis*, *M. torreyi*, *Pascopyrum smithii*, *Pleuraphis jamesii*, *Sporobolus cryptandrus*, *Artemisia carruthii*, *Artemisia dracunculus*

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Sunset Crater Volcano National Monument

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Blue Grama Herbaceous Vegetation had a total vegetation cover ranging from 25-50% (average 42%). Absolute cover in the tree layer ranged from 0-2% (average 0.4%), in the shrub layer 0-6% (average 1.3%), and in the herbaceous layer 25-60% (average 44%). On the 5 relevés sampled species richness ranged from 6-28 species (average 14).

The tree layer was sparse with only an occasional *Pinus ponderosa*. The shrub cover is low/sparse, some relevés have >5% total cover of *Ericameria nauseosa*. The herbaceous layer is the most abundant with the characteristic species being *Bouteloua gracilis*.

Globally

This association is characterized by moderate to dense (25-80% cover) herbaceous layer that is strongly dominated by the warm season, perennial shortgrass, *Bouteloua gracilis*. Associated grasses are *Bouteloua curtipendula*, *Elymus elymoides*, *Muhlenbergia montana*, *M. richardsonis*, *M. torreyi*, *Pascopyrum smithii*, *Pleuraphis jamesii* (= *Hilaria jamesii*), *Sporobolus cryptandrus* and the introduced annual grass *Bromus tectorum*. Forb cover is sparse. Associated forb species include *Artemisia carruthii* and *Artemisia dracunculoides*. Scattered *Ericameria nauseosa* shrubs and an occasional *Juniperus* spp, *Pinus edulis*, or *P. ponderosa* (in montane stands) tree may be present.

CONSERVATION RANK G4Q

DATABASE CODE CEGL001760

MAP CLASSES

Blue Grama Herbaceous Vegetation corresponds to the map classes Montane Grassland (map code 8), Montane Grassland (Rabbitbrush) (map code 9), and Montane Grassland (Bonito Park Historic Agricultural Field) (map code 10). The Rabbitbrush modifier refers to the Blue Grama Herbaceous Vegetation association with >5% total cover of *Ericameria nauseosa*. The Bonito Park Historic Agricultural Field was delineated from aerial photographs as a previous area of agricultural activity. This type was not floristically different from the Blue Grama Herbaceous Vegetation; however, it was evident as an area of past disturbance. Montane Grassland includes both the Blue Grama Herbaceous Vegetation and Mountain Muhly Herbaceous Vegetation associations. These two grasses were combined into one map class, due to often occurring as co-dominates and being indistinguishable from aerial photography.

Montane Grassland occurs mainly in small patches throughout the western half of the project boundary only in the project environs. It was not mapped in Sunset Crater Volcano NM. The total area of Montane Grassland mapped in the park environs is 349 hectares within 156 polygons, this includes 148 hectares and 104 polygons in map code 8, 100 hectares and 51 polygons in map code 9, and 101 hectares and 1 polygon in map code 10.

COMMENTS

Global Comments

This is a low confidence association. There are many other associations in the *Bouteloua gracilis* Herbaceous Alliance (A.1282).

Global Dynamics

Bouteloua gracilis is an extremely drought- and grazing-tolerant shortgrass species. It is one of the most widely distributed grasses in the interior western U.S., and is present in many different grassland, shrubland and woodland communities. It evolved with grazing by large herbivores and generally forms a short sod. However, in some stands ungrazed plants develop the upright physiognomy of a bunchgrass.

Muhlenbergia montana Herbaceous Vegetation

COMMON NAME	Mountain Muhly Herbaceous Vegetation
PHYSIOGNOMIC CLASS	Herbaceous Vegetation (V.)
PHYSIOGNOMIC SUBCLASS	Perennial graminoid vegetation (V.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar grassland (V.A.5.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (V.A.5.N.)
FORMATION	Medium-tall bunch temperate or subpolar grassland (V.A.5.N.d.)
ALLIANCE	<i>Muhlenbergia montana</i> Herbaceous Vegetation

CLASSIFICATION CONFIDENCE LEVEL Moderate

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Mountain Muhly Herbaceous Vegetation is a common grassland community that mainly occurs in high elevation mountain meadows. In the environs it occurs mainly in the northwestern section of the environs near Robinson Mountain.

Globally

This plant association forms meadows in the mountains and foothills of Colorado, Arizona and Utah.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association is represented by one relevé sampled at an elevation of 2,300m. It was sampled in a small mountain meadow with gentle slope (10%). The soil consisted of cinder sand and gravel.

Globally

This plant association has been described from meadows in the mountains, plateaus and foothills of Colorado, Arizona and Utah. Elevation ranges from 2,300- 2,800 m (7,540-9,200 feet). Sites are typically xeric forest openings or parks in the Ponderosa Pine zone with southern aspects on moderately steep slopes and ridgetops. Occasionally the stands occupy rolling parklands or volcanic cinder fields. The xeric nature of sites appears to be an important environmental factor. Substrates are shallow to moderately deep, rocky, sand to sandy loam textured soils sometimes with a distinct clay horizon. Parent materials are primarily colluvium derived from granite and gneiss or cinder. Bare soil, exposed gravels, and small rocks account for as much as 50% of the ground surface area.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Muhlenbergia montana</i>

Globally

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Muhlenbergia montana</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Bromus tectorum, *Ericameria nauseosa*, *Pinus ponderosa*

Globally

Blepharoneuron tricholepis, *Trisetum spicatum*, *Bouteloua curtipendula*, *Bouteloua gracilis*, *Carex duriuscula*, *Danthonia parryi*, *Elymus albicans*, *Festuca brachyphylla*, *Hesperostipa comata*, *Koeleria macrantha*, *Muhlenbergia filiculmis*, *Pascopyrum smithii*, *Poa secunda*, *Schizachyrium scoparium*, *Allium geyeri*, *Antennaria rosea*, *Arenaria fendleri*, *Eriogonum umbellatum*, *Harbouria trachypleura*, *Heterotheca villosa*, *Mertensia lanceolata*, *Opuntia polyacantha*, *Penstemon secundiflorus*, *Phlox diffusa*, *Artemisia frigida*, *Ericameria nauseosa*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Mountain Muhly Herbaceous Vegetation had a total vegetation cover of 35%. Absolute cover in the tree layer was 4%, 3% in the shrub layer, and 25% in the ground layer. Species richness consisted of 20 species.

Within the tree layer the cover is sparse with an occasional *Pinus ponderosa*. The shrub layer is also sparse with a low cover of *Ericameria nauseosa*. The herbaceous layer was characterized by *Muhlenbergia montana* (15% absolute cover).

Globally

This association is characterized by a moderately dense herbaceous layer that is typically dominated by the warm-season, perennial bunchgrass, *Muhlenbergia montana*, but may be codominated by *Blepharoneuron tricholepis* or *Trisetum spicatum* (= *Trisetum montanum*) (in New Mexico). Other associated graminoids include *Bouteloua curtipendula*, *Bouteloua gracilis*, *Carex duriuscula* (= *Carex eleocharis*), *Danthonia parryi*, *Elymus albicans* (= *Elymus lanceolatus* ssp. *albicans*), *Festuca brachyphylla*, *Hesperostipa comata*, *Koeleria macrantha*, *Muhlenbergia filiculmis*, *Pascopyrum smithii*, *Poa secunda*, and *Schizachyrium scoparium*. The typically sparse forb layer often consists of *Allium geyeri*, *Antennaria rosea*, *Arenaria fendleri*, *Eriogonum umbellatum*, *Harbouria trachypleura*, *Heterotheca villosa*, *Mertensia lanceolata*, *Opuntia polyacantha*, *Penstemon secundiflorus* and *Phlox diffusa*. Except for the abundant dwarf-shrub *Artemisia frigida*, scattered *Ericameria nauseosa* shrubs or occasional *Pinus ponderosa* trees, woody species are very sparse or absent. The exotic grasses *Poa pratensis* and *Bromus tectorum* are common in some of these stands. Diagnostic of this grassland association is the dominance of *Muhlenbergia montana* in the herbaceous layer and low cover of *Festuca arizonica*.

CONSERVATION RANK G3G4

DATABASE CODE Cegl001646

MAP CLASSES

Mountain Muhly Herbaceous Vegetation corresponds to the map classes Montane Grassland (map code 8), Montane Grassland (Rabbitbrush) (map code 9), and Montane Grassland (Bonito Park Historic Agricultural Field) (map code 10). The Rabbitbrush modifier refers to the Mountain Muhly Herbaceous Vegetation association with >5% total cover of *Ericameria nauseosa*. The Bonito Park Historic Agricultural Field was delineated from aerial photographs as a previous area of agricultural activity. This area is not predominantly mountain muhly dominated; however, it occurs within the Montane Grassland map class. Montane Grassland includes both Blue Grama Herbaceous Vegetation and Mountain Muhly Herbaceous Vegetation associations. These two grass associations were combined into one map class, due to often occurring as co-dominates and indistinguishable from aerial photography.

Montane Grassland is mapped as occurring mainly in small patches throughout the western half of the project boundary and only occurs in the project environs and was not mapped as occurring in Sunset Crater Volcano NM. The total area of Montane Grassland mapped in the park environs is 349 hectares within 156 polygons, this includes 148 hectares and 104 polygons in map code 8, 100 hectares and 51 polygons in map code 9, and 101 hectares and 1 polygon in map code 10.

COMMENTS

Global Dynamics

Muhlenbergia montana often grows in association with montane conifer forests, especially ones dominated by *Pinus ponderosa* and has developed a tolerance for relatively frequent fire regimes. Although *Muhlenbergia montana* resprouts after burning, it may take a few years to recover to pre-burn density (Fischer and Bradley 1987). These grasslands may be considered seral or an edaphic climax depending if there are environmental factors, such as aridity, that are preventing establishment of trees. Historically, much of the area where this association occurs was heavily grazed by livestock, primarily sheep and cattle (Shepherd 1975). Season of use is important in stands with both *Hesperostipa comata* and *Muhlenbergia montana*, fall grazing will favor *Hesperostipa comata* over the later blooming *Muhlenbergia montana* (Clary 1978). The reverse is true if grazing is always limited to summer. Overgrazing will reduce or eliminate *Hesperostipa comata*, *Muhlenbergia montana* and the other palatable species,

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leaving the more grazing-tolerant *Bouteloua gracilis* and less palatable plants such as *Hymenoxys*, *Artemisia* and *Chrysothamnus* species to dominate the site Clary (1978).

REFERENCES

Clary 1978, Fischer and Bradley 1987, Shepherd 1975

Pascopyrum smithii Herbaceous Vegetation

COMMON NAME	Western wheatgrass Herbaceous Vegetation
PHYSIOGNOMIC CLASS	Herbaceous vegetation (V.)
PHYSIOGNOMIC SUBCLASS	Perennial graminoid vegetation (V.A.)
PHYSIOGNOMIC GROUP	Temperate or subpolar grassland (V.A.5.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural (V.A.5.N.)
FORMATION	Medium-tall sod temperate or subpolar grassland (V.A.5.N.c.)
ALLIANCE	<i>Pascopyrum smithii</i> Herbaceous Alliance

CLASSIFICATION CONFIDENCE LEVEL Weak

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Western Wheatgrass Herbaceous Vegetation is an uncommon association only found in the project environs. It occurs in sites that were recently burned and have high disturbance (i.e. roadsides, cinder quarries) to the west of Robinson Mountain and on Robinson Crater.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

The two relevés sampled within this association both occurred at an elevation of 2,160m. The slope was nearly flat (2-3%) and the substrate was cinder sand and gravel.

Globally

This grassland association is widespread in the northern and western Great Plains, Rocky Mountains, the intermountain western United States and possibly Canada. Elevation ranges from 600-3,000m. Stands occur on level to gently sloping terrain. They are found on alluvial fans, swales, river terraces, floodplains, valley bottoms and basins. The soils are deep (40-100 cm) and well-developed with clay, clay loam, and silt loam textures. Some stands occur on perched water tables

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Pascopyrum smithii</i>

Globally

<u>Stratum</u>	<u>Species</u>
Herbaceous	<i>Pascopyrum smithii</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Bromus tectorum, *Cirsium wheeleri*, *Pinus ponderosa*

Globally

Eleocharis palustris, *Koeleria macrantha*, *Poa fenderiana*, *Bouteloua gracilis*, *Hesperostipa comata*, *Nassella viridula*, *Artemisia frigida*, *Artemisia ludoviciana*, *Ericameria nauseosa*, *Krascheninnikovia lanata*

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Sunset Crater Volcano National Monument

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Western Wheatgrass Herbaceous Vegetation had a total vegetation cover of 30- 45%. Absolute cover in the tree layer was 0-10%, 0-0.5% in the shrub layer, and 22-45% in the herbaceous layer. Species richness consisted of 16 species in both relevés.

Within the tree layer the cover is sparse with an occasional *Pinus ponderosa*. The shrub layer is also sparse with only an occasional shrub. The herbaceous layer was characterized by *Pascopyrum smithii* with 20-35% total cover.

Globally

This association is characterized by a moderate to dense (40-100% cover) mixed grass herbaceous canopy that grows 0.5-1 m tall and is strongly dominated by *Pascopyrum smithii*. Other graminoids that co-occur and may achieve local dominance are *Koeleria macrantha*, *Eleocharis palustris*, and *Poa* spp. Many other species common in midgrass prairies are also found in this community. These include *Artemisia frigida*, *Artemisia ludoviciana*, *Achillea* sp., *Carex* spp., *Cirsium* spp., *Eriogonum* spp., *Bouteloua gracilis*, *Nassella viridula*, and *Hesperostipa comata* (= *Stipa comata*). Shrubs and dwarf-shrubs are rare in this community, but occasional woody plants such as *Symphoricarpos* spp., *Ericameria nauseosa*, or *Krascheninnikovia lanata* may be present. Introduced species, such as *Bromus tectorum*, *Bromus inermis*, *Poa pratensis*, *Melilotus* spp., *Cirsium arvense*, *Taraxacum officinale*, or *Salsola kali*, are common in some stands, especially where disturbed.

CONSERVATION RANK G3G5Q

DATABASE CODE Cegl001577

MAP CLASSES

Western Wheatgrass Herbaceous Vegetation corresponds to the map class Ponderosa Pine Invasive Herbaceous Vegetation (map code 16). Western wheatgrass is not an invasive species; however, it is often associated with reseeding efforts and other areas of disturbance and therefore was lumped into this map class. Ponderosa Pine Invasive Herbaceous Vegetation includes both the Western Wheatgrass Herbaceous Vegetation and Ponderosa Pine Wooded Invasive Herbaceous Vegetation associations.

Ponderosa Pine Invasive Herbaceous Vegetation is mapped as occurring mainly in the northwestern half of the project environs around the base of cinder cones and on a cinder hill south of Bonito Park. It is not mapped as occurring in Sunset Crater Volcano NM. The total area of Ponderosa Pine Invasive Herbaceous Vegetation mapped in the park environs is 309 hectares within 19 polygons.

COMMENTS

Sunset Crater Volcano National Monument

Pascopyrum smithii is native to the United States; but it is not native to Arizona. However, *Pascopyrum smithii* is used in re-vegetation reseeding efforts by the Forest Service (FEIS 2001) and was possibly used to reseed the burned area northwest of Sunset Crater.

Global Comments

This community is similar to several others that are dominated or codominated by *Pascopyrum smithii*. As currently defined, it represents a western Great Plains and foothills version of the western wheatgrass types in the central Great Plains. Further work needs to be done to refine the differences in composition and environmental characteristics. See recent descriptions by Thilenius et al. (1995) (*Pascopyrum smithii* sodgrass steppe, a more playa-like wheatgrass type) and by Steinauer and Rolfsmeier (2000). In Nebraska, Steinauer and Rolfsmeier (2000) suggest that their stands may resemble *Pascopyrum smithii* - *Nassella viridula* Herbaceous Vegetation (CEGL001583).

Global Dynamics

In semi-arid climates, this association is found in relatively mesic topographic positions such as swales, river terraces, floodplains and basins that may be temporarily or intermittently flooded or in some classes, the fine textured soil sometimes perches the water table (Hansen et al. 1995, Hall and Hansen 1997). In more mesic climates it is found in extensive upland areas.

REFERENCES

FEIS 2001, Hall and Hansen 1997, Hansen et al. 1995, Steinauer and Rolfsmeier 2000, Thilenius et al. 1995

Pinus ponderosa Wooded Invasive Herbaceous Vegetation (Local Assemblage)

COMMON NAME Ponderosa Pine Invasive Herbaceous Vegetation

CLASSIFICATION CONFIDENCE LEVEL Not Rated, Unique to Monument

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa Pine Invasive Herbaceous Vegetation occurs in areas of disturbance. Frequently the association is located where intensive logging activity has historically occurred. This association is mostly found in the project environs near Robinson Mountain.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

This association was sampled at an elevation range of 2,140-2,220m (average 2,200m). Slope varied from steep to none (0-20%) (average 9%). It was found on cinder sand and gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i>
Herbaceous	<i>Bromus tectorum</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Artemisia dracunculus, *Geranium caespitosum*, *Junipers osteosperma*, *Linaria dalmatica* ssp. *dalmatica*, *Ribes cereum*, *Thalictrum fendleri*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa Pine Wooded Invasive Herbaceous Vegetation had a total cover of 28- 45% (average 38%). Absolute cover in the tree layer ranged from 5-25% (average 15%), in the shrub layer 2-5% (average 3%), and in the herbaceous layer 17-25% (average 15%). Species richness for all three relevés ranged from 19-23 species (average 21).

The tree layer was dominated by *Pinus ponderosa* with cover ranging from 5-25%. DBH for *Pinus ponderosa* ranged from 11-87cm (average 19cm). The shrub cover is sparse. The herbaceous layer consisted of a variety of weedy native and non-native species, most often dominated by *Bromus tectorum* (0.5-20% absolute cover) and *Artemisia dracunculus* that ranged from (0.5-15% absolute cover).

MAP CLASSES

Ponderosa Pine Invasive Herbaceous Vegetation is mapped as Ponderosa Pine Invasive Herbaceous Vegetation (map code 16). Ponderosa Pine Invasive Herbaceous Vegetation includes both the Western Wheatgrass Herbaceous Vegetation and Ponderosa Pine Wooded Invasive Herbaceous Vegetation associations. These two associations were combined into one map class due to both occurring in previously disturbed areas and in areas that were reseeded after recent burns.

Ponderosa Pine Invasive Herbaceous Vegetation is mapped as occurring mainly in the northwestern half of the project environs around the base of cinder cones and on a cinder hill south of Bonito Park. It is not mapped as occurring in Sunset Crater Volcano NM. The total area of Ponderosa Pine Invasive Herbaceous Vegetation mapped in the park environs is 309 hectares within 19 polygons.

COMMENTS

Sunset Crater Volcano National Monument

Ponderosa Pine Invasive Herbaceous Vegetation had a variety of understory weedy herbaceous species that varied in composition and abundance between measured relevés. The herbaceous layer may vary annually and further data collection will be needed to understand the ecology and long-term dynamics of this association within Sunset Crater environs.

This unique community must be further sampled on the Colorado Plateau to determine if it is unique to Sunset Crater Volcano NM or if it is found across the landscape. Currently it has no global information, conservation rank or database code. Observations and descriptions of additional occurrences are required to confirm it as an association within the NVCS.

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Ericameria nauseosa – *Pericome caudata* Rock Outcrop Sparse Vegetation (Local Assemblage)

COMMON NAME Rubber Rabbitbrush - Mountain Tail-leaf Rock Outcrop Sparse Vegetation

CLASSIFICATION CONFIDENCE LEVEL Not Rated, Unique to Monument

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Proposed association Rubber Rabbitbrush - Mountain Tail-leaf Rock Outcrop Sparse Vegetation occurs as small isolated stands of vegetation on lava outcrops within cinder barrens. It is found within Sunset Crater Volcano on cinder cones and within cinder barrens in the northern section of the park. In the project environs this vegetation type occurs mainly on the cinder barrens in the northeastern section of the mapping zone and on cinder cones in the northwestern section of the mapping zone.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Only one relevé was sampled of Rubber Rabbitbrush - Mountain Tail-leaf Rock Outcrop Sparse Vegetation. It had an elevation of 2100m, a slope of 10%, and was on lava outcrops within cinder barrens.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

Stratum

Shrub

Species

Ericameria nauseosa, *Pericome caudata*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

In the one sampled relevé of Rubber Rabbitbrush - Mountain Tail-leaf Rock Outcrop Sparse Vegetation total vegetation cover was 7%. The relevé was sparse and within the tree layer the cover was 1%, the shrub layer 6%, and the herbaceous layer 2%. The tree and herbaceous layer were sparse. The shrub layer consisted of *Ericameria nauseosa* (2%) and *Pericome caudata* (3%). Species richness was low with only six species.

MAP CLASSES

The proposed association Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland is represented by map class Rock Outcrop and Scree Shrubland (Map Code 3). Rock Outcrop and Scree Shrubland combines both Apache Plume - Tasselflower Brickellbush – (Ocean Spray Scree) Scree Shrubland and Rubber Rabbitbrush - Mountain Tail-leaf Rock Outcrop Sparse Vegetation local vegetation assemblages. These two assemblages were combined into one map class due to occurring in very small patches in similar habits throughout the entire project area.

This was mapped as very small polygons throughout the entire project area. The total area of Rock Outcrop and Scree Shrubland mapped in Sunset Crater Volcano is less than 0.5 hectares within 2 polygons and in the park environs is 4 hectares within 11 polygons.

COMMENTS

Sunset Crater Volcano National Monument

This monument specific community must be further sampled on the Colorado Plateau to determine if it is unique to Sunset Crater Volcano NM or if it is found across the landscape. Currently it has no global information, conservation rank or database code. Observations and descriptions of additional occurrences are required to confirm it as an association within the NVCS.

Eriogonum corymbosum Cinder Sparse Vegetation

COMMON NAME	Wild Buckwheat Cinder Sparse Vegetation
PHYSIOGNOMIC CLASS	Sparse Vegetation
PHYSIOGNOMIC SUBCLASS	Unconsolidated material sparse vegetation
PHYSIOGNOMIC GROUP	Sparsely vegetated soil slopes
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural Sparsely vegetated soil slopes
FORMATION	Dry slopes
ALLIANCE	<i>Eriogonum corymbosum</i> Sparsely Vegetated Alliance

CLASSIFICATION CONFIDENCE LEVEL This association has only been described from Sunset Crater Volcano and Wupatki NM. Until further data is collected regionally there is no global information or conservation rank.

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Wild Buckwheat Cinder Sparse Vegetation occurs in Sunset Crater Volcano on steep cinder cones. This association was mapped on Sunset Crater as well as on other unnamed cinder cones. It also occurs in the project environs on cinder cones mainly in the eastern section of the project boundary. This association was mapped on Black Mountain.

Globally

This association was also found to occur at Wupatki NM.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

The relevé sampled for this association occurred at 2,320m, on a steep slope (30%) in cinder gravel.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Shrub	<i>Eriogonum corymbosum</i>
Herbaceous	<i>Andropogon hallii</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Pinus ponderosa

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Wild Buckwheat Cinder Sparse Vegetation had a total vegetation cover of 10%. There was no tree cover. The shrub layer had 2% absolute cover, 8% absolute cover was recorded in the herbaceous layer. Species richness within the relevé consisted of 7 species.

The one relevé measured had sparse vegetation cover. *Eriogonum corymbosum* was dominant with 7% cover within the shrub and ground layers collectively. The herbaceous layer had sparse *Andropogon hallii* (1% absolute cover).

CONSERVATION RANK G?

DATABASE CODE Cegl005803

MAP CLASSES

Wild Buckwheat Cinder Sparse Vegetation corresponds to the map class Wild Buckwheat / Sand Bluestem Sparse Vegetation (map code 4). Originally, the proposed association considered sand bluestem (*Andropogon hallii*) to be an important component to the understory community; however, with additional data collected at Wupatki NM sand

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bluestem was no longer considered a dominant understory species throughout the plant association's range. Sand bluestem often co-occurs in this map class at Sunset Crater Volcano NM and therefore the map class of Wild Buckwheat / Sand Bluestem Sparse Vegetation was retained on the vegetation map. Wild Buckwheat / Sand Bluestem Vegetation is mapped as occurring in only small patches on steep cinder cones. It occurs in Sunset Crater Volcano NM in 11 polygons, 15 hectares, and occurs in the project environs in 23 polygons, 32 hectares.

Pinus ponderosa – (*Populus tremuloides*) / *Fallugia paradoxa* – (*Holodiscus dumosus*) Lava Bed Sparse Vegetation

COMMON NAME	Ponderosa pine – (Quaking Aspen) / Apache Plume – (Ocean Spray Scree) Lava Bed Sparse Vegetation
PHYSIOGNOMIC CLASS	Sparse Vegetation (VII.)
PHYSIOGNOMIC SUBCLASS	Boulder, gravel, cobble, or talus sparse vegetation (VII.B.)
PHYSIOGNOMIC GROUP	Sparsely vegetated rock flats (VII.B.2.)
PHYSIOGNOMIC SUBGROUP	Natural/Semi-natural Sparsely vegetated rock flats (VII.B.2.N.)
FORMATION	Boulder fields (VII.B.2.N.a)
ALLIANCE	AA Lava Bed Sparsely Vegetated Alliance

CLASSIFICATION CONFIDENCE LEVEL Weak

USFS WETLAND SYSTEM Upland

RANGE

Sunset Crater Volcano National Monument

Ponderosa pine – (Quaking Aspen) / Apache Plume – (Ocean Spray Scree) Lava Bed Sparse Vegetation occurs as islands of vegetation within the fractured black lava flow surface and at the edges of lava flow. This association is found within Sunset Crater Volcano NM on the jumbled and jagged aa lava beds mainly in the western portion of the park. In the project environs this association is also found on the lava beds that extend adjacent to the western park boundary and in a small section south of the park boundary.

ENVIRONMENTAL DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa pine – (Quaking Aspen) / Apache Plume – (Ocean Spray Scree) Lava Bed Sparse Vegetation's elevation is fairly constant and ranges from 2,100-2,130m (average 2,115m). The slope ranges from 0-15% slope (average 3%). The substrate consists of large soil pockets within aa lava and at the edge of the lava beds.

MOST ABUNDANT SPECIES

Sunset Crater Volcano National Monument

<u>Stratum</u>	<u>Species</u>
Tree canopy	<i>Pinus ponderosa</i> , <i>Populus tremuloides</i>
Shrub	<i>Fallugia paradoxa</i> , <i>Holodiscus dumosus</i>

ASSOCIATED SPECIES

Sunset Crater Volcano National Monument

Bouteloua gracilis, *Ericameria nauseosa*, *Pericome caudata*, *Muhlenbergia montana*, *Ribes cereum*

VEGETATION DESCRIPTION

Sunset Crater Volcano National Monument

Ponderosa pine – (Quaking Aspen) / Apache Plume – (Ocean Spray Scree) Lava Bed Sparse Vegetation relevés had total vegetation cover ranging from 5-45% cover (average 18%) cover. Within the tree layer absolute cover ranged from sparse to abundant (0-30%, average 18%). Cover within the shrub layer was consistent and ranged from 4-6% (average 5%). Cover of the herbaceous layer was sparse and ranged from 1-5% (average 2%). Species richness ranged from 4-22 (average 12 species) within the five relevés sampled.

The tree layer consists of scattered individuals of *Pinus ponderosa* (average cover 7%) and *Populus tremuloides* (average cover 4%). The shrub layer consists of mainly *Fallugia paradoxa* (average cover 3%) and *Holodiscus dumosus* (average cover 1%). The herbaceous layer is sparse.

CONSERVATION RANK G?

DATABASE CODE Cegl002929

MAP CLASSES

The association Lava Bed Sparse Vegetation is mapped as Lava Bed Sparse Vegetation (Map Code 6). This association is mapped as small inclusions of vegetation within the lava beds of Sunset Crater Volcano NM and in a small area of the project environs. The total area of Lava Bed Sparse Vegetation mapped in Sunset Crater Volcano NM is 79 hectares within 50 polygons and in the park environs is 5 hectares within 8 polygons.

BIBLIOGRAPHY

- Alexander, B. G., Jr., E. L. Fitzhugh, F. Ronco, Jr., and J. A. Ludwig. 1987. A classification of forest habitat types of the northern portion of the Cibola National Forest, NM. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-143. Fort Collins, CO. 35 pp.
- Baker, M. B. J., L. F. DeBano, and P. F. Folliott. 1995. Soil loss in pinon-juniper ecosystems and its influence on site productivity and desired future conditions. In D. W. Shaw, E. F. Aldon, and C. LoSapio (technical coordinators) Desired future conditions for pinon-juniper ecosystems. General Technical Report RM-258, Flagstaff, Arizona, August 8, 1994 (9-15p). CO: USDA Forest Service Rocky Mountain Forest and Range Experimental Station, Fort Collins.
- Bradley, Anne F.; Noste, Nonan V.; Fischer, William C. 1992. Fire ecology of forests and woodlands in Utah. Gen. Tech. Rep. INT-287. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 128 p.
- Chappell, C., R. Crawford, J. Kagan, and P. J. Doran. 1997. A vegetation, land use, and habitat classification system for the terrestrial and aquatic ecosystems of Oregon and Washington. Unpublished report prepared for Wildlife habitat and species associations within Oregon and Washington landscapes: Building a common understanding for management. Prepared by Washington and Oregon Natural Heritage Programs, Olympia WA, and Portland, OR. 177 pp.
- Clary, W. P. 1978. Arizona fescue mountain rangelands. Pages 205-207 in: D. N. Hyder, editor. Proceedings of the First International Rangeland Congress, Denver, CO, 14-18 August 1978. Society for Range Management, Denver.
- Cooper, S. V. 1975. Forest habitat types of northwestern Wyoming and contiguous portion of Montana and Idaho. Unpublished dissertation. Washington State University, Pullman. 190 pp.
- DeVelle, R. L., J. A. Ludwig, W. H. Moir, and F. Ronco, Jr. 1986. A classification of forest habitat types of northern New Mexico and southern Colorado. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-131. Fort Collins, CO. 59 pp.
- Eggler, W. A. 1941. Primary succession on volcanic deposits in southern Idaho. Ecological Monographs 11(3):278-298.
- Eyre, F. H., editor. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 pp.
- FEIS [Fire Effects Information System]. 2001. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2001, May). <http://www.fs.fed.us/database/feis/>. Accessed [11/17/03].
- Fischer, W. C., and A. F. Bradley. 1987. Fire ecology of western Montana forest habitat types. USDA Forest Service General Technical Report INT-223. Intermountain Research Station, Ogden, UT. 95 pp.
- Fitzhugh, E. L., W. H. Moir, J. A. Ludwig, and F. Ronco, Jr. 1987. Forest habitat types in the Apache, Gila, and part of the Cibola national forests. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-145. Fort Collins, CO. 116 pp.
- Hall, J. B., and P. L. Hansen. 1997. A preliminary riparian habitat type classification system for the Bureau of Land Management districts in southern and eastern Idaho. Riparian and Wetland Research Program, School of Forestry, University of Montana. Idaho Bureau of Land Management, Technical Bulletin No. 97-11. 381 pp.
- Hanks, J. P., E. L. Fitzhugh, and S. R. Hanks. 1983. A habitat type classification system for ponderosa pine forests of northern Arizona. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-97. Fort Collins, CO. 22 pp.
- Hansen, P. L., R. D. Pfister, K. Boggs, B. J. Cook, J. Joy, and D. K. Hinckley. 1995. Classification and management of Montana's riparian and wetland sites. Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana, Miscellaneous Publication No. 54. 646 pp.
- Johnston, B. C. 1987. Plant associations of Region Two: Potential plant communities of Wyoming, South Dakota, Nebraska, Colorado, and Kansas. R2-ECOL-87-2. USDA Forest Service, Rocky Mountain Region. Lakewood, CO. 429 pp.
- Kennedy, K. L. 1983. A habitat-type classification for the pinyon-juniper woodlands of the Lincoln National Forest. Unpublished thesis. New Mexico State University, Las Cruces. 87 pp.
- Lanner, R. M., and S. B. Vander Wall. 1980. Dispersal of limber pine seed by Clark's nutcracker. Journal of Forestry 78(10):637-639.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

- Lillybridge, T. R., B. L. Kovalchik, C. K. Williams, and B. G. Smith. 1995. Field guide for forested plant associations of the Wenatchee National Forest. USDA Forest Service General Technical Report PNW-GTR-359, Pacific Northwest Research Station, Portland. Portland, OR. 335 pp.
- Little, E. L. 1987. Pinyon trees (~*Pinus edulis*) remeasured after 47 years. Pages 65-68 in: Proceedings - pinyon-juniper conference. USDA Forest Service General Technical Report INT-215. Intermountain Research Station, Ogden, UT.
- Madany, M. H.; N. E. West. 1980. Fire history of two montane forest areas of Zion National Park. In: Stokes, Marvin A.; Dieterich, John H., technical coordinators. Proceedings of the fire history workshop; 1980 October 20-24; Tucson, AZ. Gen. Tech. Rep. RM-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 50-56. 269.
- Mauk, R. L., and J. A. Henderson. 1984. Coniferous forest habitat types of northern Utah. USDA Forest Service. General Technical Report INT-170. Intermountain Forest and Range Experiment Station, Ogden, UT. 89 pp.
- McDougall, W.B. 1973. Seed Plants of Northern Arizona: With Keys and Detailed Descriptions for the Identification of Families, Genera and Species. The Museum of Northern Arizona, Flagstaff, AZ.
- Muldavin, E., V. Archer, and P. Neville. 1998. A vegetation map of the Borderlands Ecosystem Management Area. Final report submitted to USDA Forest Service, Rocky Mountain Experiment Station, Flagstaff, AZ, by the New Mexico Natural Heritage Program, University of New Mexico, Albuquerque, NM. 58 pp.
- Muldavin, E., Y. Chauvin, and G. Harper. 2000. The vegetation of White Sands Missile Range, New Mexico. Volume I: Handbook of vegetation communities. U.S. Fish and Wildlife Service, Cooperative Agreement 14-16-002-91-233. New Mexico. 194 p.
- Muldavin, E. H., R. L. DeVelice, and F. Ronco, Jr. 1996. A classification of forest habitat types southern Arizona and portions of the Colorado Plateau. USDA Forest Service General Technical Report RM-GTR-287. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 130 pp.
- Peet, R. K. 1978. Latitudinal variation in southern Rocky Mountain forests. *Journal of Biogeography* 5:275-289.
- Peet, R. K. 1988. Forests of the Rocky Mountains. Pages 64-101 in: M. G. Barbour and W. D. Billings, editors. *North American Terrestrial Vegetation*. Cambridge University Press, New York.
- Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby. 1977. Forest habitat types of Montana. USDA Forest Service. General Technical Report INT-34. Intermountain Forest and Range Experiment Station, Ogden, UT. 174 pp.
- Powell, D. C. 1988. Aspen community types of the Pike and San Isabel national forests in south-central Colorado. USDA Forest Service, Rocky Mountain Region, Report R2-ECOL-88-01. 254 pp.
- Savage, M. and T. W. Swetnam. 1990. Early 19th century fire decline following sheep pasturing in a Navajo ponderosa pine forest. *Ecology* 71(6) 2374-2378.
- Sawyer, J. O., and T. Keeler-Wolf. 1995. A manual of California vegetation. California Native Plant Society, Sacramento. 471 pp.
- Shepherd, H. R. 1975. Vegetation of two dissimilar bighorn sheep ranges in Colorado. Colorado Division of Wildlife Report 4. 223 pp.
- Steele, R., S. V. Cooper, D. M. Ondov, D. W. Roberts, and R. D. Pfister. 1983. Forest habitat types of eastern Idaho - western Wyoming. USDA Forest Service General Technical Report INT-144. Intermountain Forest and Range Experiment Station, Ogden, UT. 122 pp.
- Steele, R., R. D. Pfister, R. A. Ryker, and J. A. Kittams. 1981. Forest habitat types of central Idaho. USDA Forest Service General Technical Report INT-114. Intermountain Forest and Range Experiment Station, Ogden, UT. 138 pp.
- Steinauer, G., and S. Rolfsmeier. 2000. Terrestrial natural communities of Nebraska. Unpublished report of the Nebraska Game and Parks Commission. Lincoln, NE. 143 pp.
- Stuever, M. C., and J. S. Hayden. 1997a. Plant associations of Arizona and New Mexico. Volume 2: Woodlands. USDA Forest Service, Southwestern Region, Habitat Typing Guides. 196 pp.
- Stuever, M. C., and J. S. Hayden. 1997b. Plant associations of Arizona and New Mexico. Edition 3. Volume 1: Forests. USDA Forest Service, Southwestern Region. Habitat Typing Guides. 291 pp.
- Thilenius, J. F., G. R. Brown, and A. L. Medina. 1995. Vegetation on semi-arid rangelands, Cheyenne River Basin, Wyoming. USDA Forest Service. General Technical Report RM-GTR-263. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 60 pp.
- USFS [U.S. Forest Service]. 1992. Draft habitat types of the Little Missouri National Grasslands. Medora and McKenzie ranger districts, Custer National Forest. Dickinson, ND.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

- Wright, H. A. and A. W. Bailey. 1980. Fire ecology and prescribed burning in the Great Plains--A research review. USDA Forest Service Gen. Tech. Report INT-77. Intermountain Forest & Range Exp. Station, Ogden, Utah.
- Wright, H. A., L. F. Neuenschwander, and C. M. Britton. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities: A state of the art review. USDA Forest Service General Technical Report INT-58.
- Youngblood, A. P., and R. L. Mauk. 1985. Coniferous forest habitat types of central and southern Utah. USDA Forest Service, Intermountain Research Station. General Technical Report INT-187. Ogden, UT. 89 pp.

APPENDIX G

G. Sunset Crater Volcano National Monument Species List

(Species list was compiled from the relevé data collected in 1999
as part of the USGS-NPS National Mapping Program)

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Family	Scientific Name	Common Name
Anacardiaceae	<i>Rhus trilobata</i> Nutt.	skunkbush sumac
Asclepiadaceae	<i>Asclepias subverticillata</i> (Gray) Vail	horsetail milkweed
	<i>Asclepias</i> sp. L. ¹	milkweed
Asteraceae	<i>Ageratina herbacea</i> (Gray) King & H.E. Robins.	fragrant snakeroot
	<i>Ambrosia acanthicarpa</i> Hooke.	flatspine burr ragweed
	<i>Ambrosia psilostachya</i> DC.	Cuman ragweed
	<i>Artemisia campestris</i> ssp. <i>pacifica</i> (Nutt.) Hall & Clements	field sagewort
	<i>Artemisia carruthii</i> Wood ex Carruth.	Carruth's sagewort
	<i>Artemisia dracunculus</i> ssp. <i>dracunculus</i> L.	tarragon
	<i>Artemisia ludoviciana</i> Nutt.	white sagebrush
	<i>Artemisia</i> sp. L.	sagebrush
	<i>Bahia dissecta</i> (Gray) Britt.	ragleaf bahia
	<i>Brickellia californica</i> (Torr. & Gray) Gray	California brickellbush
	<i>Brickellia eupatorioides</i> var. <i>eupatorioides</i> (L.) Shinnery	false boneset
	<i>Brickellia grandiflora</i> (Hook.) Nutt.	Tasselflower brickellbush
	<i>Chaetopappa ericoides</i> (Torr.) Nesom	rose heath
	<i>Cirsium wheeleri</i> (Gray.) Petrak	Wheeler's thistle
	<i>Ericameria nauseosus</i> ssp. <i>nauseosa</i> var. <i>nauseosa</i> (Pallas ex Pursh) Nesom & Baird	rubber rabbitbrush
	<i>Erigeron divergens</i> Torr. & Gray	spreading fleabane
	<i>Erigeron flagellaris</i> Gray	trailing fleabane
	<i>Erigeron</i> sp. L.	fleabane
	<i>Gaillardia pinnatifida</i> Torr.	red dome blanketflower
	<i>Gutierrezia sarothrae</i> (Pursh) Britt. & Rusby	broom snakeweed
	<i>Helenium arizonicum</i> Blake	Arizona sneezeweed
	<i>Helianthus annuus</i> L.	common sunflower
	<i>Hymenopappus filifolius</i> var. <i>lugens</i> (Greene) Jepson	Idaho hymenopappus
	<i>Hymenoxys richardsonii</i> (Hook.) Cockerell	pingue rubberweed
	<i>Lactuca serriola</i> L.	prickly lettuce
	<i>Packera multilobata</i> (Torr. & Gray ex Gray) W.A. Weber & A. Löve	lobeleaf groundsel
	<i>Senecio</i> sp. L.	ragwort
	<i>Stephanomeria minor</i> (Hook.) Nutt. var. <i>minor</i>	narrowleaf wirelettuce
	<i>Stephanomeria</i> sp. Nutt.	wirelettuce
	<i>Tetradymia canescens</i> DC.	spineless horsebrush
	<i>Tragopogon dubius</i> Scop.	yellow salsify
Berberidaceae	<i>Mahonia fremontii</i> (Torr.) Fedde	Fremont's mahonia
Boraginaceae	<i>Cryptantha cinerea</i> var. <i>jamesii</i> Cronq.	James' cryptantha
	<i>Cryptantha</i> sp. Lehm. ex G. Don	cryptantha
	<i>Lappula occidentalis</i> (S. Wats.) Greene	flatspine stickseed
	<i>Lappula</i> sp. Moench	stickseed
	<i>Lithospermum multiflorum</i> Torr. ex Gray	manyflowered stoneseed
Brassicaceae	<i>Arabis fendleri</i> (S. Wats.) Greene	Fendler's rockcress
	<i>Arabis</i> sp. L.	rockcress
	<i>Descurainia incana</i> ssp. <i>incana</i> (Bernh. ex Fisch. & C.A. Mey.) Dorn	mountain tansymustard

¹ Genera that do not include specific epithets are unique unidentified species.

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	<i>Descurainia obtusa</i> (Greene) O.E. Schulz	blunt tansymustard
	<i>Descurainia sophia</i> (L.) Webb ex Prantl	herb sophia
	<i>Erysimum capitatum</i> (Dougl. ex Hook.) Greene	sanddune wallflower
	<i>Physaria newberryi</i> Gray	Newberry's twinpod
	<i>Sisymbrium altissimum</i> L.	tall tumbledmustard
Cactaceae	<i>Echinocereus</i> sp. Engelm.	hedgehog cactus
	<i>Opuntia</i> sp. P. Mill.	pricklypear
Capparidaceae	<i>Cleome serrulata</i> Pursh	Rocky Mountain beeplant
Chenopodiaceae	<i>Chenopodium album</i> L.	lambsquarters
	<i>Chenopodium berlandieri</i> Moq.	pitseed goosefoot
	<i>Chenopodium graveolens</i> Willd.	fetid goosefoot
	<i>Chenopodium leptophyllum</i> (Moq.) Nutt. ex S. Wats.	narrowleaf goosefoot
Commelinaceae	<i>Commelina dianthifolia</i> Delile	birdbill dayflower
Cupressaceae	<i>Juniperus deppeana</i> Steud.	alligator juniper
	<i>Juniperus osteosperma</i> (Torr.) Little	Utah juniper
	<i>Juniperus</i> sp. L.	juniper
Euphorbiaceae	<i>Chamaesyce fendleri</i> (Torr. & Gray) Small	Fendler's sandmat
	<i>Euphorbia brachycera</i> Engelm.	horned spurge
	<i>Euphorbia</i> sp. L.	spurge
	<i>Tragia ramosa</i> Torr.	branched noseburn
Fabaceae	<i>Alhagi maurorum</i> Medik.	camelthorn
	<i>Astragalus</i> sp. L.	milkvetch
	<i>Lotus wrightii</i> (Gray) Greene	Wright's deervetch
	<i>Lupinus argenteus</i> Pursh	silvery lupine
	<i>Lupinus</i> sp. L.	lupine
	<i>Oxytropis lambertii</i> Pursh	purple locoweed
	<i>Phaseolus angustissimus</i> Gray	slimleaf bean
Fagaceae	<i>Quercus gambelii</i> Nutt.	Gambel oak
Geraniaceae	<i>Geranium caespitosum</i> var. <i>eremophilum</i> (Woot.& Standl.) W.C. Martin & C.R. Hutchins	purple cluster geranium
Grossulariaceae	<i>Ribes cereum</i> var. <i>pedicellare</i> Brewer & S. Wats.	whisky currant
Hydrophyllaceae	<i>Phacelia crenulata</i> Torr. ex S. Wats.	cleftleaf wildheliotrope
	<i>Phacelia egea</i> (Greene ex Brand) Greene ex J.T. Howell	Kaweah River phacelia
	<i>Phacelia serrata</i> J. Voss	saw phacelia
	<i>Phacelia</i> sp. Juss.	phacelia
Lamiaceae	<i>Marrubium vulgare</i> L.	horehound
	<i>Monardella odoratissima</i> Benth.	mountain monardella
Liliaceae	<i>Yucca angustissima</i> Engelm. ex Trel.	narrowleaf yucca
	<i>Yucca baccata</i> Torr.	banana yucca
Linaceae	<i>Linum lewisii</i> Pursh	prairie flax
	<i>Linum neomexicanum</i> Greene.	New Mexico yellow flax
	<i>Linum</i> sp. L.	flax
Loasaceae	<i>Mentzelia pumila</i> Nutt ex Torr. & Gray	dwarf mentzelia
	<i>Mentzelia</i> sp. L.	blazingstar
Malvaceae	<i>Sphaeralcea</i> sp. St.-Hil.	globemallow
Nyctaginaceae	<i>Mirabilis decipiens</i> (Standl.) Standl.	broadleaf four o'clock
	<i>Mirabilis linearis</i> (Pursh) Heimerl	narrowleaf four o'clock

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	<i>Mirabilis multiflora</i> (Torr.) Gray	Colorado four o'clock
	<i>Mirabilis</i> sp. L.	four o'clock
Oleaceae	<i>Forestiera pubescens</i> var. <i>pubescens</i> Nutt.	stretchberry
Onagraceae	<i>Gaura coccinea</i> Nutt. ex Pursh	scarlet beeblossom
	<i>Oenothera cespitosa</i> Nutt.	tufted evening-primrose
	<i>Oenothera</i> sp. L.	evening-primrose
Pinaceae	<i>Pinus edulis</i> Engelm.	twoneedle pinyon
	<i>Pinus flexilis</i> James	limber pine
	<i>Pinus ponderosa</i> P. & C. Lawson	ponderosa pine
	<i>Pseudotsuga menziesii</i> (Mirbel) Franco	Douglas-fir
Plantaginaceae	<i>Plantago patagonica</i> Jacq.	woolly plantain
Poaceae	<i>Achnatherum hymenoides</i> (Roemer & J.A. Schultes) Barkworth	Indian ricegrass
	<i>Agropyron desertorum</i> (Fisch. Ex Link) J.A. Schultes	desert wheatgrass
	<i>Andropogon hallii</i> Hack.	sand bluestem
	<i>Aristida divaricata</i> Humb. & Bonpl. ex Willd.	poverty threeawn
	<i>Aristida</i> sp. L.	threeawn
	<i>Bouteloua curtipendula</i> (Michx.) Torr.	sideoats grama
	<i>Bouteloua gracilis</i> (Willd. ex Kunth) Lag. ex Griffiths	blue grama
	<i>Bromus ciliatus</i> L.	fringed brome
	<i>Bromus rubens</i> L.	red brome
	<i>Bromus tectorum</i> L.	cheatgrass
	<i>Bromus</i> sp. L.	brome
	<i>Elymus elymoides</i> ssp. <i>elymoides</i> (Raf.) Swezey	squirreltail
	<i>Festuca arizonica</i> Vasey	Arizona fescue
	<i>Festuca</i> sp. L.	fescue
	<i>Hordeum jubatum</i> L.	foxtail barley
	<i>Muhlenbergia minutissima</i> (Steud.) Swallen	annual muhly
	<i>Muhlenbergia montana</i> (Nutt.) A.S. Hitchc.	mountain muhly
	<i>Muhlenbergia rigens</i> (Benth.) A.S. Hitchc.	deergrass
	<i>Pascopyrum smithii</i> (Rydb.) A. Love	western wheatgrass
	<i>Poa fendleriana</i> (Steud.) Vasey	muttongrass
	<i>Schizachyrium scoparium</i> ssp. <i>scoparium</i> (Michx.) Nash	little bluestem
Polemoniaceae	<i>Ipomopsis aggregata</i> ssp. <i>aggregata</i> (Pursh) V. Grant	scarlet gilia
Polygonaceae	<i>Eriogonum corymbosum</i> var. <i>aureum</i> (M.E. Jones) Reveal	crispleaf buckwheat
	<i>Eriogonum racemosum</i> Nutt.	redroot buckwheat
	<i>Eriogonum wrightii</i> Torr. ex Benth.	bastardsage
	<i>Eriogonum</i> sp. Mitchx.	buckwheat
Polypodiaceae	<i>Pellaea atropurpurea</i> (L.) Link	purple cliffbrake
	<i>Pellaea truncata</i> Goodding	spiny cliffbrake
Ranunculaceae	<i>Thalictrum fendleri</i> Engelm. ex Gray	Fendler's meadow-rue
Rosaceae	<i>Cercocarpus montanus</i> Raf.	alderleaf mountain mahogany
	<i>Chamaebatiaria millefolium</i> (Torr.) Maxim	fernbush
	<i>Fallugia paradoxa</i> (D. Don) Endl. ex Torr.	Apache plume
	<i>Holodiscus dumosus</i> (Nutt. ex Hook.) Heller	rock spirea
	<i>Purshia stansburiana</i> (Torr) Henrickson	Stansbury cliffrose
Rubiaceae	<i>Galium stellatum</i> Kellogg	bedstraw
	<i>Galium wrightii</i> Gray	Wright's bedstraw

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Salicaceae	<i>Populus tremuloides</i> Michx.	quaking aspen
Scrophulariaceae	<i>Castilleja integra</i> Gray	wholeleaf Indian paintbrush
	<i>Castilleja</i> sp. Mutis ex L. f.	Indian paintbrush
	<i>Linaria dalmatica</i> ssp. <i>dalmatica</i> (L.) P. Mill.	Dalmatian toadflax
	<i>Penstemon barbatus</i> (Cav.) Roth	beardlip penstemon
	<i>Penstemon clutei</i> A. Nels.	Sunset Crater beardtongue
	<i>Penstemon jamesii</i> Benth.	James' beardtongue
	<i>Penstemon</i> sp. Schmidel	penstemon
	<i>Pericome caudata</i> Gray	mountain tail-leaf
Solanaceae	<i>Verbascum thapsus</i> L.	common mullein
	<i>Physalis hederifolia</i> var. <i>fendleri</i> (Gray) Cronq.	Fendler's groundcherry

APPENDIX H

H. Visual Guide and Descriptions of the Sunset Crater Volcano National Monument Map Classes

Introduction

This document is a guide to the photointerpretation of vegetation map classes for Sunset Crater Volcano National Monument. It provides a ground photo image for each map class as well as at least one example of each map class as it appears on the aerial photographs.

This guide does not attempt to show all variations of each map class; only the most common or significant representations are included. The descriptions should be sufficient to give the user a feel for the imagery and an understanding of the relationships between the vegetation and the map classes. This guide describes the vegetation map classes and two separate photointerpreted coverages of aspen (*Populus fremontii*) and off-highway vehicle use.

How this guide is organized

This guide describes and illustrates every vegetation map class used in the Sunset Crater vegetation mapping project and the two photointerpreted coverages with one map class per page. The images are aerial photographs with their Mylar overlays scanned so as to show the photointerpreter's work. The assigned map class codes and the aerial photograph flight line numbers are in yellow or black depending on the visibility of the color on the photograph. Ground photos of each type are included where available. The photos are accompanied by a brief description of the distribution of the map class within the project area and how it generally appeared on the aerial photos. Other information about the map class or the polygon may be included if it improved understanding or recognition of that particular map class.

Merrick & Company of Aurora Colorado flew the color infrared (CIR) aerial photographs for SUCR on October 8, 1996. The photos were taken at a flight altitude of 6,000 feet above sea level using Kodak Aerochrome Infrared 2443 film. The photo mission was designed to take photos with about 30% side lap (between each flight line) and 60% overlap (along each flight line). The scale of the 9 x 9-inch photos is 1:12,000 (approximately 1 inch = 1000 ft.). Two sets of contact prints and positive transparencies were produced and used for stereoscopic interpretation. A total of 46 frames taken over 6 flightlines covered the project area.

Color Infrared Film (CIR)

CIR film is best for highlighting subtle changes in deciduous and wetland vegetation. Evergreen vegetation can also be distinguished using CIR film, although not as clearly as deciduous trees and shrubs. CIR film presents a "false color" picture that combines infrared reflectance with green and red visible bands. These differences in reflectance create differences in tone and color that can be easily distinguished and delineated as different plant communities. Reflectance is influenced by structure of the canopy, the orientation of the plants and their leaves, and the thickness and pigment content of leaves.

Texture is also important to the photointerpreter. For shrubs, texture is influenced by density of plants on the landscape, crown size and shape, and leaf size. Dense, medium-sized shrubs such as rabbitbrush give a grainy texture to the photographs. Small shrubs such as snakeweed show little or no texture, since the plants are about the same size as a small bunchgrass. Grasslands

tend to have a smooth texture, except where interrupted by prairie dog holes or anthills, which appear as pinhole-sized white dots. These are imprecise terms, but nonetheless provide important visual cues to the imagery.

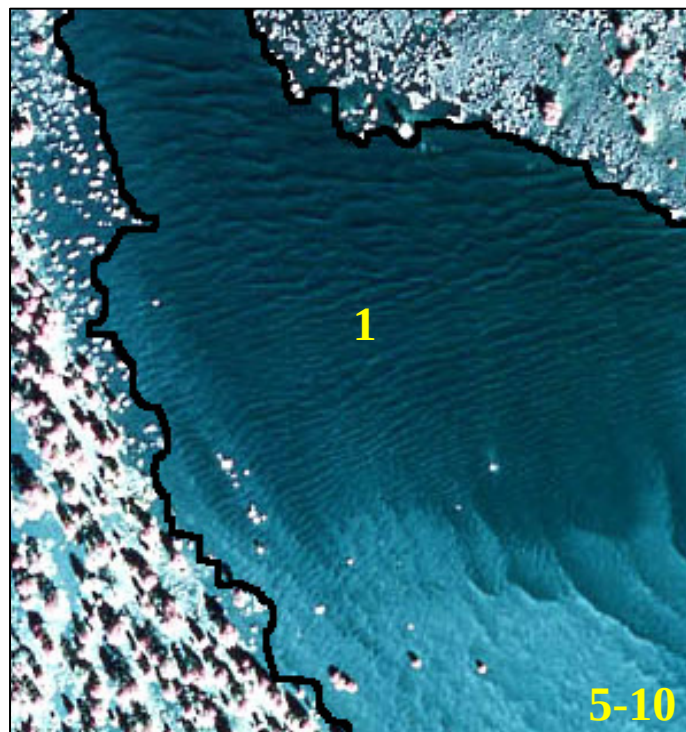
CIR photography generally is not consistent enough to allow a species or type to be described precisely. Film batch, printing process, sun angle, light intensity, shadow, and exposure can all affect the appearance of CIR photography. For accurate mapping at SUCR, ground verification by the photointerpreter was very important for to successful interpretation of types with confusing or similar signatures.

Cinder Sparse Mosaic (1)

Location. This map class is scattered in small and large patches throughout the eastern half of the mapping area. Smooth slopes and windblown dunes of sparsely vegetated black cinder characterize it.



Photosignature. This map class has a unique signature because it is largely unvegetated volcanic cinder. The color ranges from a very dark greenish-black to a pale blue green. The texture is generally smooth, but sometimes it has a wavy texture created by dune formations. Small inclusions of vegetation appear generally as white dots and specks.

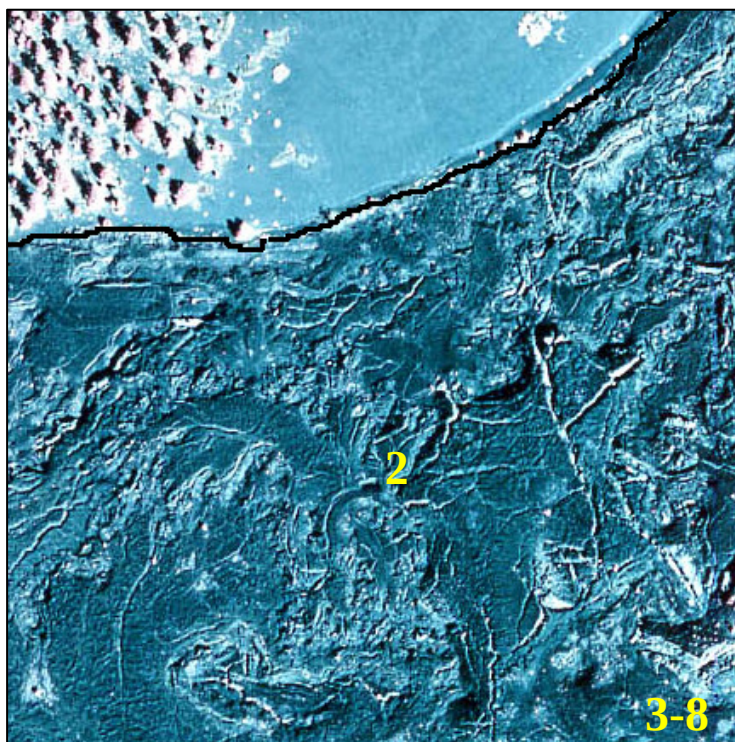


Lava Beds (2)

Location. This map class consists of the unvegetated portions of two large lava flows located near the center of the mapping area. It interfingers with map code 6 (Lava Bed Sparse Vegetation).



Photosignature. This map class has a unique signature because it is largely unvegetated lava flow. The color ranges from a very dark greenish-black to a pale blue green. The texture is rough and irregular, reflecting the broken surface of the lava. Small inclusions of vegetation appear generally as white dots or specks or as light blue-green smudges. Some areas of the flow were subsequently covered by volcanic ash and cinder; these areas appear smoother and much darker, and are often vegetated (not visible on this photograph).



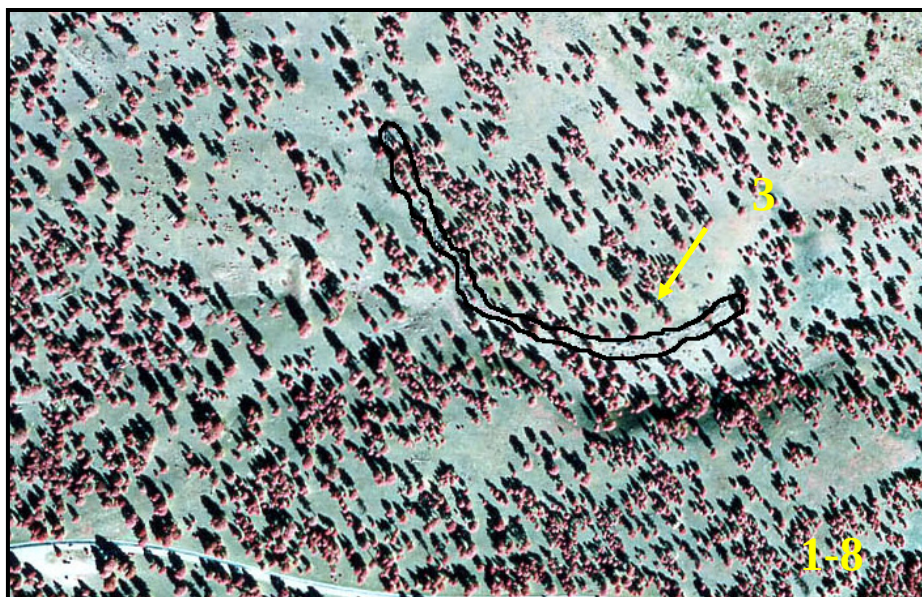
Rock Outcrop and Scree Shrubland (3)

Location. This map class consists of a complex of shrubland plant communities characterized by their preference for rocky substrates. It occurs in very small polygons scattered throughout the mapping area.



Photosignature.

Only the larger occurrences of this type were visible on the aerial photos; even so, most are less than the minimum mapping unit in size. They appear as breaks in the dominant vegetation, characterized by a grayish color and rough texture. Some, as in the example pictured here, are linear in shape and partly obscured by trees.

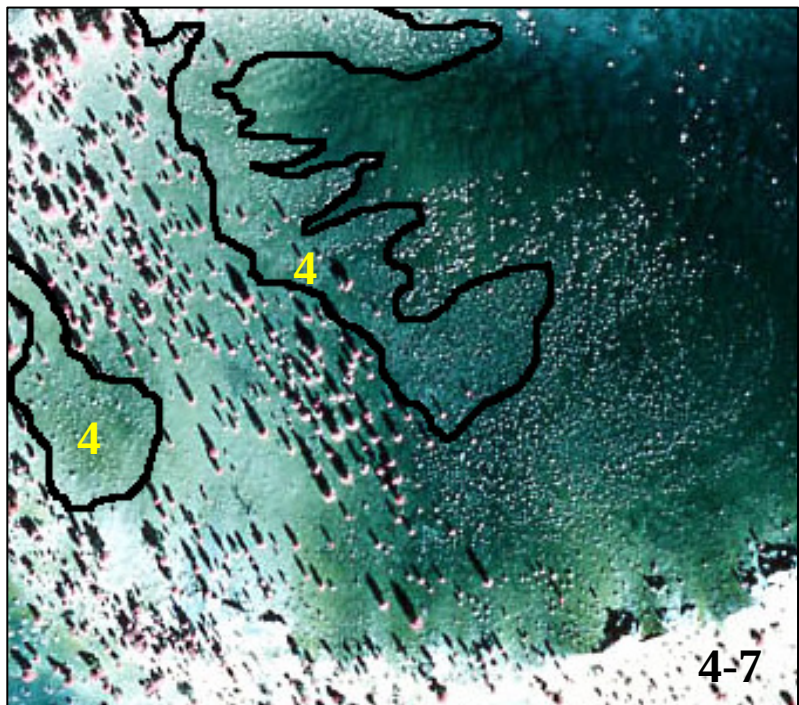


Wild Buckwheat – Sand Bluestem Sparse Vegetation (4)

Location. This map class occurs in small polygons scattered in areas of deep cinder deposition. The best occurrences are on the upper parts of the Sunset Crater cone and in the northeastern part of the mapping area. The vegetation consists of the two named species with little other vegetation present.



Photosignature. For the most part, occurrences were mapped from direct field observations. This type is very similar in appearance to map code 7, Sand Bluestem Herbaceous Vegetation, which often occurs in adjacent polygons. The cinder substrate gives the map class a greenish-black color, while the vegetation contributes a blue-green cast (the grass) with tiny white specks (the shrubs).

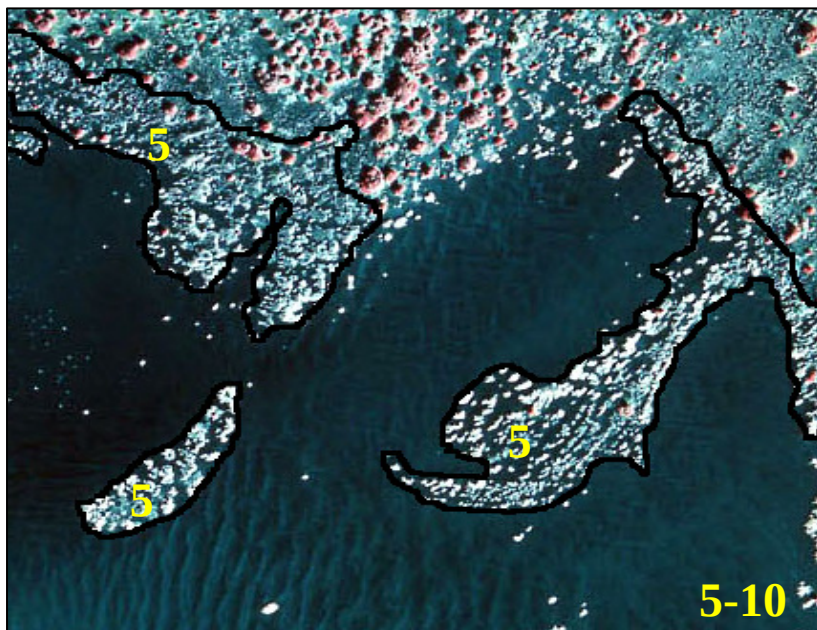


Apache Plume / Cinder Sparse Vegetation (5)

Location. This map class is common and widespread, except in the southwestern corner and the western edge of the mapping area. It is best developed on lava outcrops mixed with volcanic cinder. It consists of sparse to dense stands of apache plume, generally with few associated species.

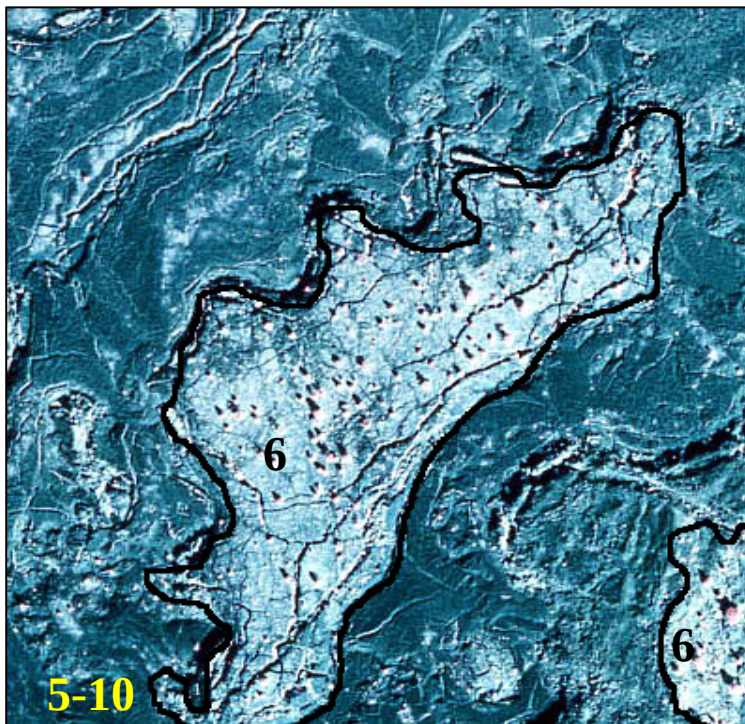


Photosignature. The characteristic signature for this map class consists of irregular small grayish white to blue-white speckles set in a matrix of smooth black cinder or rough black lava. The pink dots of trees are very sparse or absent.



Lava Bed Sparse Vegetation (6)

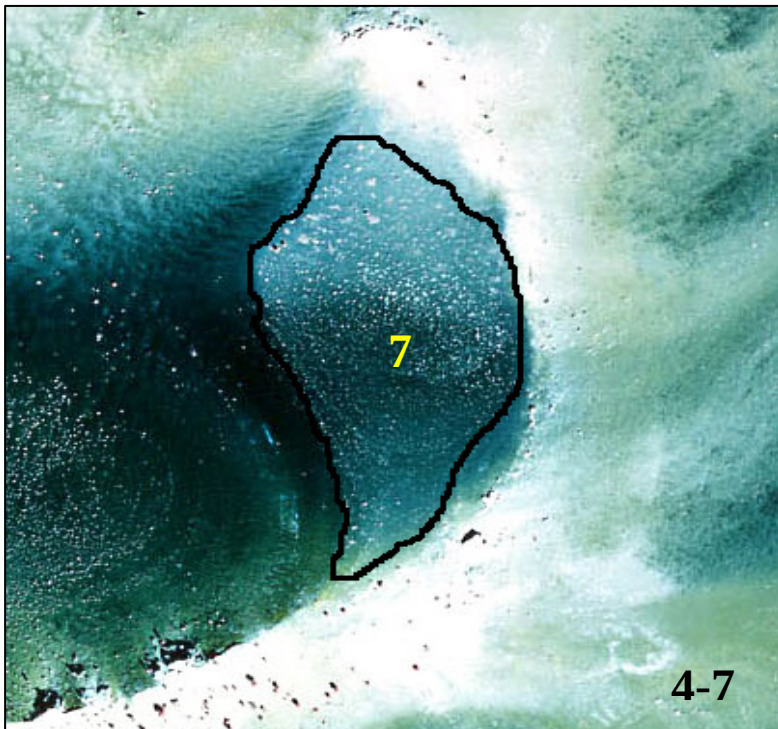
Location. This map class is closely associated with map code 2 (Lava Beds). It includes small patches of several different kinds of vegetation, including aspen woodlands, ponderosa pine woodlands, apache plume shrublands, and mixed shrublands that include ocean spray. It is generally restricted to the lava flows near the center of the mapping area.



Photosignature. Because of the variety of plant communities included within this map class, the signature is also somewhat variable. The map classes are associated with the two large lava flows, so they are either within or along the margins of the flows. The map class appears as a light bluish-white patch, with a gritty texture if shrubs are present, or small red-brown dots where aspens or ponderosa pines grow. This example is from the large lava flow north of the main park road.

Sand Bluestem Herbaceous Vegetation (7)

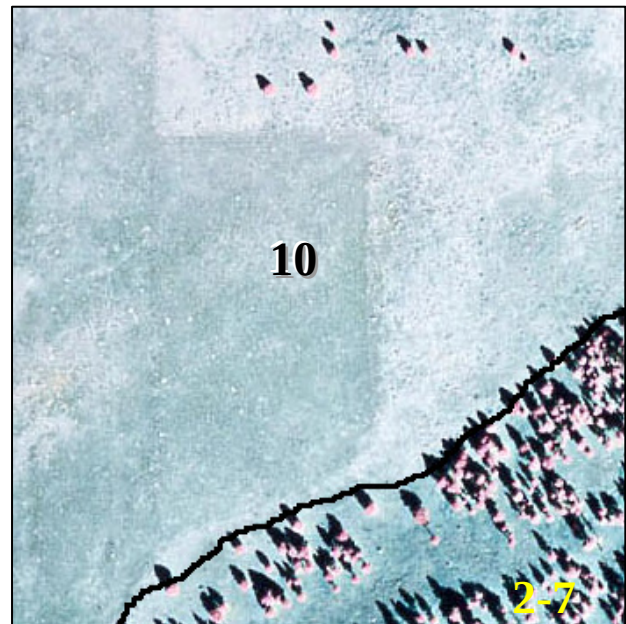
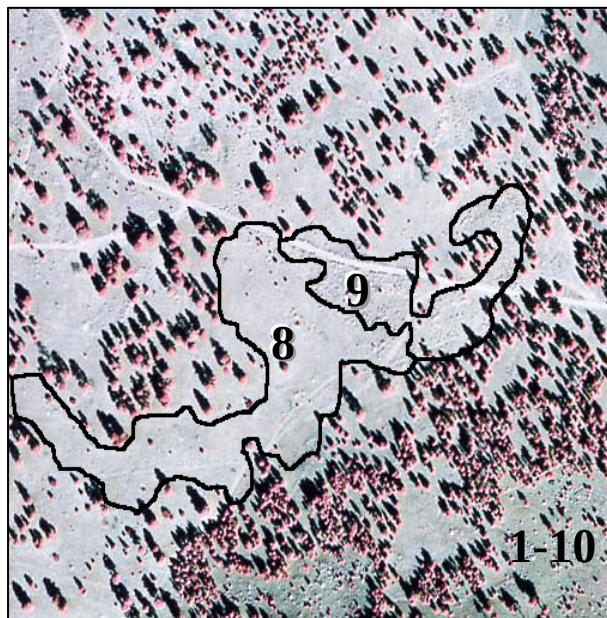
Location. This map class is restricted to cinder slopes on the eastern and southern flanks of Sunset Crater. It consists of sparse but nearly pure stands of sand bluestem growing in volcanic cinder.



Photosignature. The characteristic signature for this map class consists of minute grayish white to blue-white specks set in a matrix of smooth greenish-black cinder. A thin litter layer sometimes imparts a whitish cast to the matrix. The texture of the specks is generally finer and more regular than that of map codes 4 or 5. This example is from the rim of Sunset Crater.

Montane Grassland (8-10)

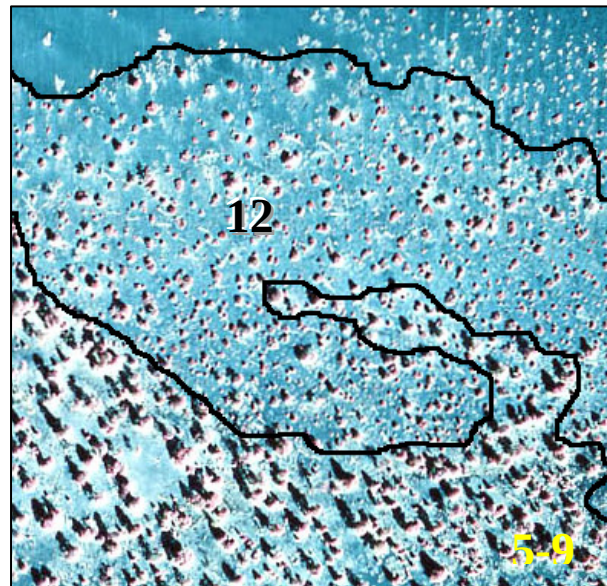
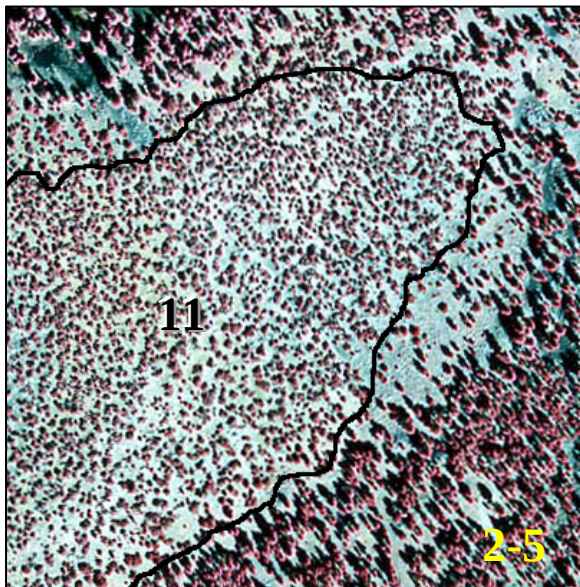
Location. This map class is best developed in the western part of the mapping area. It includes native grasslands of blue grama and mountain muhly as well as more disturbed situations that include stands of rabbitbrush or native forb species (such as Bonito Park).



Photosignature. Native bunchgrass grasslands (8) appear as light gray, smooth patches, usually within areas of ponderosa pine or other woody vegetation. Stands of rabbitbrush (9) are distinguishable by the texture of the small bumps the shrubs create. Bonito Park (10) forms a single class, marked by the presence of fence lines and lines marking the edge of old fields, visible in the center of the right picture.

Pinyon Pine – Utah Juniper / Blue Grama Woodland (11-12)

Location. This map class occurs in large patches on the slopes of the cinder cones within the mapping area. There are also stands on the windswept upper slopes of some of the larger cinder cones in the area. The understory is usually poorly developed, but may include sparse grasses or shrubs. Areas with more open pinyon-juniper canopy generally have a better-developed understory.



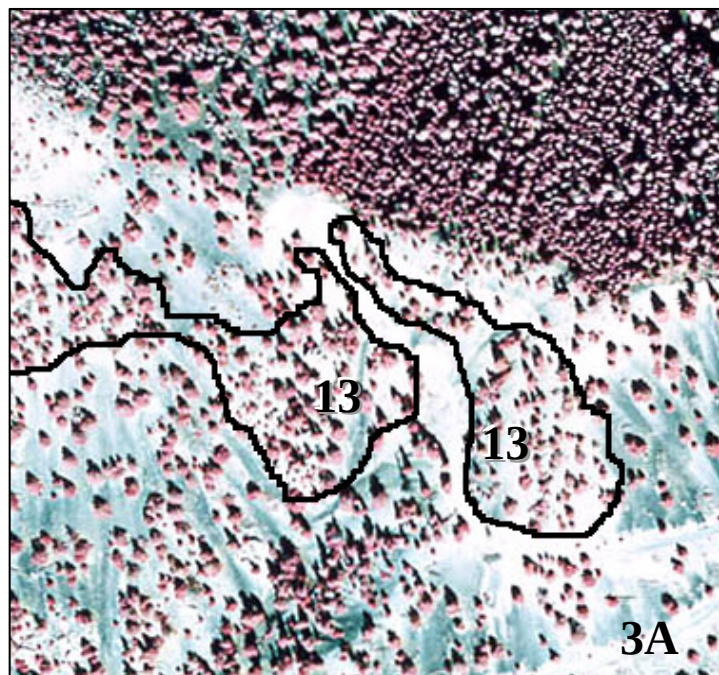
Photosignature. Mature pinyon pines and Utah junipers (11) are easily distinguished from ponderosa pine by their flatter, more irregular crowns and generally shorter stature (little or no shadow). Sparse stands (12) generally have a significant cover of shrubs, including skunkbush sumac (*Rhus trilobata*) and apache plume (*Fallugia paradoxa*), which contribute a rough texture to the appearance of the understory.

Limber Pine Woodland (13)

Location. This map class is restricted to small polygons on the exposed, south-facing upper slopes of O’Leary Peak.

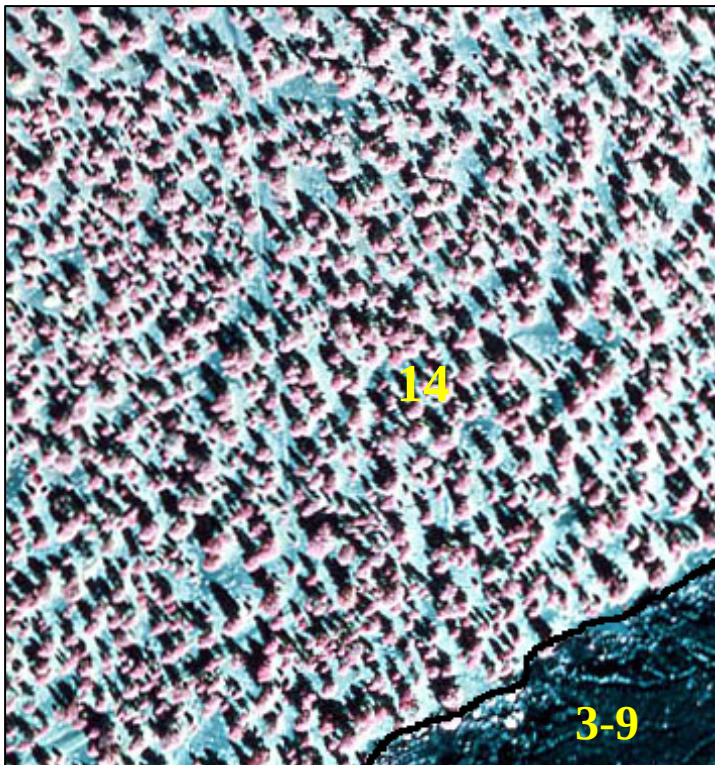


Photosignature. This map class was mapped from field observations. In general the appearance is similar to that of sparse pinyon-juniper stands (12), except that the individual tree crowns tend to be taller and broader. The understory is generally sparse, but appears white because the ground is covered with litter. The pictured example is from the shoulder of O’Leary Peak below the summit ridge.



Ponderosa Pine / Cinder Woodland (14)

Location. This map class is widespread, occurring in large areas in a north-south belt separating map codes 15 (Ponderosa Pine/Montane Grass Mosaic) and 17 (Ponderosa Pine/Apache Plume). While scattered clumps of grass or shrubs may occur in the understory, the general ground cover is barren cinder. This type contains most of the known populations of the rare beardtongue (*Penstemon cluteii*).



Photosignature. Ponderosa pines appear as reddish-brown spots, generally accompanied by significant black shadows. White patches, occurring around the base of individual trees, are the result of pine litter, not a grass understory. The ground between the tree crowns has the greenish-black appearance of barren cinder.

Ponderosa Pine / Montane Grass Mosaic (15)

Location. This map class is widespread, occurring in large polygons in the western third of the mapping area. Blue grama and/or mountain muhly may form a significant understory layer.

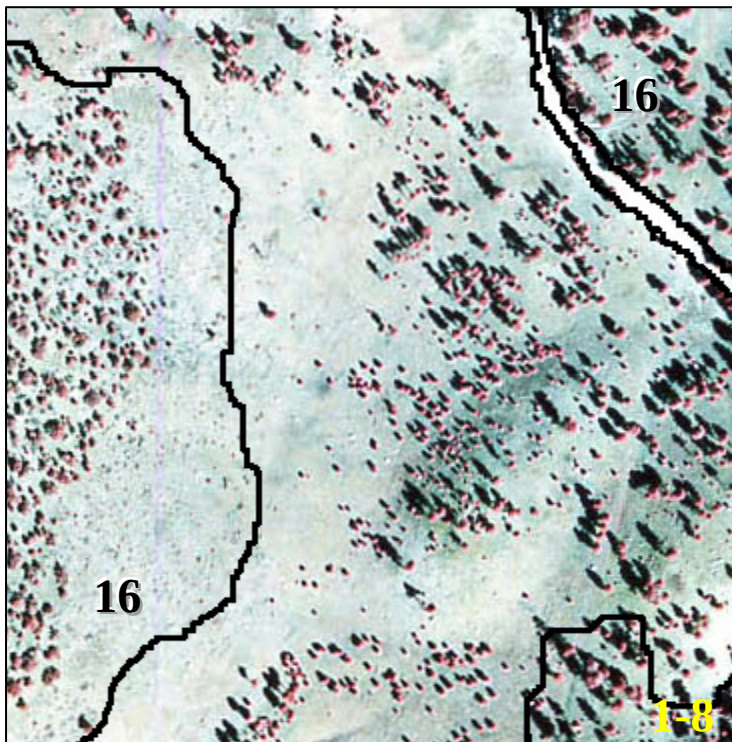


Photosignature. As in map code 14, ponderosa pine appears as reddish-brown spots accompanied by significant black shadows. The ground between the tree crowns usually appears uniformly light gray because of a combination of grass understory and pine litter. This example is immediately north of Bonito Park. The type may contain small inclusions of map code 17 (Ponderosa Pine/Apache Plume) and map code 14 (Ponderosa Pine/Cinder).



Ponderosa Pine Invasive Herbaceous Vegetation (16)

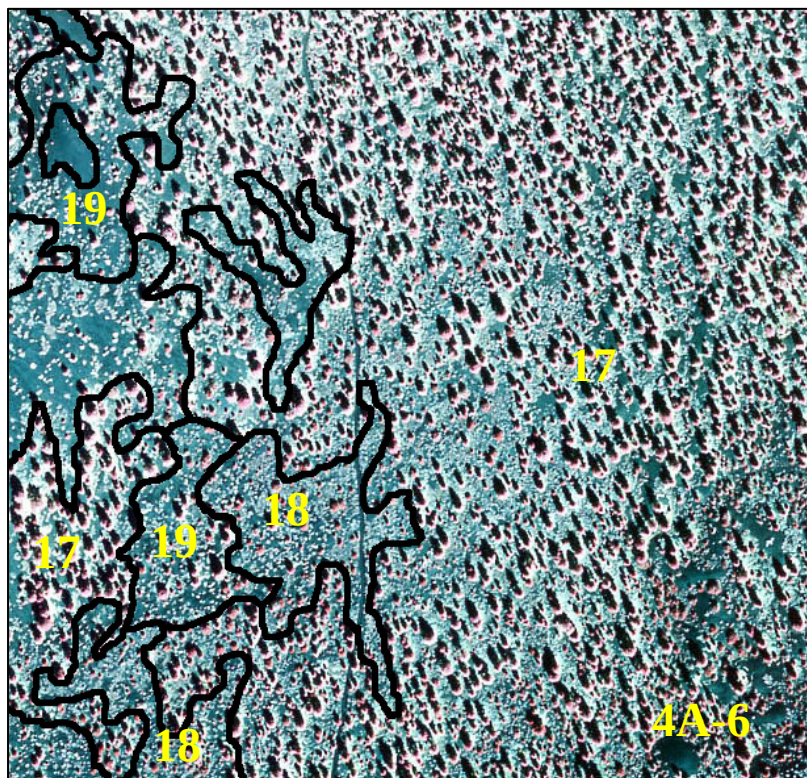
Location. This map class occurs in large polygons in the west central part of the mapping area, in parts of the area that burned 5-30 years ago, along disturbed roadsides and in the vicinity of the larger gravel pits. In these areas, invasive, non-native species became dominant in the understory, forming dense herbaceous stands where trees were killed, and forming the understory in areas where the canopy trees survived.



Photosignature. This map class is a mixture of wooded and herbaceous vegetation. As in map code 14, ponderosa pines appear as reddish-brown spots, generally accompanied by long black shadows. Some areas lack tree cover; many of the burned trees have fallen and appear as narrow gray lines on the light yellowish-gray of the invasive herbaceous vegetation.

Ponderosa Pine / Apache Plume Woodland (17-19)

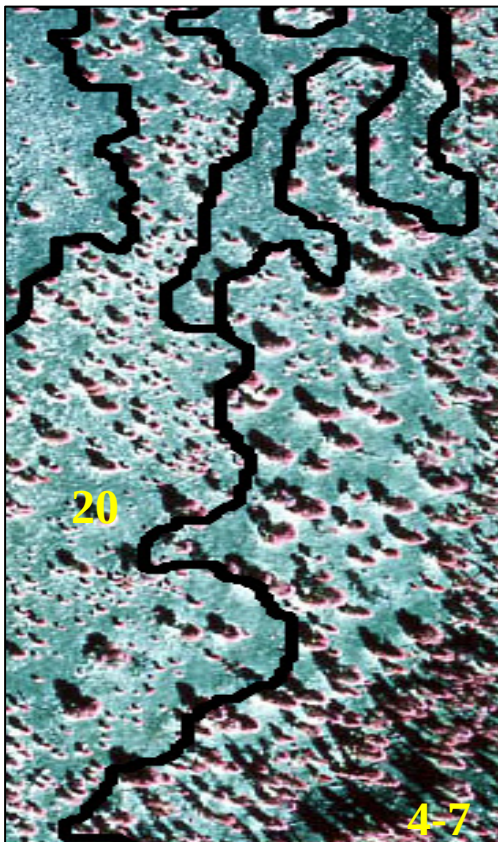
Location. This common and widespread map class occurs in large polygons throughout the mapping area, although most of the type is in the eastern half of the area. Apache plume shrubs and sometimes rabbitbrush shrubs form a significant understory in open ponderosa pine woodlands.



Photosignature. In the best developed examples (17), ponderosa pine appear as red-brown spots, usually associated with larger, oblong black shadows. The understory appears rough-textured because of the shrubs. Rabbitbrush shrubs are small, white, somewhat fuzzy round specks, whereas Apache plume appears as irregularly-shaped white or red-brown specks. The dark cinder/lava substrate is more evident in examples with a sparse ponderosa overstory (19). Mixed ponderosa-pinyon-juniper examples (18) tend also to have a sparse overstory of trees.

Ponderosa Pine / Sand Bluestem Woodland (20)

Location. This map class is best developed outside the park boundary. However, a few small polygons occur within the mapping area, on the flanks of Sunset Crater and smaller cinder cones in the vicinity. This class was mapped primarily from observations made in the field.



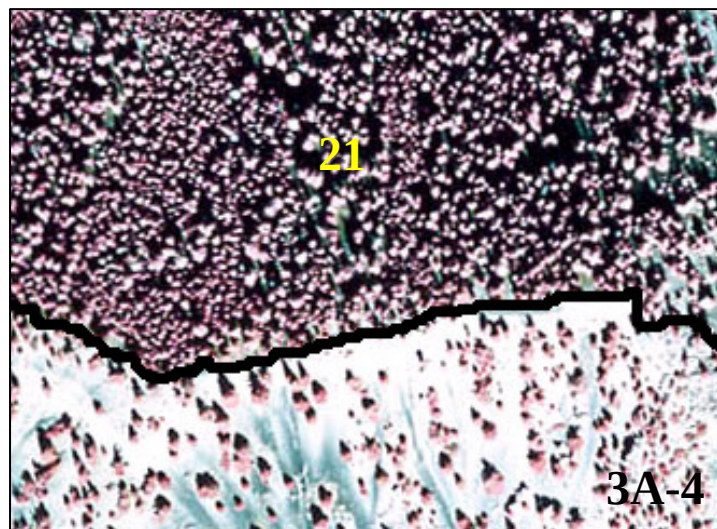
Photosignature. There is little in the aerial photosignature to distinguish this type from map code 14 (Ponderosa Pine/Cinder Woodland) or map code 15 (Ponderosa Pine/Montane Grass Mosaic). Because the canopy is usually open, the grass understory sometimes appears as regularly spaced tiny white specks against the greenish-black cinder substrate.

Douglas-fir Forest (21)

Location. This map class includes all stands where Douglas-fir is dominant or co-dominant with ponderosa pine or limber pine. Within the mapping area, this type is restricted to steep, north-facing upper mountain slopes on lava and mixed lava-cinder substrates.



Photosignature. The principal distinguishing characteristic of this map class is the dense, dark canopy of red-brown trees with consistently pointed crowns. Very little of the black cinder/lava substrate is visible. When viewed in stereo, the steepness and northerly aspect of the habitat is evident. This example is from the summit ridge of O'Leary Peak.

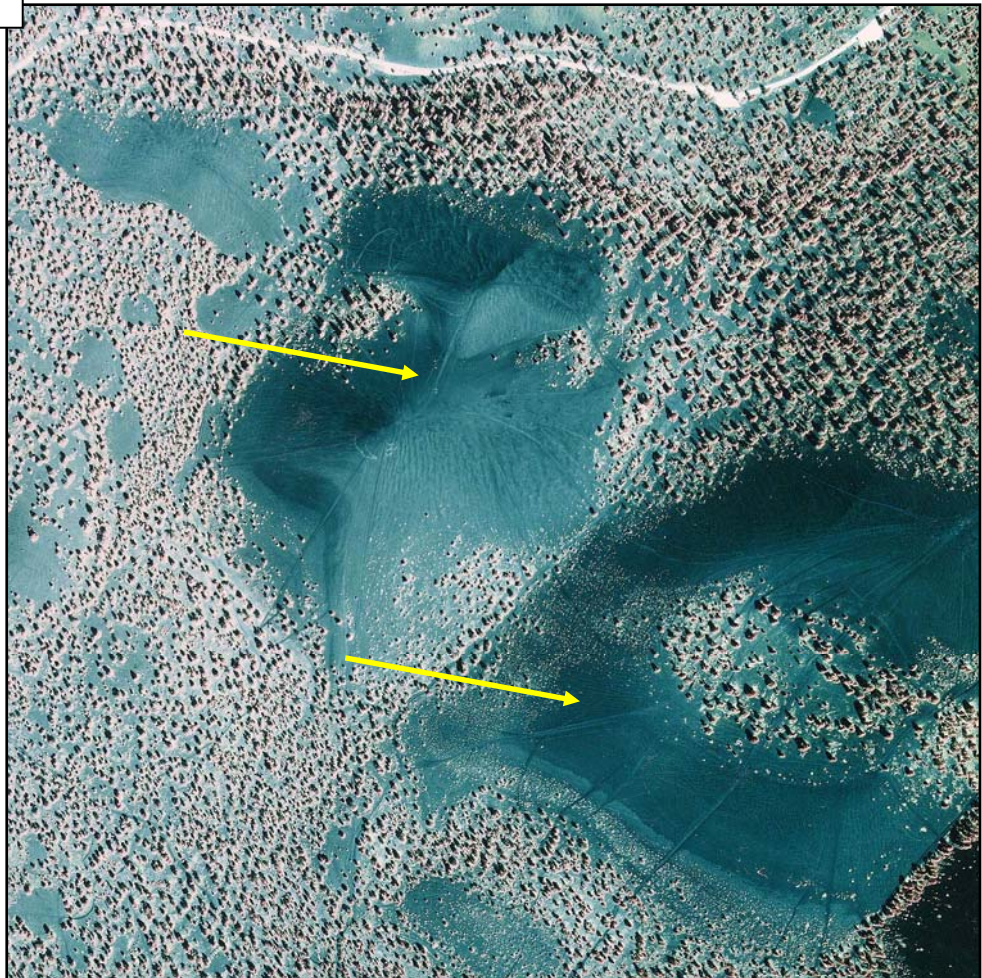


OTHER MAPPING COVERAGES

OFF-Highway Vehicle (OHV) Class

Location. The OHV Class was used to delineate disturbed areas surrounding SUCR. The highest concentration of OHV use appeared in the south, east and northeast portions of the project area.

No Ground Photo



Photosignature. This class is characterized by having linear lines resulting from temporary tracks left by OHVs. Tracks usually cross and radiate from a common starting point, usually an established road, pull-out or parking lot. Tracks on cinders appear slightly lighter than undisturbed sites. Tracks through vegetation usually expose the cinder substrate.

Quaking Aspen / Cinder Woodland

Location. The Quaking Aspen / Cinder Woodland Class was used to delineate small stands of aspen (*Populus tremuloides*) in and around SUCR. Only two patches were mapped using four polygons. One patch occurred within the monument just south of the Sunset Crater road on the north slope of Lenox Crater. The other patch occurred in the northwest portion of the study area in the project environs. Other scattered aspen stands were not big enough to map.



Photosignature. Aspen trees were difficult to distinguish from ponderosa pines due in part to their intermixing and the pale color of the infrared photography. Aspen trees canopies were slightly pinker than pines and appeared as “fluffs” rather than cones. Ground verification by the ecologists supplemented the photo interpretation for this class.

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The use of aerial photographs in studies of marsh vegetation

David P. Olson

December 1964

Bulletin 13, Technical Series
Maine Agricultural Experiment Station

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Foreword

David Olson, who conducted this study for his Master's thesis in wildlife management, had previously served in the United States Air Force for two years as a photo interpretation officer. His interest and skills in photo interpretation were essential to the pursuit of this research project.

This is one of the very first studies to explore the use of air photos for the identification of marsh vegetation in a clear cut scientific manner. It can serve as a guide for future studies of other low growing species that are important in wildlife management.

Albert D. Nutting
Director
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Summary and Conclusions

Aerial photographs of marsh habitat in Merrymeeting Bay, Maine, were studied to determine the kind of information relative to marsh vegetation that could be obtained from them, and also to determine the accuracy of the photographic interpretation. Four films were exposed at three altitudes over the same section of the marsh. On the basis of the photographic images, the vegetation on the study area was classified into 11 types: wildrice, river bulrush, round stem bulrush, yellow waterlily, pickerel weed, sweetflag, three-square bulrush, submersed aquatics, mixtures of the above, sand, silt, and high tide zone. Eighty areas representing all of these types were selected for interpretation tests. Each area was identified on the ground and accurately located on the aerial photography. Seven individuals, representing four levels of photo interpretation experience and/or experience in marshes, interpreted the 80 areas on the aerial photographs. The photo interpretations were compared with the ground identifications. The most important of the results were analysed statistically. The following conclusions may be deduced from this study:

1. The testing procedure appeared to be satisfactory for evaluating film, scales, and interpreters. It also seemed adequate for the classification of vegetation with the exception of three-square bulrush.
2. The classes of vegetation, recognizable on the aerial photographs, are similar to the plant associations that can be recognized on the ground with the exception of plants which usually grow in sparse stands.
3. There were no differences between the relative accuracies of interpretations on the four film materials.
4. With each increase in the scale of photography*, an increase in accuracy of interpretation was obtained. The increase (10 per cent) between scales of 1:20,000 and 1:12,000 was larger than the increase (5 per cent) observed between the scales of 1:12,000 and 1:5,000.
5. Biologists who have had experience in ecology of marshes, even though lacking prior training in photo interpretation, were able to interpret aerial photographs of marshes more accurately than experienced photo interpreters who had no experience in marshes.

* The representative fraction is the simplest method of expressing scales of aerial photography, and it is used in this report. At 1:5,000, one unit of measurement on the photograph equals 5,000 of the same units on the ground.

6. Training in the satisfactory use of the stereoscope can be accomplished in two hours or less. Likewise, only three to ten hours of practice in the identification of images on aerial photography (provided training aids and/or instruction are available) will permit interpretation of such aerial photographs with a relatively high degree of accuracy.
7. The images produced on aerial photographs result as much from the physical structure of the plant or stand of vegetation as they do from the color or tone of the plant.
8. Density of the marsh vegetation could not be interpreted accurately from the photographs, regardless of scale.
9. Mixtures of vegetation were interpreted with less accuracy than were pure stands.
10. Photographic penetration of water was less than two feet with the film materials used.
11. Aerial photographs are a useful means of studying marshes. In addition to recognizing the general types of marsh vegetation and the broad ecological zones, many plant species and associations can be recognized with a reasonable degree of accuracy.

THE USE OF AERIAL PHOTOGRAPHS IN STUDIES OF MARSH VEGETATION¹

DAVID P. OLSON²

Introduction

The physical and biological characteristics of a marsh are constantly changing. Some of these changes are slow and may progress for centuries, while others may be comparatively rapid. One of the biological characteristics which may change either slowly or rapidly is plant composition.

The evaluation of marshes for wildlife purposes and the selection of management procedures is dependent upon a knowledge of the variety, quantity, and location of marsh plants. Several methods have been devised to measure the composition of such vegetation. Information from quantitative sampling procedures is accurate, but it is costly as well as time-consuming to obtain. By general observation, less accurate information can be economically obtained, but it is often inadequate for use in management.

Aerial photographs have been used with a high degree of success to obtain quantitative information of certain natural resources, but their use in marsh ecology has been only partially determined. The purpose of this investigation was to further evaluate aerial photography as a means of studying marsh vegetation.

The objectives were:

1. To determine the type of information about marsh plants that may be obtained by studying aerial photographs.
2. To compare four film materials for use in aerial photography of a marsh.
3. To compare three scales of aerial photography of a marsh.
4. To compare interpretations by individuals of varying experience in marsh ecology and/or aerial photography.

Twelve aerial photographic coverages were obtained of a portion of Merrymeeting Bay, Maine, on August 25, 1957. Test areas on these photographs have been interpreted by seven photo interpreters, and the interpretations were checked against the actual stands of vegetation or portions of marsh habitat.

¹ Contribution from the Maine Cooperative Wildlife Research Unit, Orono, Maine: Maine Department of Inland Fisheries and Game, University of Maine, Wildlife Management Institute, and the Bureau of Sport Fisheries and Wildlife, U. S. Department of the Interior, cooperating.

² Currently a member of the faculty at the University of New Hampshire Forestry Department.

Material and Methods

The study area

Merrymeeting Bay is a large, shallow body of water at the junction of the Kennebec and Androscoggin rivers near Bowdoinham, Sagadahoc County, Maine. Its waters are fresh, and it has an average tide of four feet. According to the classification of Shaw and Fredine (1956), it is a combination of shallow fresh coastal and deep fresh coastal marsh.

At low tide a variety of vegetation may be seen. Dense stands of wildrice³ (*Zizania aquatica*) and yellow waterlily (*Nuphar spp.*) grow in the numerous coves and along five sluggish tidal rivers. Farther out in the bay are large expanses of silt and sand. Clumps of sweetflag (*Acorus Calamus*), pickerel weed (*Pontederia cordata*), soft stem bulrush (*Scirpus validus*), and yellow waterlily are scattered over the silt areas. Various species of submersed aquatics and three-square bulrush (*Scirpus americanus*) also grow on the open areas of silt, but their growth is diffuse. Typical of the sandy areas are large, dense stands of bulrush (*Scirpus validus* and *Scirpus fluvialis*). These bulrush stands are called "islands" by residents of the bay.

At high tide, only the tops of the bulrush and wildrice remain above the water, giving the bay the appearance of an expansive lake with scattered, short, emergent vegetation.

An area approximately three miles long and one-half mile wide which contained a variety of marsh vegetation was selected to be photographed (figure 1).

The reasons for choosing Merrymeeting Bay as an area in which to study marsh vegetation were:

1. It contained an excellent abundance and variety of marsh plants.
2. The vegetation could be examined in detail during low tides.
3. Aerial photographs of the area, which were taken in 1956, were available for preliminary study.
4. Merrymeeting Bay is an important waterfowl hunting area.

Photographic films and scales

The four types of film available for this study were two panchromatic films, Kodak Super-XX Aerographic and Kodak Plus-X Aerecon; and two color films, Kodak Ektachrome Aero, High Contrast (a positive color transparency film), and Kodak Ektacolor SO-1185, a color negative film. Black and white prints were made from the panchromatic films, and color prints from the color negative film. The color

³ Common names of plants are primarily from Hotchkiss (1950). Scientific nomenclature is taken from Fernald (1950).

MERRYMEETING BAY

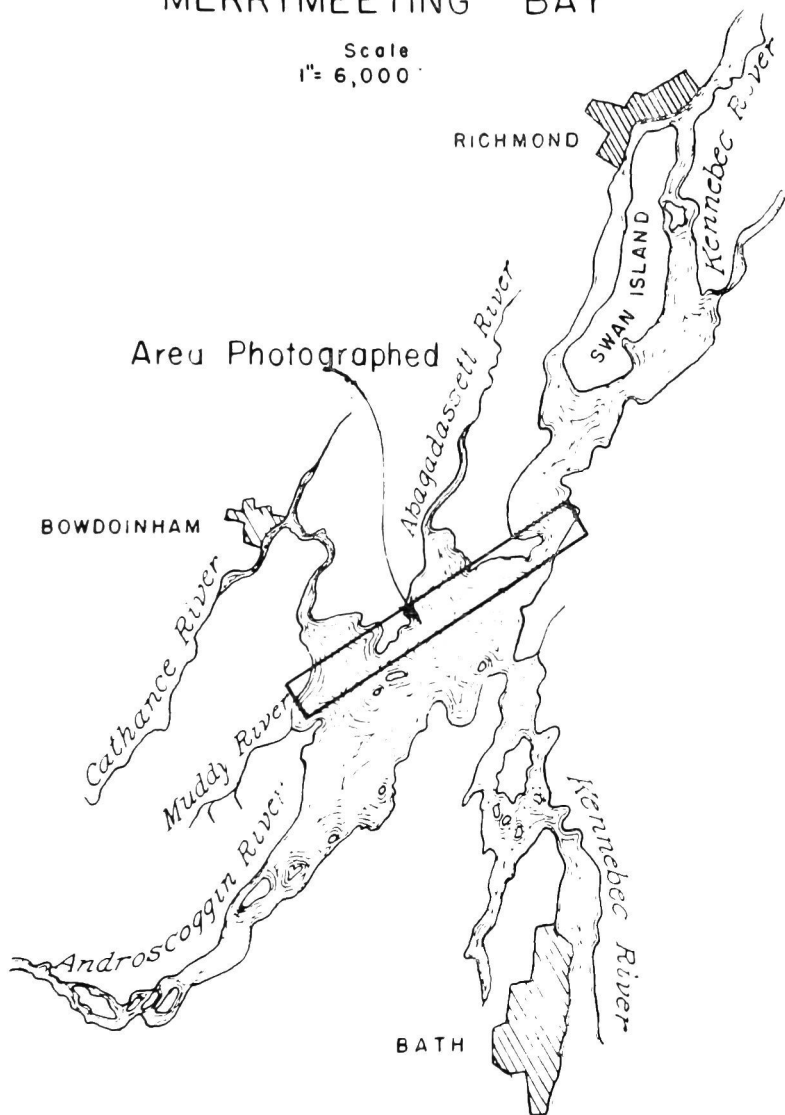


Figure 1

Merrymeeting Bay and the Area Photographed

transparencies were placed in cellophane envelopes and studied on a light table.

The films were exposed with filters recommended by the manufacturer. A minus blue (haze and contrast) filter was used with both panchromatic films. The color negative film was exposed through a Wratten 2A (minus ultra violet and blue) filter. Various filters were used in exposing the color transparencies. These were selected by the photographer according to the film manufacturer's instructions, and the haze conditions at the time of photography.

As the scale of aerial photographs increases, the amount of detail in the photographic images increases, and it is possible to distinguish smaller differences in the heights of objects (figure 4). To evaluate the effects of these differences on the interpretation of marsh vegetation, all four films were exposed through an 8.25 inch focal length lens at altitudes of 3,360 feet, 8,250 feet, and 13,750 feet. The resulting scales of photography were 1:5,000, 1:12,000, and 1:20,000.

Photographic conditions

It was decided that photographs would be most useful if taken when the marsh vegetation was at its maximum development. This decision was based primarily on the results obtained from the photographs of Merrymeeting Bay made in 1956, and partially on estimation. Other conditions that were necessary for exposing the films were low tides and clear weather. Morning low tides were preferable since haze and clouds usually developed by early afternoon.

The photographs were taken at low tide on the morning of August 25, 1957. The time of photography extended from one-half hour before low tide until one hour and 45 minutes after. By the time the last 1:20,000 exposures were made, the tide had risen considerably (appendix I). Field observations at the time of photography indicated that the vegetation was slightly beyond maximum growth, as the wild-rice had produced fruit, and the pickerel weed leaves were starting to deteriorate.

Photo interpreters

Studies (although not pertaining to marsh vegetation) have indicated that persons who are most experienced with subjects photographed are the best interpreters of the photographs (DeLancie, 1957). Because of a general lack of familiarity with aerial photographs, many persons feel that special training and experience are necessary to interpret them.

Seven individuals of varying levels of experience in marsh ecology

and/or photo interpretation, were selected to ascertain variations in interpretive ability. All seven were given the Moessner Floating Circles Test (Moessner, 1954) to determine if they had normal stereoscopic perception. The experience, occupation, and stereoscopic perception scores of the interpreters are given in table 1. Interpreter A was the most experienced in using aerial photographs of marshes. His experience was obtained in the Delta Marsh, Manitoba, and at Merrymeeting Bay, Maine. Interpreters B and C were wildlife biologists, both of whom have had considerable experience in marshes. They were familiar with the Merrymeeting Bay marsh, but they had not used aerial photographs in the field except to a very limited extent. Interpreters D and E had both used aerial photographs extensively, but little or none of their experience was with marsh vegetation. Interpreters E and F were students in wildlife conservation with little or no experience in marshes or with aerial photographs.

Table 1
Experience, Occupation, and Stereo Perception Scores* of the
Photo Interpreters

Interpreter	Interpretation experience	Marsh experience	Occupation	Stereo perception
A	extensive	extensive	wildlife graduate student	100
B	little	extensive	biologist	96
C	very little	extensive	biologist	96
D	extensive	little	professor of photogrammetry and forestry	96
E	extensive	little	specialist in soil interpretation	96
F	very little	little	wildlife student	88
G	very little	little	wildlife graduate student	96

*Any score of 80 or more is considered good stereo perception.

Young (1956) indicated that the accuracy of photo interpretation varied with a person's interest in the subject and photography. No comparisons of interest between interpreters were made, but it is probably correct to assume that the interest of each was high. All of the test personnel voluntarily spent considerable time interpreting the aerial photography.

Establishment of a classification scheme

Before interpretation of aerial photography can be made, the images on the photographs and their counterparts on the ground must be classified into recognizable groups. The procedure recommended

by Young and Stoeckeler (1956) was employed in this study. The steps in this procedure are field reconnaissance, trial interpretations, and field verifications.

Prior to the time the test photographs were taken, field reconnaissance¹ was conducted by utilizing the 1956 aerial photographs. The images on the 1956 photographs were compared with areas in the marsh and a tentative classification was established. Trial interpretations employing the tentative classifications were made and verified in the field, and the classification scheme was modified to permit increased speed and accuracy of interpretation.

The final classification scheme for this study contained 11 types: wildrice, round stem bulrush, river bulrush, yellow waterlily, pickerel weed, sweetflag, submersed aquatics, three-square bulrush, sand, silt, and high tide zone.² It was also decided to designate density of vegetation as sparse, medium, or dense. Complete descriptions of each of the 11 types are provided in appendix II.

Initial phase of interpretations

For the initial tests 210 areas of varying tone and color were selected on the 1:5,000 color transparencies. These were then interpreted by interpreter A. Since the color prints were not available at the time, the 210 test areas were interpreted on each of the nine remaining film/scale combinations. The interpreted identity and density were recorded for each area. It is possible that clues to the identity of test areas may be obtained when interpreting one set of aerial photographs and employed while interpreting the next set. To reduce this "carry-over" of information, not more than one photographic coverage was interpreted in any one day; also, for this reason, the coverages which were believed to be most difficult were interpreted first, and the least difficult last. An Abrams, Model CB1, 2-4 lens stereoscope was used for all interpretations in the study.

When the initial phase of photo interpretation was completed, each of the 210 test areas was verified in the field according to the classification scheme. Density and vegetation composition were recorded for each area (table 2). The initial interpretations were compared with field identification with the following results:

1. An average accuracy of 78 per cent was obtained.
2. Little difference in accuracy was noted among the four kinds of photography.

¹ During the initial studies the author refrained from going into the area which was to be photographed in order to avoid bias in his interpretation. The type called high tide zone in this study is "coastal shallow fresh marsh", as classified by Shaw and Fredine (1956).

Table 2
Composition of Interpretation Tests in Terms of Vegetative Types and Densities

Type	Initial interpretations (210 areas)				Initial interpretations (80 areas)			
	Number of areas	Densities sparse	attempted medium	dense	Number of areas	Densities sparse	attempted medium	dense
wildrice	21	1	—	4	8	1	—	1
yellow waterlily	32	9	15	9	8	2	2	—
pickerel weed	15	1	8	5	6	1	2	1
river bulrush	7	—	—	—	7	—	—	—
round stem bulrush	37	5	13	18	8	2	2	2
sweetflag	24	—	3	13	8	—	2	2
submersed aquatic	9	1	2	2	7	1	2	2
three-square bulrush	7	3	4	—	5	2	2	—
high tide zone	9	—	—	—	5	—	—	—
sand	5	—	—	—	5	—	—	—
silt	8	—	—	—	6	—	—	—
mixtures	28	—	—	—	7	—	—	—
Totals	202*	20	45	51	80	9	12	8

*This figure varies from the original 210 areas selected because 8 areas either were not located on the ground or were eliminated because they were not included in the 11 types listed.

3. More accuracy was obtained on the photographs taken at a scale of 1:12,000 than on the 1:20,000 photographs.
4. Little difference in accuracy was obtained between the 1:12,000 and 1:5,000 scales.
5. Accuracy of interpretation varied with each of the 11 types in the classification.

Photo interpretation tests

To supplement the results of the initial interpretations, as well as to compare interpretations of individuals of varying experience in marsh ecology and/or photo interpretation, a series of photo interpretation tests was conducted. The test consisted of 80 acres selected from the original 210 by stratified random sampling. Each of the 11 classifications was represented between five and eight times, and seven areas of mixed vegetation were also included. Twenty-nine of the 80 areas were designated for interpretation of density.

Each of the interpreters who were to take these tests lacked experience with marsh vegetation and/or aerial photographs. Therefore, a period of orientation and training was necessary, but this training had to be conducted in such a way that no bias would be introduced. To minimize bias in training, each interpreter used the same reference material and the same practice interpretation areas. Also, the interpreter, rather than the instructor, decided when his training would cease.

The wildlife students utilized the most training (approximately ten hours). The experienced photo interpreters trained for the shortest time (two hours), and the biologists' training was intermediate in length. Variations in the amount of time spent in training resulted from personal desires for more or less training and differences in the amount of time which the interpreters could devote to training. An important part of the training program for each interpreter was stereo examination of areas pointed out by the instructor. Practice interpretations were made of areas which were selected during the field checks. The reference materials⁶ which were used in training were obtained during the field verification and included the following:

1. A description of each of the 11 types to be interpreted.
2. Photographs of each type taken from the ground and stereo pairs⁷ taken from a step ladder.
3. Ecological information for all types including location, soil, and associated types.

⁶ Reference materials are given in appendix II.

⁷ Stereo pairs are 2 photographs of the same area which are taken from different positions. When they are viewed with a stereoscope, a 3-dimensional image is obtained.

4. Descriptions of the photographic images (color and panchromatic) for the various types.
5. Examples⁸ of each type on the aerial photography.

Due to time limitations, each of the six interpreters did not interpret all sets of aerial photographs. However, the tests were arranged so that an interpreter of each experience level interpreted each film scale combination (table 8). As in the initial interpretations, precautions were taken to minimize "carry-over" of information. Also, the interpreters were instructed that the 80 test areas contained some of each of the 11 types and some mixtures, but they did not know the number. Instructions to interpret density on 29 of the test areas served as a clue that these areas were vegetative and not sand or silt, but the information gained in this matter was negligible. Scores of the tests were not revealed to the interpreters until all the tests were completed.

At first, the interpreters located the test areas, interpreted them, and recorded their decisions. After about one-third of the interpretation tests were completed, the instructor began pointing out test areas and recording the interpretations. This procedure shortened the time necessary to complete each test, reduced eye strain, and did not affect the interpretation, as judged by subsequent results in comparison with earlier scores.

Photographic penetration of water

During the initial phase of this investigation, several attempts were made to interpret depths of water from the 1956 photographs. In each case the interpretation was very inaccurate. Therefore, it was decided to measure water penetration on the test photography.

Seven markers, approximately ten feet square, were made by sewing strips of burlap and white cloth together. At low tide, immediately before the photographic flight, areas with approximately 1, 2, 3, and 4 feet of water depth were located and marked. One marker was placed on the bottom at each depth, and one marker was floated on the surface beside each bottom marker. During photography, depth readings were taken from a boat at the 4-foot marker. The water depth at each marker was measured immediately before and after photography, and calibrated for the time of photography. By this procedure water depths at four stations on each set of photographs were known within one or two inches. Secchi disk readings, which provide an index to the transparency of the water, were taken from the boat when the depth measurements were made.

Each of the 12 sets of photographs was examined by two in-

⁸ See aerial photographs of Merrymeeting Bay in Appendix I.

interpreters who recorded whether or not they could see the bottom markers at the stations.

Analytical procedures

Each interpretation was scored "one" when the area was identified correctly. If the interpreter called a single plant type a mixture, and the mixture included the correct type, it was scored "one-half" "One-half" score was also obtained for naming only part of a mixture. The total possible score was 80.

Interpreter C 1:20,000 Aerecon		Total score, 48 of 80 60% Density, 2 of 29 7% Mixture, 2 of 7 = 29%									
Actual Identity	Interpreted Identity										
	sand	silt	submersed aquatics	three-square bulrush	pickerel weed	yellow waterlily	river bulrush	round stem bulrush	sweetflag	high tide zone	wildrice
sand	4					1					
silt		4	2								
submersed aquatics			4	1				1.5			.5
three-square bulrush			3					2			
pickerel weed					3	1		2			
yellow waterlily				1		6					
river bulrush						1	1	2			
round stem bulrush				1	1			1	2		
sweetflag									1		
high tide zone										5	
wildrice											8
Per cent Correct	100	100	57	0	75	67	100	26	67	100	84

Figure 2
Example of Table Used for Compiling Scores

Densities were scored separately. Since a density designation is meaningless when the vegetative type is not correctly stated, no credit was given for density designations unless the vegetation was identified correctly. Each correct density interpretation was scored "one", and the total possible score was 29.

The most convenient method for compiling these data is a table comparing interpretations with known identities, as used by Young and Stoeckeler (1956). Figure 2 is an example of such a table. It will be noted that the correct interpretations occur in a diagonal row from upper left to lower right. This table also depicts the number and identity of incorrect interpretations. One table was made from each of the 65 test interpretations, and from them, composite tables were compiled for each variable being investigated. The scores on mixture and density interpretations were compiled separately. The data were analyzed statistically, and these calculations are presented in appendix IV.

Results

Identification of marsh vegetation

There was considerable variation in the accuracy of identifying the 11 types of vegetation. In table 3 the total number of times each type was interpreted and the average accuracy of identification are listed. Wildrice, yellow waterlily, river bulrush, high tide zone, and sand were all interpreted with a high degree of accuracy, while pickerel weed, round stem bulrush, submersed aquatics, sweetflag, and silt were identified with an intermediate degree of accuracy. Of the 11 types studied, three-square bulrush alone was identified with an average accuracy of less than 50 per cent. The relative accuracies for the identification of types were the same in all tests regardless of interpreter, film, or scale.

Accuracy of identification in relation to scale

With an increase in the scale of photography, the accuracy of identifying most marsh types increased. However, there were some exceptions. At all scales, accuracy of identifying three-square bulrush stands varied little from what could be obtained by chance. By contrast, accuracy was consistently high for identification of the high tide zone. Table 4 contains the average accuracy for identification of vegetative types on the three scales investigated. The average increase in accuracy was 10 per cent between the 1:12,000 and 1:20,000 scales, and 5 per cent between the 1:12,000 and 1:5,000 scales. These differences are significant at the 99 per cent level (appendix IV).

Table 3
Variation in Accuracy of Identifying Eleven Classifications
of Marsh Vegetation
(all interpretations)

Marsh type	Number of interpretations	Average per cent accuracy
high tide zone	325	94
wildrice	525	93
sand	325	90
river bulrush	455	86
yellow waterlily	525	82
pickerel weed	390	75
silt	390	66
submersed aquatics	455	65
round stem bulrush	525	57
sweetflag	525	56
three-square bulrush	325	12

Accuracy of identification in relation to type of film

Since the accuracy in identifying the 11 types varied little on the four films tested (table 5), the differences between films were not statistically significant. Pickerel weed was correctly identified more often on the color films than on the panchromatic films. Sweetflag was identified less accurately on the color transparencies than with all other films, but the low accuracy with this plant occurred mainly on the 1:20,000 color transparencies.

Accuracy of identification in relation to experience of the interpreters

As might be expected, interpreters varied in their ability to identify the 11 types of vegetation. Comparison of the average scores as shown

Table 4
Accuracy of Identifying Eleven Classifications of Marsh
Vegetation on Three Scales of Photography

Type	Per cent accuracy		
	1:20,000	1:12,000	1:5,000
high tide zone	94	93	95
wildrice	88	92	98
sand	85	91	93
river bulrush	68	92	99
yellow waterlily	68	84	94
pickerel weed	63	80	82
silt	56	64	78
submersed aquatics	59	66	71
round stem bulrush	47	60	62
sweetflag	48	59	61
three-square bulrush	9	15	12
Average for all types	62	72	77

in table 6 indicated that the interpreters with the most experience with marshes identified the marsh types most accurately. A statistical analysis of the average scores of each interpreter, with the exception of interpreter A, indicated that there was a significant difference between the lowest and highest scores. There were no significant differences between the scores of biologists and students, and, with one exception, none between students and experienced interpreters.

Table 5
Accuracy of Identifying Eleven Classifications of Marsh Vegetation
on Four Film Materials

Type	Per cent accuracy for all scales			
	Aereographic	Aerecon	Ektachrome	Ektacolor
high tide zone	90	93	97	96
wildrice	94	93	92	92
sand	90	87	91	90
river bulrush	87	91	88	84
yellow waterlily	82	81	82	84
pickerel weed	65	73	82	82
silt	64	60	67	73
submersed aquatics	68	62	67	65
round stem bulrush	55	58	58	55
sweetflag	61	62	47	58
three-square bulrush	13	11	14	13
Combined average	70	70	71	72

The members of each pair of interpreters (B and C, D and E, and F and G) had similar scores for all scales and film materials. Also, their errors in identification were, for the most part, very similar. Statistical analysis of the scores obtained with the 1:12,000 photographs, on which all interpreters were tested, indicated that the interpreters in each pair did not vary significantly from one another (appendix IV).

Identification of mixed stands

Seven stands of mixed vegetation were included in the 80 test areas. Of these, only two were identified with appreciable accuracy. The seven mixtures and the number of times each was identified wholly correctly or one-half correctly are listed in table 7. Wildrice-round stem bulrush, and wildrice-river bulrush mixtures were recognized much more frequently than the remaining five.

In table 8 the mixture interpretation scores for all seven individuals are listed. Two interpreters obtained higher scores on mixtures than did the other five. As in identification of pure stands, no differences between film materials were noted, but the mixture score was higher with each increase in scale.

Table 6
Comparison of Interpretations—Accuracy in Per Cent of Identifying Marsh Vegetation

Interpreter and experience	Film scale combination												Aver
	Aereographic Super-XX 1:5-1:12-1:20			Aerecon Plus-X 1:5-1:12-1:20			Ektachrome 1:5-1:12-1:20			Ektacolor 1:5-1:12-1:20			
A: Marsh ecology, extensive Photo interpretation, extensive	83	78	74	81	79	73	81	82	75	—	—	—	78
B: Marsh ecology, extensive Photo interpretation, little	76	78	61	—	71	—	74	72	68	—	79	—	72
C: Marsh ecology, extensive Photo interpretation, little	—	69	—	78	76	60	—	78	—	78	78	67	73
D: Marsh ecology, little Photo interpretation, extensive	73	66	59	—	63	—	74	66	66	—	66	—	67
E: Marsh ecology, little Photo interpretation, extensive	—	62	—	74	65	59	—	69	—	72	71	57	66
F: Marsh ecology, little Photo interpretation, little	74	67	65	79	73	58	81	72	57	79	78	52	70
G: Marsh ecology, little Photo interpretation, little	77	71	61	73	73	57	74	64	58	79	74	60	68

Table 7
Interpretations of Seven Stands of Mixed Marsh Vegetation
(all films, scales, interpreters combined)

Composition of stands	Number of completely correct interpretations	Number of half-correct interpretations	Analysis of half-correct interpretations	
three-square bulrush and submersed aquatics	3	50	three-square bulrush	14
			submersed aquatics	36
round stem bulrush and wildrice	40	15	round stem bulrush	13
			wildrice	2
round stem bulrush and sweetflag	0	51	round stem bulrush	50
			sweetflag	1
river bulrush and wildrice	23	26	river bulrush	2
			wildrice	24
river bulrush and sweetflag	0	25	river bulrush	24
			sweetflag	1
yellow waterlily and wildrice	7	21	yellow waterlily	18
			wildrice	3
pickerel weed and round stem bulrush	5	29	pickerel weed	13
			round stem bulrush	16

Table 8
Comparison of Interpretations—Accuracy in Per Cent of Identifying Mixed Marsh Vegetation

Interpreter and experience	Film/scale combination												Aver.
	Aereographic Super-XX			Aerecon Plus-X			Ektachrome			Ektacolor			
	1:5-1:12-1:20			1:5-1:12-1:20			1:5-1:12-1:20			1:5-1:12-1:20			
A: Marsh ecology, extensive Photo interpretation, extensive	86	59	59	79	71	64	71	71	64	—	—	—	69
B: Marsh ecology, extensive Photo interpretation, little	64	50	21	—	27	—	57	43	36	—	57	—	44
C: Marsh ecology, extensive Photo interpretation, little	—	50	—	57	43	29	—	50	—	50	50	38	46
D: Marsh ecology, little Photo interpretation, extensive	50	43	50	—	50	—	50	43	50	—	43	—	47
E: Marsh ecology, little Photo interpretation, extensive	—	36	—	50	43	29	—	50	—	57	50	36	44
F: Marsh ecology, little Photo interpretation, little	43	50	36	50	64	21	57	43	43	57	57	21	45
G: Marsh ecology, little Photo interpretation, little	64	57	36	64	57	50	71	57	50	71	64	36	56

Table 9
Comparison of Interpretations--Accuracy in Per Cent of Interpreting Density of Marsh Vegetation

	Film/scale combination												Aver.
	Aereographic Super-XX			Aerecon Plus-X			Ektachrome			Ektacolor			
	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20	1:5-1:12-1:20		
A: Marsh ecology, extensive Photo interpretation, extensive	28	31	24	31	24	17	28	17	21	—	—	—	25
B: Marsh ecology, extensive Photo interpretation, little	31	31	28	—	21	—	35	21	24	—	10	—	25
C: Marsh ecology, extensive Photo interpretation, little	—	24	—	28	31	7	—	24	—	35	35	35	27
D: Marsh ecology, little Photo interpretation, extensive	38	21	17	—	21	—	24	31	28	—	17	—	25
E: Marsh ecology, little Photo interpretation, extensive	—	24	—	31	14	24	—	10	—	24	21	14	20
F: Marsh ecology, little Photo interpretation, little	24	17	38	14	28	14	17	24	14	31	3	17	20
G: Marsh ecology, little Photo interpretation, little	21	17	21	24	31	28	14	17	24	21	17	21	21

Interpretation of vegetation density

The relative accuracies of the interpretations of density for all interpreters and for each of the 12 sets of aerial photographs are listed in table 9. The average accuracy (23 per cent) varies little from what might be obtained by chance. Since there were three classes of density, chance should have yielded 33 per cent accuracy. However, to consider density, the vegetation first had to be identified correctly. Types of vegetation were identified with an average accuracy of 71 per cent. Multiplying the average accuracy of vegetation identification by expected accuracy due to chance (0.71×0.33) amounts to 22 per cent. This approximates the accuracy that was obtained.

Photographic penetration of water

The maximum depth at which any bottom marker could be identified on the photographs was 23 inches (table 10). At depths of 24 and 25 inches the two interpreters could detect an object below the surface, but they could not state with certainty that it was a marker. In depths exceeding 27 inches, the markers were not visible. These figures agree with observations made in the field during the reconnaissance phase of the study.

Table 10
Depths of Water at Which Markers Were Visible

Water depth (in inches)	Film	Scale	Marker visible
14	Aerecon Plus-X	1:12,000	yes
14	Aereographic Super-XX	1:5,000	yes
15	Aerecon Plus-X	1:5,000	yes
15	Aereographic Super-XX	1:12,000	yes
15	Ektacolor	1:5,000	yes
17	Ektachrome	1:5,000	yes
18	Ektacolor	1:12,000	yes
20	Ektachrome	1:12,000	yes
24	Aerecon Plus-X	1:5,000	questionable
24	Aerecon Plus-X	1:12,000	questionable
25	Ektacolor	1:5,000	questionable
25	Aerecon Plus-X	1:5,000	questionable
25	Aereographic Super-XX	1:12,000	questionable
27	Ektachrome	1:5,000	no
*			

*Markers were definitely not seen in depths from 27 to 56 inches.

Discussion

The volume and accuracy of information varied between the types of vegetation, the scales of photography, and the experience of the interpreters, but not between the film materials used. A discussion of these factors may indicate some of the reasons for this variation.

Films

Color films have a greater potential for recording detail than panchromatic films because there are many more colors and hues than there are shades of gray (Colwell, 1954, and Ray and Fischer, 1957). Nevertheless, with the 11 types of vegetation studied, the only benefits obtained from the color materials were slight increases in accuracy when identifying pickerel weed stands, and a possible increase in accuracy of identifying silt.

All of the interpreters used the added clue of color when studying the color films, and on many of the color coverages, they stated that they were more certain of their interpretations. However, the scores did not reflect the supposed added certainty.

It is possible to obtain more detail on aerial photographs by using a camera equipped with a device to compensate for movement of the aircraft. Since this equipment was not available, it is quite possible that the full potential of the films was not realized. This is particularly true with the Aerecon film, which is designed to give maximum detail. The prints made from the Aerecon film had greater contrast than those made from Aereographic film. The added contrast seemed to make interpretation more difficult, but only small differences in scores were obtained.

Ektachrome transparencies were slightly over-exposed at the 1:20,000 scale and slightly under-exposed at the 1:5,000 scale. These differences in exposure did not appear to affect interpretation in general, but the low accuracy of identifying sweetflag on the 1:20,000 scale may have resulted from the over-exposure.

Color transparencies were more difficult to use, because extra equipment, such as a light table and a mirror stereoscope, were necessary to view them properly. In this study a simple lens stereoscope was used, but the field of vision was small and considerable manipulation of the photographs was necessary. Since the color transparencies were the original film, they could not be replaced if damaged or destroyed. Therefore, caution was necessary when they were used.

As the color negative film is comparatively new, considerable difficulty was encountered in obtaining prints from it. The results from the interpretations of this material did not vary significantly from those from the other films. However, the accuracy of identifying vegetation types on the 1:12,000 color prints was 4 per cent greater than the accuracy obtained with the other 1:12,000 photography.

Scales and experience of interpreter

Except for differences in accuracy of interpretation associated with plant species or types, the major variables seemed to be the scale and

the experience of the interpreter. These two closely related variables are compared in figure 3.

Differences in the overall accuracy of interpretation for the four levels of interpreter experience are apparent. Since the photographic images were relatively easy to memorize, the differences were probably caused by variations in experience with marsh ecology. Interpreters with a greater knowledge of marsh ecology used more deductive reasoning (interpretation) when making their decisions, while the interpreters with less knowledge of marsh ecology relied on identification of photo-

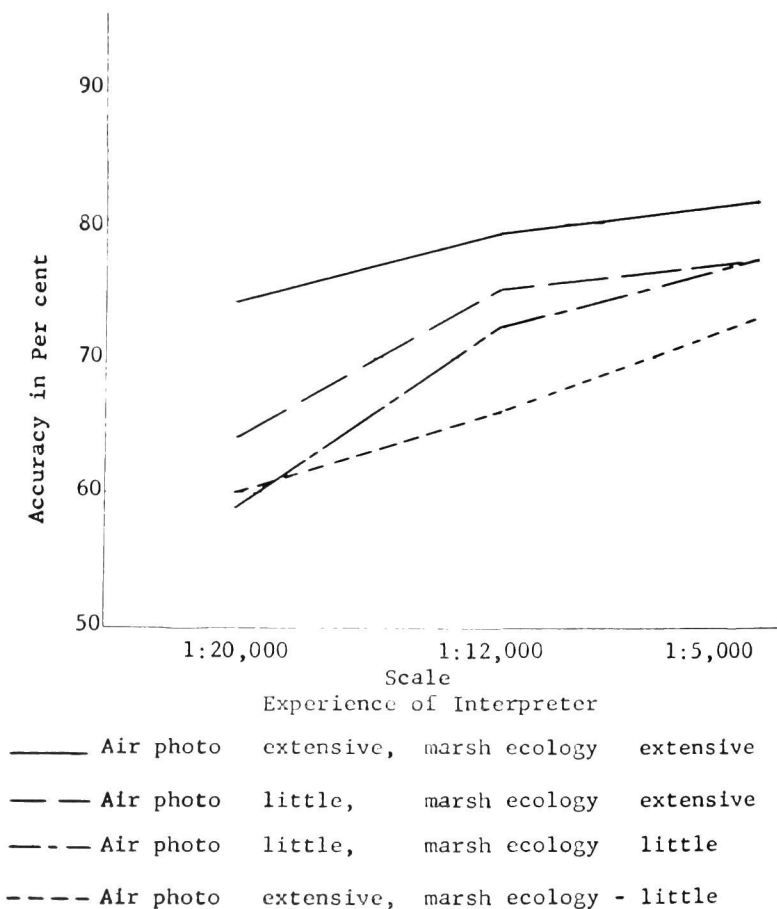


Figure 3
Relation Between Interpreter Experience and Scale in
the Identification of Marsh Vegetation

graphic images (photo reading). Both student interpreters were able to devote much more time to studying marsh ecology through the training aids than were the experienced interpreters. The higher scores obtained by the students seem to reflect this additional study. The experienced interpreters relied only a limited extent on ecological information, as obtained in a brief study of the training aids.

While developing the classification system, trial interpretations and field verification were possible for interpreter A. His higher scores at all scales indicated that these field verifications contributed to accurate interpretation. Interpretations made by the test personnel undoubtedly would have been more accurate had they been able to verify some of them in the field.

The photo interpreters with experience or training in marsh ecology interpreted nearly as accurately on the 1:12,000 photographs as on the 1:5,000 photographs. This indicates that, to some extent, more field experience is necessary to use smaller scales of photography. The wide range of accuracies obtained by the interpreters when using the 1:20,000 photography further supports this premise; also the interpreters without actual field experience stated they were uncertain of many identifications on the 1:20,000 photography.

Smaller differences in height were discernable with each increase in scale. With the exception of round stem bulrush and three-square bulrush, the heights detected in the vegetation corresponded with the calculated heights for each scale (figure 4). Apparently, leaves or inflorescence on the upper parts of the plants are necessary for height perception, and the leaves and/or inflorescence of round stem bulrush and three-square bulrush were not sufficient.

Photographic images

The physical structure of the plant is probably as important in producing the photographic images as the tone or color of the plant. The marsh types studied can be discussed in groups by physical structures.

Leafy-topped rushes and grasses

The characteristic images produced by leafy-topped rushes and grasses are medium in tone. The heights of these stands are evident. The stands of river bulrush on the photographs of Merrymeeting Bay (appendix I), and the stands of cane (*Phragmites communis*) on the photographs of the Delta Marsh, Manitoba⁹, are examples of such leafy-topped plants. Wildrice stands at maturity may produce images with light tones. Those at Merrymeeting Bay were usually flattened down

⁹ Aerial photographs of the Delta Marsh, Manitoba are included in appendix I to further illustrate some of the photographic images of marsh plants.

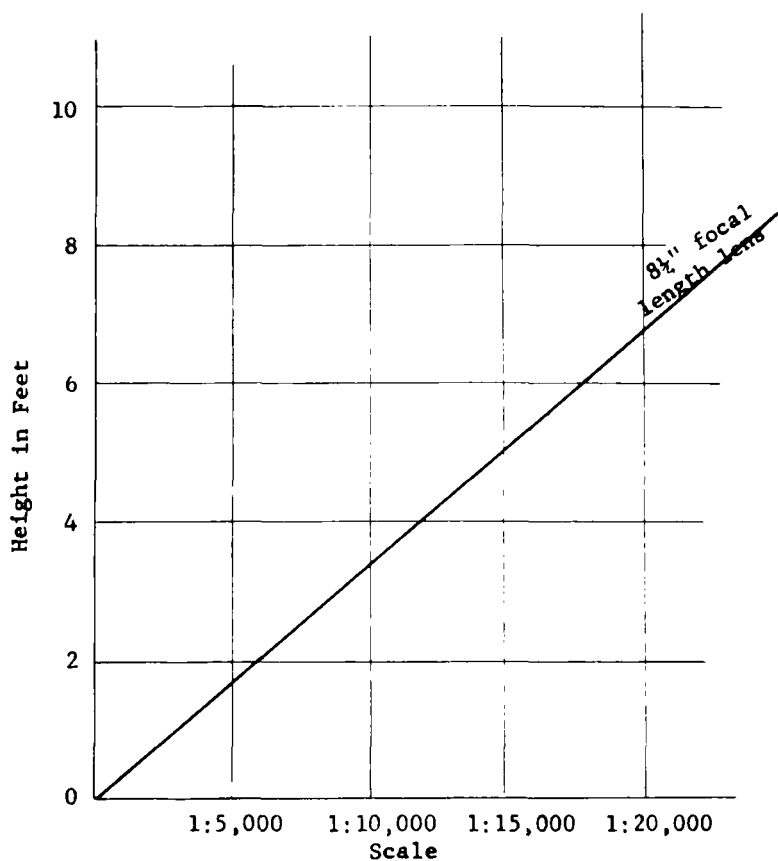


Figure 4

Calculated Height Perception for Photographic Scales
Employed in This Study

by wind and tidal action so that no height was obtained from their photographic images.

Bulrushes without leafy tops

The most characteristic feature of the images of round stem bulrush is that height cannot be determined unless the stand is extremely dense or the photography is of very large scale. The edges of the stands are usually indistinct. The tone is dark and the image appears to be formed by the shadows within the stands. The presence of shallow standing water darkens these images considerably; when the water is two feet

or more deep, as with hard stem bulrush (*Scirpus acutus*), the plants frequently cannot be seen. Stands of three-square bulrush produce images which are very diffuse and somewhat reticulated. The denser three-square bulrush stands tend to be confused, in the interpretation, with round stem bulrush; also, due to lack of height perception, both of these types are frequently confused with submersed aquatics.

Plants with sword-shaped leaves

Sweetflag stands have very dark tones (darker than bulrushes) and images with very sharp edges. The flattened, upright leaves produce more shadow than the round stem or three-square bulrushes. The height of these stands is discernible on large scale photography. Cattail (*Typha latifolia* and *Typha angustifolia*) stands which are labeled on the Delta photographs (appendix I) also have sharp, black images which are uneven in height. Several stands of giant burreed (*Sparganium eurycarpum*) were examined in the field and on the aerial photography. Their images were darker than the round stem bulrush images, but sharp edges were not discernible.

Plants with large flat leaves

Both yellow waterlily and pickerel weed stands produced granular photographic images and tones which were similar to the tone of the individual leaves. The reason probably is that these large-leaved plants reflect more light than most plants with small leaves. The granular image results from clusters of leaves. Height of these stands is evident only on large scale photography. In this study yellow waterlily and pickerel weed could usually be separated by differences in tone and texture.

Submersed aquatic plants

The most characteristic image features of submersed aquatic plants are lack of height and extreme variability in pattern and tone. At Merrymeeting Bay most of the submersed aquatics were exposed at low tide. Their images varied from solid or patchy areas to diffuse reticulations. When reticulations were present they tended to line up with the current or in the direction that the tide receded. Some tone differences were evident on all scales. Beds of submersed linear-leaved arrowhead (*Sagittaria spp.*) were always lighter. On 1:5,000 photographs several tones were evident in beds of submersed aquatics.

The depth to which one can see into water on aerial photographs influences the amount of submersed aquatics that can be observed. Several submersed aquatic beds at Merrymeeting Bay were not visible except on photography made at the lowest stage of tide. Species which grow to the surface are more likely to have discernible images. On the

Delta photography (appendix I), several beds of submersed aquatics with surface growth are labeled. If the three stereo pairs of Delta photographs are examined, it will be noted that the water in certain areas is lighter in tone and that beds of submersed aquatics are easily seen. These differences are due to planktonic algae. A light wind may also indicate beds of submersed aquatics with surface growth, because such growth disrupts the patterns which the wind ripples produce.

Duckweeds and algae

Duckweeds (*Lemna spp.*) have a high light reflectance and produce images with light tones and no height. As duckweeds are not rooted, they are found in places which are protected from the wind. Filamentous algae, which grow at the surface in stagnant waters, also reflect much light. Study of the Delta photography indicated that these duckweeds and algae are likely to be confused. Also, because of their light tones, such areas may be confused with sand and mud flats. Duckweeds are annotated on the aerial photographs of the Delta marsh in appendix I.

Sand and silt

Images of sand are very light in tone and usually have a characteristic pattern. On bars the pattern is rippled and wave-like, and along shore lines the pattern is smooth. Certain areas in this study were elected to test confusion of sand images with those of flattened, dense wildrice. Little confusion was noted.

On the Merrymeeting Bay photographs, silt images were usually medium in tone and with or without a pattern. If a pattern was present it consisted of diffuse reticulations that paralleled the channels or bays. These reticulations resulted from areas of fine sediments on the surface of the silt. Silt or mud flats have a very high light reflectance on some photography; consequently, they appear very light in tone and can be confused with other light-toned images.

Mixed vegetation

Two kinds of mixtures were evaluated in this study. One was a rather coarse mixture of vegetative types, such as round stem bulrush and pickerel weed, and the other was the high tide zone, a finely integrated mixture of many species.

In the mixtures of types the correct identity was stated more often when the tones of the components were dissimilar. Mixtures of similar tones tended to be identified as one of the components.

The high tide zone was composed of many species, none of which could be recognized. The tone and texture were both very even, prob-

ably because of the finely integrated nature of the type. The white top sloughs on the Delta photographs are also examples of finely integrated mixtures.

Review of literature

The use of aerial photographs for the study and mapping of wetlands is not new. They have been used to identify these areas and to map the broad ecological zones within various kinds of wetlands. Some of the previous studies have recognized species of plants on aerial photographs as indicators of the ecological zones. However, no quantitative evaluation of such interpretation was found in the literature.

Several workers have described the use of aerial photographs in mapping vegetation of marsh areas. In Massachusetts, MacConnell and Garvin (1956) recognized five types of fresh wetlands and one of salt marsh. Their classification is based in part on the wetlands classification which was set up by Martin, *et al.* (1953). Dalke (1937) stressed the value of aerial maps and ecological principles in mapping vegetation, and described the mapping of ecological zones such as submersed vegetation, floating leafed species, and also rushes and cattail. Nicholson and Van Deusen (1953) recognized six types of coastal marshes in Maryland. However, the aerial photographs were used chiefly for delineating major plant zones, and identification of the plant composition of these zones was made in the field. O'Neill (1953) studied the vegetative types in the Chesapeake Bay area. He constructed a set of keys for interpreting ecological zones in coastal marshes during the four seasons of the year. In the Wetlands Survey of Maine (1954) aerial photographs were used primarily for locating marsh areas. Zohari, *et al.* (1955) studied tone differences on aerial photographs of papyrus stands in the Hula Marshes of Israel. They were unable to find a relation between density of plants and tone of photographic images.

Tundra and range vegetation have some photographic characteristics which may apply to marsh vegetation. Churchill (1951) studied aerial photographs of tundra vegetation. He found considerable variation in the photographic images and was unable to establish the reliability of using aerial photographs of tundra vegetation. The Manual of Photogrammetry (1952) indicates that species composition and density of range vegetation can be mapped by using aerial photographs in part and field identification in part. Colwell (1946, 1948) demonstrated that several kinds of tropical crops and natural low vegetation could be identified on aerial photographs.

Cameron (1950) identified seaweed beds off the coast of Nova Scotia on panchromatic and color photography. He recommended pan-

chromatic film with a green filter for general survey procedure. With this film/filter combination, seaweed beds in water up to four fathoms deep could be mapped. In low-altitude continuous-strip photography he found color transparencies superior to panchromatic prints. Several other comparisons of film material have been made; however, none of these were on photographs of marsh vegetation. Young (1953) counted plots of trees using infra-red prints, infra-red positive transparencies and color transparencies and found no significant differences between films. Shulte (1951) evaluated infra-red prints, panchromatic prints, and color transparencies for identification of tree species in southeastern Canada. He found that infra-red was superior to, and panchromatic about equal to, color transparencies. Spurr and Brown (1946) also found that infra-red was superior to panchromatic and color positive films for tree identification, but that color, when properly processed, was superior to panchromatic.

Young (1953) compared the accuracies of counting trees on several scales of photography and reported a 20 per cent overall increase in accuracy between 1:15,840 and 1:3,500. Spurr (1948) reviewed the scales of photography which are commercially available and recommended 1:15,840 for general forestry work, and larger scales for more detailed interpretation. On the basis of accumulated research information, Stone (1956) suggested that species of brush and grass, and specific crops could be identified at scales larger than 1:10,000.

The military photo interpretation schools recognize that a familiarity with the subject being interpreted is an aid to accurate interpretation (Gardner, 1948). Military photo interpreters are trained in a series of phases, each of which covers one subject. During a particular phase a student learns what the subject looks like on aerial photographs, and he also becomes familiar with it on the ground.

Pomeroy and Cline (1953) studied the preparation of soil maps by various persons. They found that if a person had no field experience in the area being mapped his accuracy was lower than that of a person with field experience. They also found that as areas increased in complexity the accuracy of mapping decreased. DeLancie, *et al.* (1957) also evaluated the factor of experience in their study of photo interpretation keys. When interpreting naval vessels and abstract objects, inexperienced photo interpreters scored as well as the experienced photo interpreters, but the experienced photo interpreters had a higher accuracy when interpreting vegetation.

Literature Cited

- American Society of Photogrammetry. 1944. *The Manual of Photogrammetry*. Banta Publishing Co., Menasha, Wisconsin.
- Cameron, H. L. 1950. The Use of Aerial Photography in Seaweed Surveys. *Photogrammetric Engineering*, 16 (4):493-501.
- Colwell, Robert N. 1946. The Estimation of Ground Conditions from Aerial Photographic Interpretation of Vegetation Types. *Photogrammetric Engineering*, 12 (2): 151-161.
- . 1948. Aerial Photographic Interpretation of Vegetation for Military Purposes. *Photogrammetric Engineering*, 14 (4): 472-481.
- . 1954. A Systematic Analysis of Some Factors Affecting Photographic Interpretation. *Photogrammetric Engineering*, 20 (3): 433-454.
- Churchill, Ethan D. 1951. Plant Community Studies and Plant Ecological Aerial Photographic Interpretation at Umiat, Alaska. *Proceedings of the Biological Section of the Annual Meeting of the American Association for the Advancement of Science*, Philadelphia, Pennsylvania.
- Dalke, Paul D. 1937. The Cover Map in Wildlife Management. *Jour. Wildl. Mgt.*, 1 (4):100-105.
- DeLancie, R., W. W. Steen, R. E. Pippen, and A. Shapiro. 1957. Quantitative Evaluation of Photo Interpretation Keys. *Photogrammetric Engineering*, 23 (5):858-864.
- Fernald, M. L. 1950. *Gray's Manual of Botany*. American Book Co., New York.
- Gardner, J. W. and S. M. Johnson. 1948. Training Activities of the Naval Photographic Interpretation Center. *Photogrammetric Engineering*, 13 (3):352-358.
- Hotchkiss, Neil. 1950. Check-list of Marsh and Aquatic Plants of the United States. *Wildlife Leaflet No. 210*, U. S. Fish and Wildl. Serv.
- MacConnell, William P. and Lester E. Garvin. 1956. Cover Mapping a State from Aerial Photographs. *Photogrammetric Engineering*, 22 (4):702-707.
- Martin, A. C., Neil Hotchkiss, F. M. Uhler, and W. S. Brown. 1953. Classification of Wetlands of the United States. *Special Scientific Report, Wildlife No. 20*, U. S. Fish and Wildl. Serv.
- Moessner, Karl E. 1954. A Simple Test for Stereoscopic Perception, Floating Circles Stereogram. *Technical Paper 144*, Central States Forest Experiment Station.
- Nicholson, William R. and R. D. VanDeusen. 1953. Vegetative Type Mapping of Eastern Shore and Atlantic Coastal Marshes in Maryland. *Proc. 9th Annual Conf. Northeast Wildl. Soc.*, pp. 1-6.
- O'Neill, Hugh. 1953. Investigation of Methods of Determining Terrain Conditions by Interpretation of Vegetation from Aerial Photography, Part II. *Arctic Institute, Catholic University of America*.
- Pomeroy, James A. and Marlin G. Cline. 1953. The Accuracy of Soil Maps Prepared by Various Methods that Use Aerial Photograph Interpretation. *Photogrammetric Engineering*, 19 (5):809-817.
- Ray, Richard A. and William A. Fischer. 1957. *Geology from the air*. Science, 126(3277):726-735.
- Shaw, Samuel P. and C. Gordon Fredine. 1956. Wetlands of the United States. *Circular 39*, U. S. Fish and Wildl. Serv.
- Schulte, O. W. 1951. The Use of Panchromatic, Infra-red, and Color Aerial Photography in the Study of Plant Distribution. *Photogrammetric Engineering*, 17 (4):688-714.

- Snedecor, George W. 1937. Statistical Methods. Collegiate Press, Inc., Ames, Iowa.
- Spurr, Stephen H. 1948. Aerial Photographs in Forestry. Ronald Press Co., New York.
- Spurr, S. H. and C. T. Brown, Jr. 1946. Specifications for Aerial Photographs Used in Forest Management. Photogrammetric Engineering, 12 (2):131-141.
- Stone, Kirk H. 1956. Air Photo Interpretation Procedures. Photogrammetric Engineering, 22 (1):123-132.
- U. S. Fish and Wildlife Service. 1954. Wetlands of Maine. U. S. Dept. of the Interior, Office of River Basin Studies, Region V, Boston, Mass.
- Young, Harold E. 1953. Tree Counts on Air Photos in Maine. Photogrammetric Engineering, 19 (1):111-116. 1956. Personal Communication.
- Young, Harold E. and Ernest G. Stoeckeler. 1956. Quantitative Evaluation of Photo Interpretation Mapping. Photogrammetric Engineering, 22 (1):137-143.
- Zohari, M., G. Orshan, H. V. Muhsam, and M. Lewin. 1955. Weight Estimate of the Papyrus Culms Growing in the Hula Marshes. Bull. of the Res. Council of Israel, 5C (1).

Appendix I

Aerial Photography

Six stereo pairs of aerial photographs illustrate some of the problems discussed.

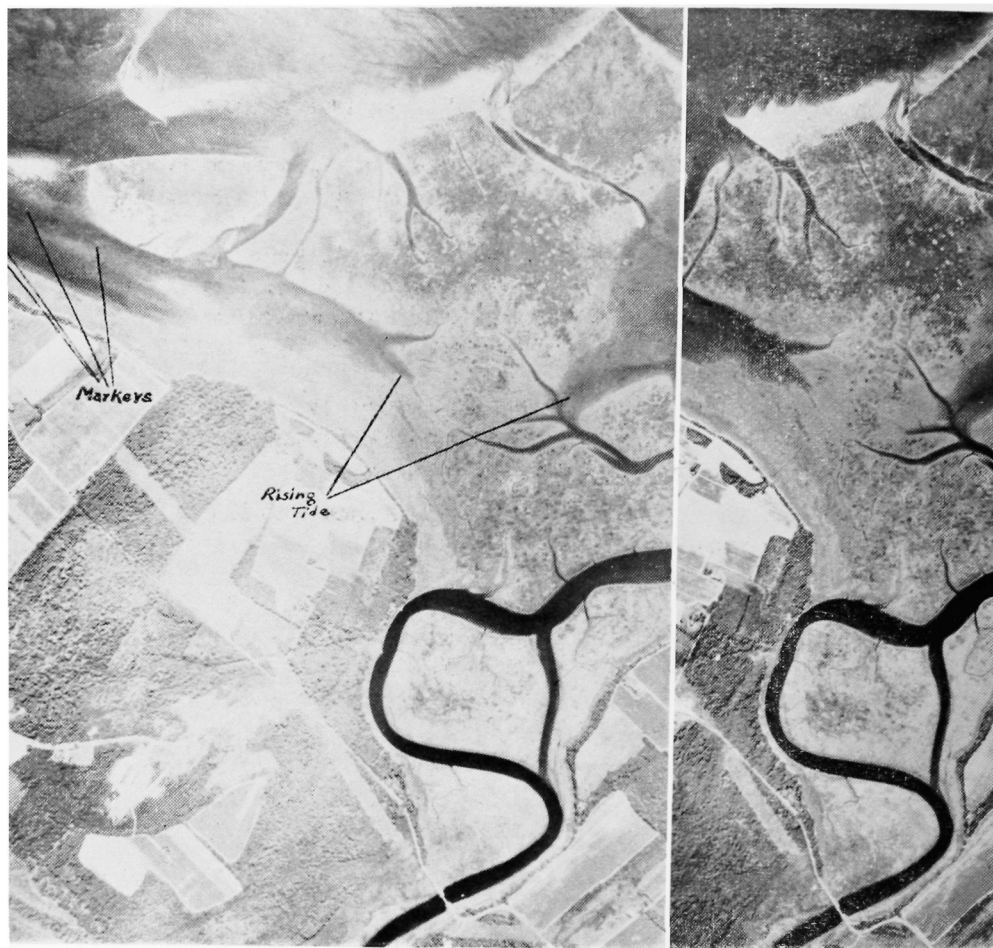
The first three sets are panchromatic prints of a portion of the Merrymeeting Bay study area. Some of these areas were used in the interpretation tests.

The last three sets are panchromatic prints of the De'ta Marsh, Manitoba. While they are not a part of this study, they have been included to supplement the illustrative material. Information concerning these was obtained by the author while assisting S. T. Dillon in field work on the area in 1956.

The photographic images, which are separated by 2 1/8 inches, allow stereo vision for the average range of interpupillary distances.

Annotations used on the photography are as follows:

Wildrice — Wr	Submersed aquatics — Sub
Round stem bulrush — Rs	Sand — Sand
River bulrush — Rb	Silt — Silt
Sweetflag — Sf	Duckweeds — Du
Yellow waterlily — Wl	Phragmites (cane) — Ca
Pickereel weed — Pw	Cattail — Ct
High tide zone — Ht	White top sloughs — Wt
Three-square bulrush — 3 sq	



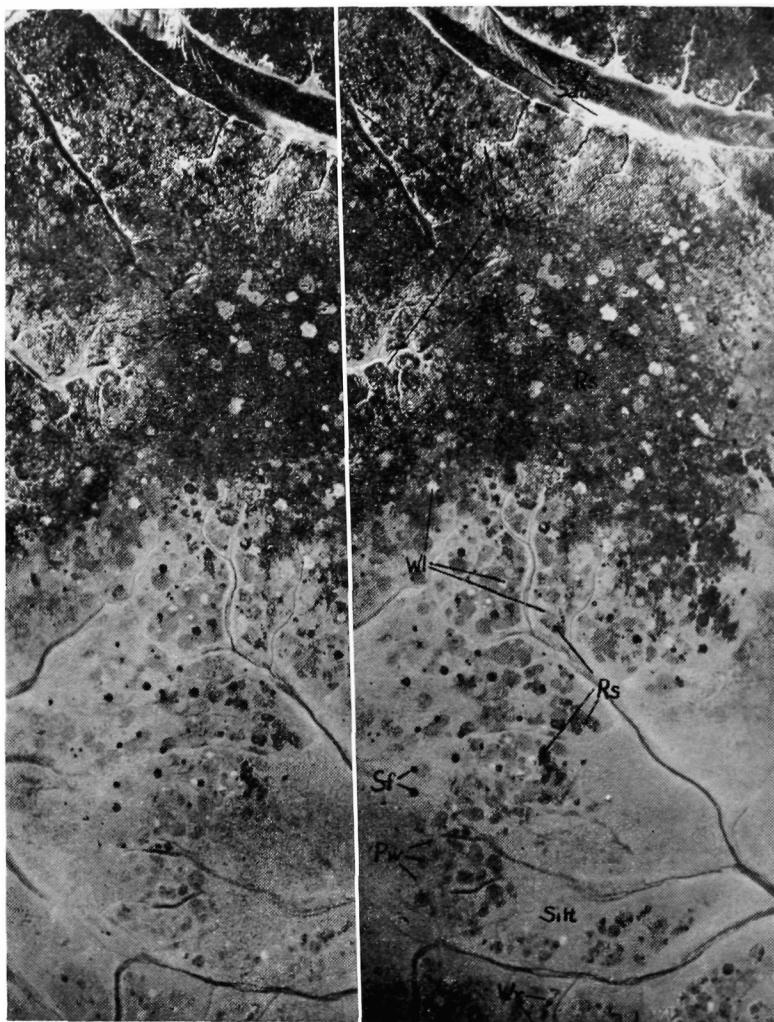
Panchromatic Aerial Photographs of Merrymeeting
Bay, Maine, Scale—1:20,000
Date—August 25, 1957

Note:

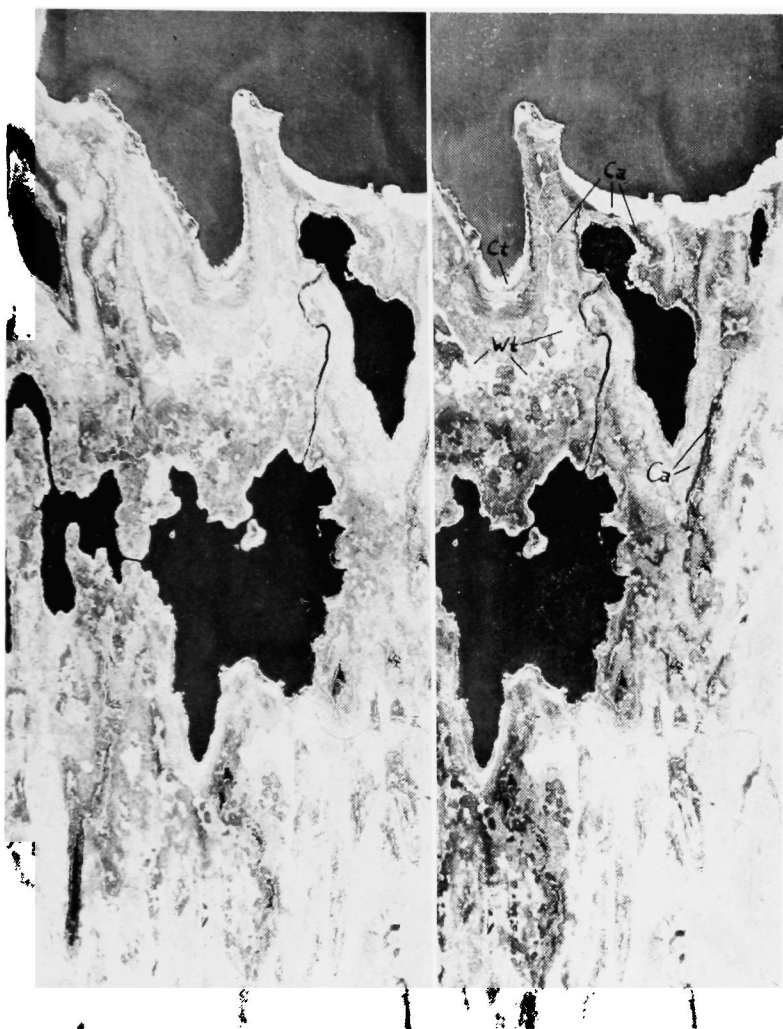
1. Surface markers of tests for photographic penetration of water.
2. Increase in area covered by water of rising tide as compared to the 1:12,000 and 1:5,000 photographs.



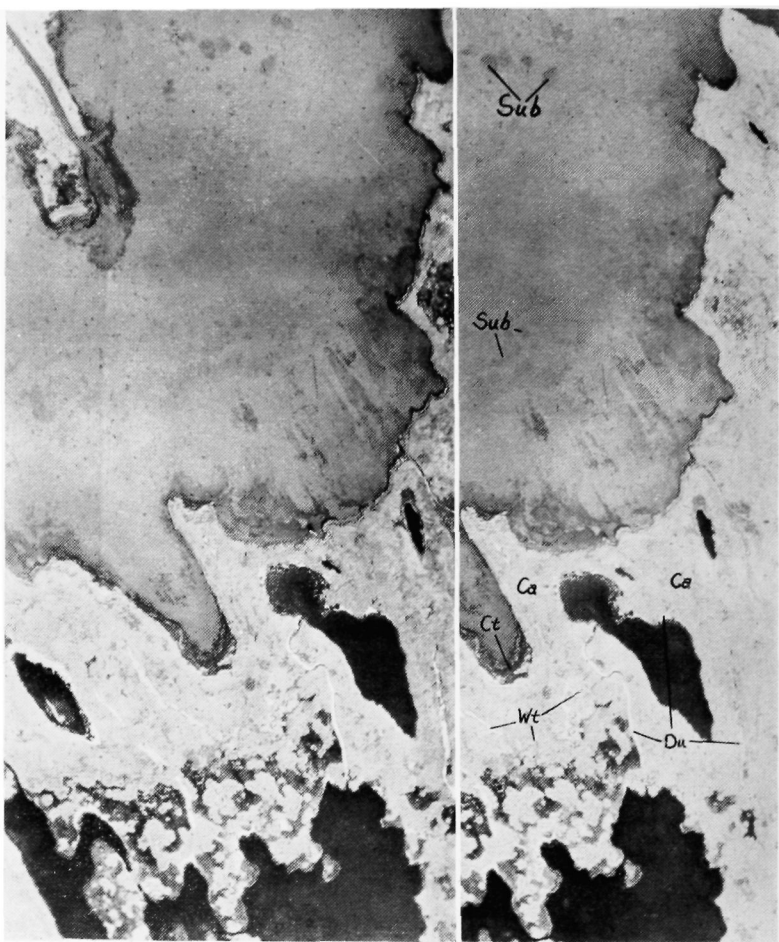
Panchromatic Aerial Photographs of Merrymeeting
Bay, Maine, Scale—1:12,000
Date—August 25, 1957



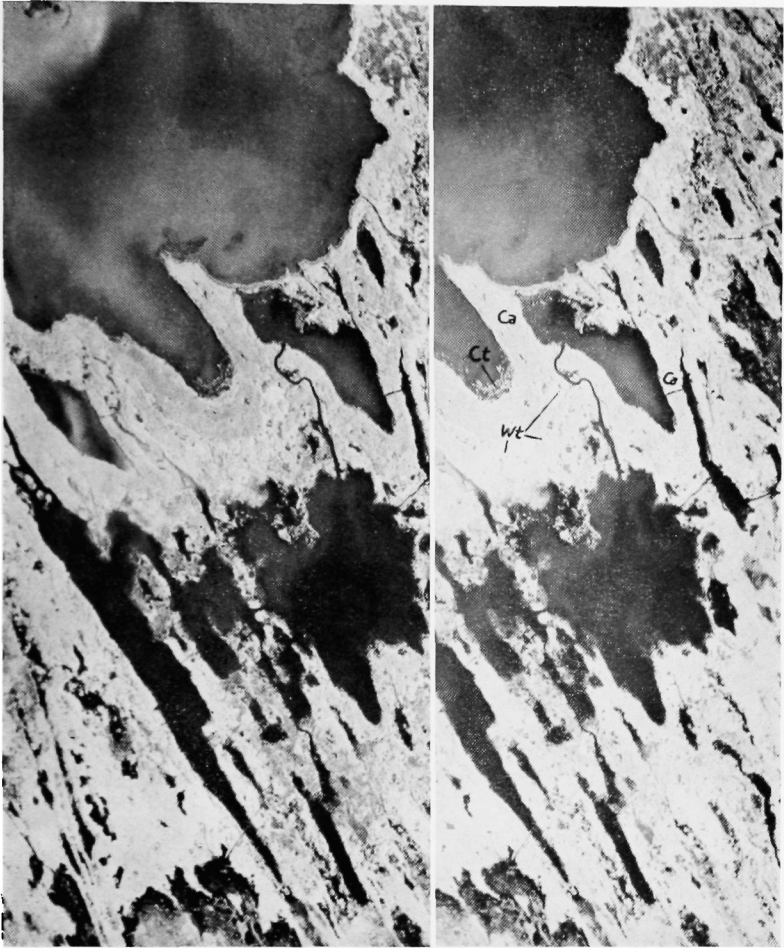
Panchromatic Aerial Photographs of Merrymeeting
Bay, Maine, Scale—1:5,000
Date—August 25, 1957



Aerial Photographs of the Delta Marsh, Manitoba Taken in
Early Spring at Normal Water Level. Scale—1:15,840
Date—May 8, 1946



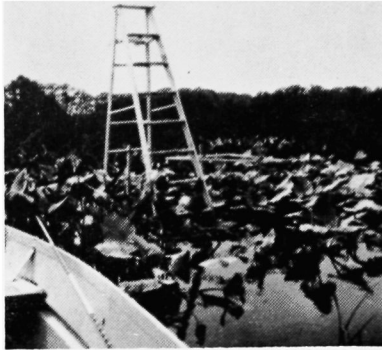
Aerial Photographs of the Delta Marsh, Manitoba Taken in
Late Summer at Normal Water Level, Scale—1:17,000
Date—September 1, 1948



Aerial Photographs of the Delta Marsh, Manitoba Taken in
Late Summer at High Water Level, Scale—1:20,000
Date—September 3, 1954

Appendix II

Descriptions of the Eleven Classifications of Marsh Vegetation Interpreted



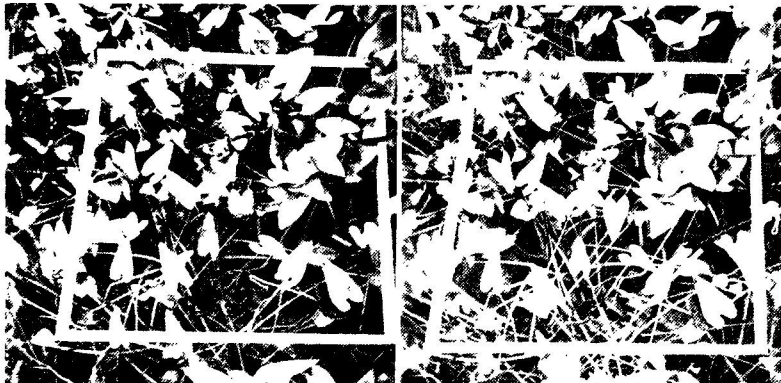
Type: Yellow Waterlily (W1)

Photographs: A medium-dense stand just as the tide was flooding.

Description: In addition to the waterlily or spatter dock, this type contains occasional stems of round stem bulrush, three-square bulrush, submersed aquatics, and wildrice. It grows in sparse patches on exposed areas, as medium to dense patches in other vegetation, and as extensive beds in protected coves. The soil is usually silt or sandy silt, and it is found in association with all of the types except sand.

Image Characteristics: This type has a very granular image which is green or yellow-green on color films, and a medium gray on panchromatic films. Height is evident only at scales of 1:5,000 and the granular texture may not be noticed at scales of 1:20,000.

Remarks: The round or lobate patches of this type, which occur in most situations, and the large unbroken stands of waterlily suggest that this is a very successful species on the study area.



Type: Pickerel Weed (Pw)

Photographs: Sparse stand on silt flat (left). Dense stand (right)

Description: Pickerel weed usually occurs in pure stands, but there may be a few submersed aquatics present. It seems to be a pioneer species, for it grows regularly on open areas of silt as lobate patches and along edges. The soil is usually silt, and it is associated most often with three-square bulrush, submersed aquatics, round stem bulrush, sweetflag, and waterlily.

Image Characteristics: Pickerel weed has a slightly granular image and is usually medium to dark green on color photography, and medium gray on pan-chromatic photography. The edges of stands are usually distinct.

Remarks: Pickerel weed seems to be a pioneer type, because it is frequently found on open areas of silt or edges, and it is seldom found in dense vegetation.



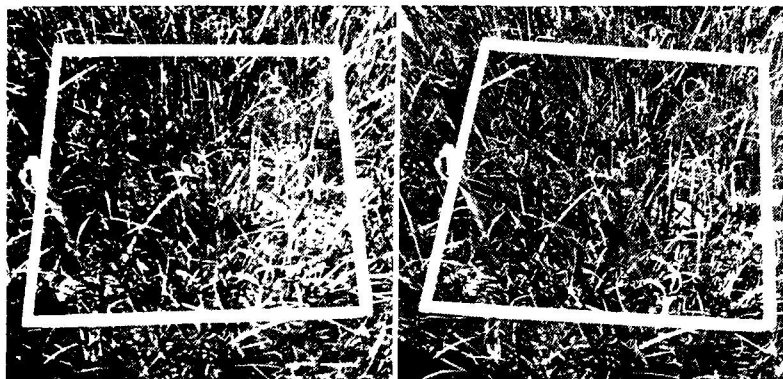
Type: Three-square Bulrush (3 sq)

Photographs: Sparse stands of three-square bulrush on silt. Notice submersed aquatics.

Description: Frequently mixed with submersed aquatics and always grows on areas of open silt or along edges. This type does not grow in dense stands.

Image Characteristics: Indistinct pale green areas on color films, and indistinct medium gray areas on panchromatic films. This image is very "fuzzy," but it may be quite distinct in some stands near the high water areas.

Remarks: Very hard to separate from sparse submersed aquatics, or silt.



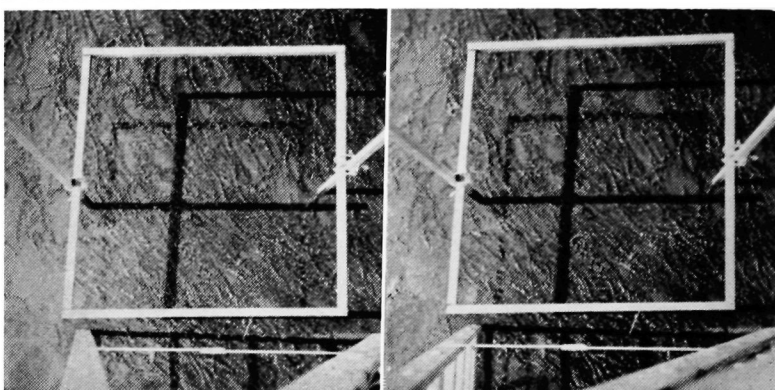
Type: Sweetflag (Sf)

Photographs: A dense clump of sweetflag growing on an open silt area.

Description: Sweetflag usually occurs in dense, pure stands, but occasionally stems of wildrice, round stem bulrush, three-square bulrush, and submersed aquatics are found. It is found most often with silt, pickerel weed, round stem bulrush, and waterlily, and it grows on silty soils.

Image Characteristics: The texture is smooth and the edges of the stand are sharp. This is the darkest image (dark green or black) found on any of the photography. Height is not visible at scales of less than 1:5,000. Stands are mostly round or lobate, but they may be reticulate.

Remarks: Sweetflag grows most thriftily in open areas where its stands are round or lobate. Frequent "doughnut" shaped stands indicate that it creates conditions in the center that are unfit for its own growth. In areas of mixed dense vegetation, sweetflag stands are usually reticulate or irregular in form.



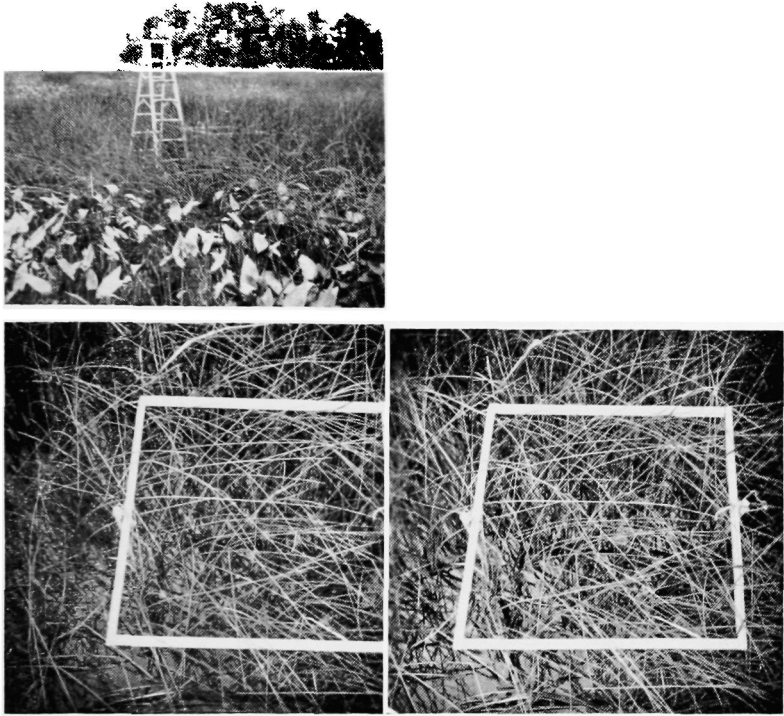
Type: Submersed Aquatics (Sub)

Photographs: Dense beds of claspingleaf pondweed (*Potamogeton perfoliatus*)

Description: Submersed aquatics grow on silty soils and are always found in the water or on areas that are exposed the least by low tides. This classification includes all the submersed species found on the study area. The types most frequently found with submersed aquatics are silt, three-square bulrush, and round stem bulrush.

Image Characteristics: Extremely variable. Occur as patches, strings, or solid beds. Color (green) and shades of gray are variable. Frequently there is a reticulate pattern with most lines running in the direction of the tide.

Remarks: Association with water or low tide is a definite aid in interpreting submersed aquatics. Variations in color suggest some species identification may be possible.



Type: Round Stem Bulrush (R_s)

Photographs: Dense stand of round stem bulrush

Description: Occurs mostly as pure dense stands in protected areas and as sparse stands in exposed areas. Frequently stems of wildrice are found in and near round stem bulrush stands. This is the plant at exposed sandy edges. It grows on either sand or silt and is usually associated with wildrice, submersed aquatics, silt, sand, and river bulrush.

Image Characteristics: The most characteristic feature of round stem bulrush images is that height cannot be detected at any of the scales tested. The images are blotchy and dark and have indistinct edges. Dark green on color, and dark gray on panchromatic.

Remarks: Occasionally many plants in a stand will be bent over, and heights of such stands can be seen.



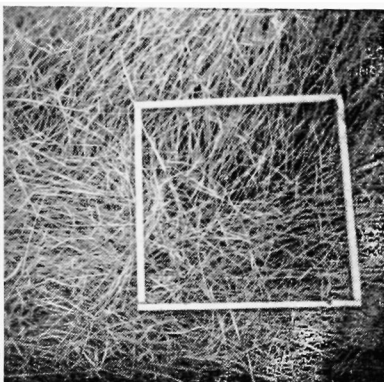
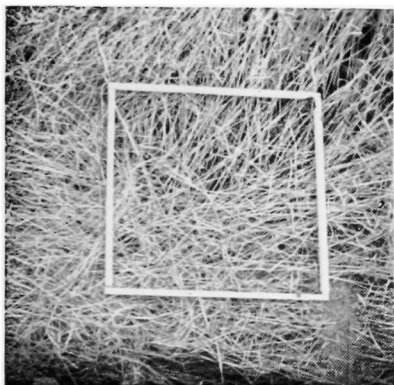
Type: High Tide Zone (Ht)

Photographs: General and detailed views

Descriptions: This type is the "shallow fresh coastal marsh" described by Shaw and Fredine (1956). It always occurs near the high tide limit along shores. Plants composition is variable, but it usually includes scattered wildrice, three-square bulrush, and spike rush (*Eleocharis* spp.). Soil type is either sand or silt.

Image Characteristics: Smooth tones of gray on panchromatic photography, and amber colors on color photography indicate this area.

Remarks: Very easily interpreted because of location and color. Widely different plant compositions in this area produce similar photographic images.



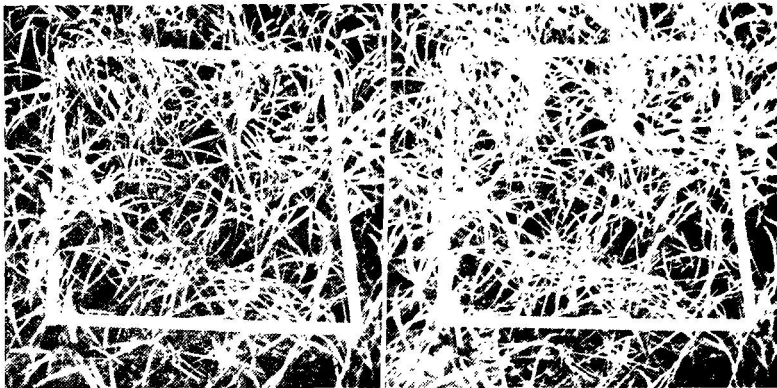
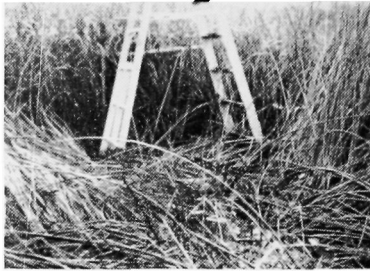
Type: Wildrice (Wr)

Photographs: Dense stands of wildrice (prostrated by the tides).

Description: Usually occurs as pure dense stands and, as on this photography, it is usually prostrate. Typically found in protected coves with soft silt bottoms. The high tide zone and yellow waterlily are most often associated with wildrice.

Image Characteristics: Images usually have no height, or the rice appears to lean on other vegetation. Wildrice appears white on panchromatic photography and yellow-green or yellow on color photography.

Remarks: Some areas of standing wildrice may be present. These areas have light colored, uneven images and the height is evident.



Type: River Bulrush (Rb)

Photographs: A patch of river bulrush within a larger stand of round stem bulrush.

Description: Grows in dense stands. Usually in areas of round stem bulrush, waterlily, and wildrice. Usually the river bulrush stands do not have any other species mixed with them. The soil material is commonly silt.

Image Characteristics: The leaves are primarily at the tops of these plants and they produce a very noticeable height on the photographic image. The texture of the photographic image is smooth with occasional pits.

Remarks: Difficult to see height on 1:20,000 photography, but very definite heights on 1:5,000 and 1:12,000 scales. Always occurs within a vegetated area.



Type: Silt (silt)

Photographs: Stereo pair of a typical silt flat showing blotches or streaks.

Description: This type consists of silt flats barren of vegetation, or with extremely sparse growth. Commonly found near water and with three-square bulrush or submersed aquatics.

Image Characteristics: Smooth in texture. On color silt appears brown or purple-brown, and on panchromatic photography it has a medium gray tone. Reticulations are often present, and they parallel the channels.

Remarks: When silt areas have considerable sand present they may appear very light.

No Photographs Available

Type: Sand (sand)

Photography: None

Description: Areas of granular quartz sand, which support little vegetation except round stem bulrush and three-square bulrush. Usually bare sand is found along the edges of channels or in open water areas where there is considerable wave action.

Image Characteristics: Very light due to large amounts of reflected light. On panchromatic photography the sand areas are usually white, and on color they are pale yellow-brown. Frequently has scalloped surfaces due to wave action.

Remarks: Found only in areas with strong currents.

Appendix III

Description of the Line Intercept Sampling Method

In an attempt to describe accurately the plant composition of the test areas, the following modification of the line intercept sampling procedure was employed.

Materials:

1. One steel rod ten feet long and $\frac{3}{8}$ -inch in diameter, on which each 1-foot, and each 1/10-foot unit was marked (see photograph, page 53).
2. Two wooden stakes four feet long with adjustable loops to support the ends of the rod.
3. Mimeographed cards on which to record data (see sample card, page 53).

Procedure:

The location of the rod within each area to be sampled was selected randomly. The rod was passed through the vegetation, or over it, and supported at both ends by the stakes. Care was taken not to alter the position or composition of the plants prior to recording data.

Each species that occurred above or below a 1/10-foot unit was marked "one." Data were recorded for each 1-foot unit, and totaled for the 10-foot sample. The height of the rod above the ground was adjustable to three feet, but frequently data for taller species had to be estimated. Visual examinations were made in the areas around the samples, and any species not included in the samples were recorded. Estimates of density (sparse, medium, and dense) were also made for each species.

The information obtained was species composition, an approximation of the per cent of ground covered by each species, and an index of frequency.

Advantages of Method:

1. Rapid to use (about five minutes for a 10-foot sample).
2. One person can use it effectively.
3. Suitable for plants of different heights.
4. Does not disturb sample area prior to recording data.
5. Results vary little between observers (five trials of two persons averaged 1 per cent difference).

Disadvantages of Method:

1. Per cent of ground covered is exaggerated for some species which occur sparsely.
2. Per cent of ground cover is exaggerated when species such as wildrice are prostrate.
3. Estimations have to be made for the taller species.



Sampling Rod in Sparse Three-Square Bulrush

Area:			Sample No.							Date				
Plant Assoc:					Soil Type:									
Wind:		Foot Number:								C*	T*	D*	Remarks	
Species	1	2	3	4	5	6	7	8	9	10				
Other Species found:														

*C – percent of cover; T – Discernible height; D – Density

Example of Card for Recording Sampling Data

Appendix IV

Statistical Analysis

Analysis of Variance

Photo Interpretation Accuracy in Terms of Films, Scales,
and Interpreter Experience for Test Areas
on Merrymeeting Bay, Maine

Due to:	Degrees of freedom	Sum of square	Mean square	F ratio	Significance
Film	3	27.063	9.021	0.743	
Scale	2	2053.16	1026.583	84.583	**
Interpreter experience	3	230.230	76.743	6.323	*
Error	39	473.340	12.137		
Total	47	2,783.800			
Correction factor	1	22,945.020			
Grand total	48	232,279			

**Significant at the 99 per cent level.

*Significant at the 95 per cent level.

Analysis of Variance

Photo Interpretation Accuracy in Terms of Films and
Interpreter Experience at a Scale of 1:20,000 for
Test Areas on Merrymeeting Bay, Maine

Due to:	Degrees of freedom	Sum of square	Mean square	F ratio	Significance
Film	3	40.663	13.554	0.62	
Interpreter experience	3	82.688	27.563	1.27	
Error	9	157.087	21.227		
Total	15	275.438			
Correction factor	1	58,201.562			
Grand total	16	58,477			

Analysis of Variance

Photo Interpretation Accuracy in Terms of Films and
Interpreter Experience at a Scale of 1:12,000 for
Test Areas on Merrymeeting Bay, Maine

Due to:	Degrees of freedom	Sum of square	Mean square	F ratio	Significance
Film	3	102.792	39.264	2.50	
Interpreter experience	5	350.375	70.075	5.27	*
Error	15	199.458	13.297		
Total	23	652.652			
Correction factor	1	120,550.395			
Grand total	24	121,211.000			

*Significant at the 95 per cent level.

Analysis of Variance
Photo Interpretation Accuracy in Terms of Films and
Interpreter Experience at a Scale of 1:5,000 for
Test Areas on Merymeeting Bay, Maine

Due to:	Degrees of freedom	Sum of square	Mean square	F ratio	Significance
Film	3	8.188	2.729		
Interpreter experience	3	52.438	17.479	3.07	
Error	9	51.312	5.701		
Total	15	114.938			
Correction factor	1	92,264.062			
Grand total	16	92,379.000			

Appendix V

Results of a Survey of the Costs of Aerial Photography

Cost of aerial photography is based primarily on the length of time the photographic aircraft is in the air. Other factors which affect cost to a lesser extent are flying weather, work load, season, size of area covered, type of film material, and exactness of specifications.

In January, 1958, a letter-type questionnaire was circulated to 12 aerial photographic concerns in the United States and Canada to obtain general information on costs and capabilities. Seven of these letters were answered and returned. Costs are extremely variable and change particularly with time; the information here presented should be evaluated accordingly.

Estimates of costs for photographing 36 square miles with 1:20,000 panchromatic film varied from \$285 to \$1,440. Most of the estimates were between \$500 minimum and \$1,000 maximum.

The costs for photographing one square mile at the same specifications were also requested. These estimates varied from \$50 to \$350 if flown at the photographer's convenience, and from \$75 to \$500 if flown at the customer's convenience.

Most of the concerns indicated that costs vary by season, flying weather, and work load.

A general rule has often been stated that "as scale is doubled cost is quadrupled." Two of the concerns agreed with this rule. The other five concerns estimated doubling or tripling of cost as scale doubled. Five of the concerns indicated that they could take aerial photographs on color transparencies, and four indicated that they could expose and process the color print material.

Estimates of the additional costs for color photography varied from a flat rate of \$50 to \$100, or 20 to 100 per cent more than panchromatic. It should be pointed out that with large flying contracts, the extra cost of color is absorbed by the large size of the job.

In summary, the primary factor in costs of photography is the length of time the aircraft is airborne. Costs can be expected to double, triple, or quadruple for each doubling of scale. Costs for color photography are higher when small amounts of photography are taken.

Information Received on Seven Letter Questionnaires to
Aerial Photographic Concerns

1. What is your estimate for flying 36 square miles of stereo coverage with the following specifications?
 - a. 1:20,000 scale
 - b. panchromatic film
 - c. six inch focal length
 - d. within 100 mile radius of your airport
 - e. normal amount of overlap, number of prints, mosaics, etc.

Maximum price	Minimum price
\$1,440	\$900
1,200	750
1,000	750
1,000	500
750	500
500	350
285	250

2. What will the cost be to cover one square mile at the above specifications?

At your convenience	At the customer's convenience
\$ 75	\$100
200	350
350	500
200	500
75	75
100	200
50	110

3. Will the cost vary with work load (yes 5, no 2), season (yes 6, no 1), and flying weather (yes 7, no 0)?
4. A general rule has been stated that as scale is doubled cost is quadrupled. Do you agree with this statement (yes 2, no 5)? If not, can you cite a figure? Doubled 3, Tripled 1, Doubled to tripled 1.
5. Does your firm have the capacity to expose and process the following?
 - a. color positive aerial photography, i.e., Ektachrome
yes 4, no 2, limited 1
 - b. color negative materials, i.e., Ektacolor
yes 4, no 3

6. How much more would the 36 square miles of coverage mentioned in question No. 1 cost if flown in color positive aerial photography?

Answers:

no figure available

20 per cent

we don't do color photography

1.5 to 2.0 X

\$50 maximum

\$100 maximum

Appendix VI

Suggestions for Obtaining and Interpreting Air Photos of Marsh Vegetation

Use of existing photography

Practically all of the United States and large portions of Canada have been photographed from the air one or more times; prints of most of this photography are available at prices much below that of new material. When planning to obtain photographs of an area, one should consider these prior coverages. Frequently, the date, season, or scale of prior coverages is unsuitable, but in most cases some information can be obtained and in a few cases prior coverages are very useful. The table on page 62 contains a list of scales commonly available, descriptions of what the photography is used for, and some information as to how extensive it is.

Examination of vegetation

If existing photographic coverages are not available or not useful, new photography may be considered. Before ordering new photography, the structure, color, and tones of the vegetation should be examined in the field. These comparisons may indicate how useful a new photographic coverage would be.

In Merrymeeting Bay, vegetation at distances of 100 yards appeared either as patches of one species or mixtures of many species, which were mostly unidentifiable. On aerial photographs of the same area the "patches of species" could be recognized, but the mixtures could only be recognized as such.

It is doubtful whether areas of very sparse plant growth can be recognized on aerial photographs.

Selection of film

Panchromatic aerial photographs were less expensive, more easily obtained, and as useful for interpretations of this type as the other three films. Based on the results which Cameron (1950) obtained with seaweed, it may be advisable to employ a green filter when areas of submersed aquatics are photographed. Also, it may be advisable not to employ haze filters when water penetration is desired, as they tend to darken images of water.

Selection of scale

When selecting photographic scales, the information desired, the

experience of the person who will use the prints, and the costs¹⁰ of the photography should be considered. For mapping or non-quantitative evaluations of marshlands, 1:20,000 photography is adequate. It is an excellent scale for studying the broad ecological relationships within and between marshes, because nearly nine square miles can be viewed on each photograph. Most mapping of wetlands has been with photography of this scale. For detailed identification of plant species, scales of 1:15,000 or larger are advisable. In this study, interpreters who were familiar with marshes interpreted 1:12,000 photographs nearly as well as 1:5,000 photographs. For inexperienced personnel, the largest scale possible should be obtained.

Time of photography

When planning aerial photography of marshlands, or when using existing coverages, the date, time of day, and water level should be considered. The photographs of Merrymeeting Bay were taken at near maximum plant growth in late summer. Although there were no suitable coverages of different dates for comparison, these seemed to provide adequate information. Comparison of the Delta photographs made in spring and late summer (appendix I) indicates that interpretation is much easier with the latter. In the spring, *Phragmites* growth shows three different tones, and in summer it appears as one tone only. Likewise, in the spring, cattail and round stem bulrush stands are very light and hard to separate, and the submersed aquatics have not developed sufficiently to be seen. The white top sloughs, however, are more evident on the spring photographs.

For many purposes aerial photographs are best taken at mid-day. For marshes it is suggested that they be taken in the morning or afternoon. Marsh vegetation does not produce extensive shadows, while those that are produced are useful in interpretation. Also, as the sun's rays approach an angle of 90° the reflectance from water and wet surfaces will increase. Morning photography is preferable, because haze and clouds are usually less.

When photography has to be timed for low tides, and the range is four to six feet, the time of photography should not be more than one hour on either side of low tide.

In this study the presence of water in and around stands of vegetation made interpretation much more difficult. Therefore, it is suggested that aerial photographs of marshes be taken at low water levels. Water level fluctuations which last over considerable periods of time change both the amount of and species composition of the vegetation. While aerial photographs may be an important means of measuring these

¹⁰ In appendix IV the results of a survey concerning costs of aerial photography are presented.

changes, analysis of vegetation on photographic coverages should be made with consideration of water levels and time of photography. A comparison of photographs on pages 40 and 41 illustrates long-term water level changes and their effects.

Interpreter training

An adequately trained interpreter can work more accurately, more rapidly, and will have more confidence in his interpretations than an interpreter with insufficient training. Results of this study indicate that training in the use of a stereoscope can be obtained easily and quickly; also, that some field training, which may be self-acquired, is necessary, regardless of prior experience. Experience and training are usually acquired during the steps in the selection of a satisfactory classification system, but each set of interpretations and field checks adds to this training.

A classification system

Before accurate and efficient interpretation of vegetation can be performed, a satisfactory classification system must be devised. The steps necessary are the same in all photo interpretation studies. They consist of; examination of photographic images and the corresponding objects, selection of a tentative classification, trial interpretations, and field checks. Usually, repetition of these steps is necessary. All of the types in the classification system should be those which can be identified on aerial photographs. The situation with respect to three-square bulrush, described in this study is a good example of a classification which should not be included.

Field verification

Since photo interpretation is an art as well as a science, some errors are unavoidable (Young, 1953). For information obtained by interpretation to be properly assessed, the errors must be quantitatively determined by a series of field samples.

In this study, the true identity of all stands of vegetation was known. Obviously, this cannot be done in practical applications, but a field sample consisting of a number of stands of each type can be identified, and the accuracy of the sample applied to the photo interpretation results.

Scale Equivalents, General Usage, and Availability* of Aerial Photography

Reciprocal fraction	Equivalent	General uses	Availability
1:5,000	1" - 416'	Detailed interpretation. Town planning.	Limited, usually small areas.
1:7,920	1" - 660'	Forestry, detailed interpretation.	Limited, usually forest lands.
1:10,000	1" - 833'	Agriculture - crops.	Limited
1:12,000	1" - 1,000'	Highway planning. Detailed soils studies.	Very limited
1:15,840	1" - 1,320' 4" - 1 mile	Agriculture, forestry mapping.	Extensive of Canada, United States, Alaska
1:20,000	1" - 1,667'	Mapping, Soil Conservation Service. General uses, agriculture.	Most available and widely used civilian photography
1:24,000	1" - 2,000'	Geological Survey Mapping	Available in states with current topographic mapping
1:31,680	1" - 2,640' 2" - 1 mile	Mapping, forest inventory	Extensive
1:40,000	1" - 3,333'	Mapping, reconnaissance	Extensive of U. S. usually old photos.
1:50,000	1" - 4,166'	Air Force Reconnaissance	Much of Alaska
1:70,000	1" - 6,333'	Reconnaissance	Parts of Maine

*Information concerning availability of coverages of particular areas is available from the Office of Map Information, U. S. Geological Survey, Washington 25, D. C.

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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Earth Science Applied to Military Use of Natural Terrain

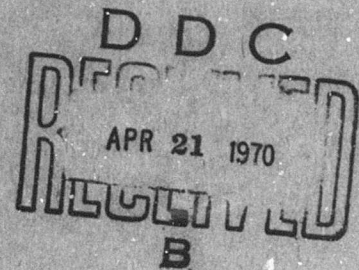
Editor

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TERRESTRIAL SCIENCES LABORATORY PROJECTS 7600, 7628

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

**Earth Science Applied to Military Use of
Natural Terrain**

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OFFICE OF AEROSPACE RESEARCH
United States Air Force



Abstract

A survey of the state-of-the-art in the evaluation of natural terrain by earth-science techniques and measurement systems is presented in response to a need that existed for many years. This report considers the terrain as an envelope of the environment and all related parameters that are basic in an evaluation for relevant military applications such as unimproved landing areas, trafficability, site selection for operational facilities, terrain reconnaissance and surveillance, and target detection within a masked terrain complex. Methods of terrain-data acquisition, analysis, and evaluation and their limitations are reviewed. The status of research and development, specifying the gaps in technology, is summarized with accompanying conclusions. The report forecasts the requirement for an automated terrain-data acquisition, storage, and display system. Recommendations are suggested for further investigation to advance technology that will provide quantitative terrain factor values. A simplified matrix method of digitizing terrain data is described in the appendix as a necessary intermediate step to the computerization of pertinent data. Information pertaining to the classification of terrain data, field devices to measure bearing strength, and a visualized optimum remote sensing system is also given in the appendix. A glossary and a comprehensive bibliography are included.

Preface

Reliable methods for predicting terrain conditions on a quantitative basis are vital in the planning of military operations. In the past an equilibrium was maintained regarding terrain-classification and weapon-system capabilities, but recent and rapid advances in weapon-system technology have made present terrain-classification methods inadequate.

Chapter I (Introduction) of this report describes the problem and delineates the need for terrain information. Methods of analysis and performance prediction of military activity by considering the terrain parameters, criteria, and environmental effects on the proposed activities are contained in Chapter II.

Chapter III on Remote Sensing is a summary of airborne sensing methods used for rapidly obtaining terrain and related scientific data over vast areas of the world. This chapter also introduces the concept of incorporating all types of sensors into systems that would produce imagery depicting the properties of different terrain.

Terrain utilization is discussed in Chapter IV. Many of the applications demonstrate the value of applied geoscientific analysis and evaluation for superior terrain-engineering planning.

Research and development to improve non-contact sensing technology is discussed in Chapter V. Gaps in the science and methodology and the status of present objectives are summarized. Some of these objectives are site selection, determination of aircraft trafficability on natural surfaces, development of analytical techniques, and evaluation of the effects of climate and weather on materials and terrain conditions.

Conclusions and Recommendations in Chapter VI identify the gaps in the knowledge of techniques for terrain utilization, and suggest areas warranting further research to develop a capability for acquiring and using data in a faster response to existing technological and operational needs.

A Glossary of earth-sciences terminology is included for the benefit and quick reference of the lay reader. The References and Bibliography contain selected material from the voluminous literature of the scientific and engineering community.

The Appendices present detailed information to supplement the material in the body of the report.

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EARTH SCIENCE APPLIED TO MILITARY USE OF NATURAL TERRAIN

I. Introduction

1. PURPOSE

The utilization of earth-science technology in determining the potential of practical military use of natural terrain could greatly enhance the global mobility of our military forces. The purpose of this report is to delineate these techniques to scientific, engineering, and military interests, and to present salient background information for use in further research or terrain appreciation. The contents may be used for specialized training programs, guidance in planning, engineering needs, and strategic and tactical situations.

2. SCOPE

This report presents significant information, with pertinent references, on the properties of natural terrain. It defines terrain and its primary parameters; evaluates methods of analysis and data-acquisition techniques; surveys the research and development status of science and technology pertinent to the solution of military environmental problems; and points out the deficiencies in our present knowledge. The report also recommends programs to eliminate many of the limitations in our earth-science technology, with emphasis on non-contact sensing of terrain.

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3. STATEMENT OF THE PROBLEM

The military concept of maintaining global capability requires sufficient and precise information on terrain and related environmental conditions. The records reflect many instances where the lack of proper and timely information resulted in critical loss of time, life, material, and tactical superiority. These include problems primarily in vehicle and aircraft trafficability, shore landings, and the construction of installations.

These problems are adequately summarized by the following quotation of Lt. General William B. Bunker, USA, Former Deputy Commanding General of the Army Material Command: "Mother Nature, in the guise of swamps, mountains and deserts or as blizzards, fogs, and blinding heat is the true immobilizer of armies."

Since time immemorial, commanders have sought an army that could move in concert--combat, tactical support, and administrative elements--over the same terrain and at the same speed. This challenge is not always met successfully when operating in complex terrain.

The lack of terrain data for large areas of the world is a serious handicap. The primary sources of information (reports, maps, photographic documentations, etc.) are inadequate for producing necessary detailed data. Subtle conditions of the terrain complex cannot be estimated from small-scale maps or from data in the inventory that are not suitable for efficient use by performance-prediction models. Rapid non-contact measurement techniques of terrain parameters are only supplementing, not replacing, the standard, slower, ground sampling and testing methods.

The classification of terrain for analogous studies is difficult even in well mapped areas of the world. The formulas for direct comparison of terrain parameters of construction materials; surface roughness; temperature and moisture content as a function of climate and weather; drainage and water supplies; vegetative cover; horizontal and vertical distribution of surficial materials; and the nature of underlying geologic formations are based on proper data acquisition.

Today, planners, strategists, and operations analysts are frequently forced to use information that limits their decisions to the generalized rather than specific effects of terrain on the various military activities. However, today, a delay of an hour or the incapacitation of a portion of the tactical force through an unanticipated environmental or terrain condition could comprise the difference between defeat and victory.

4. NEED FOR TERRAIN INFORMATION

Since man's activities are predominantly terrestrial, they are largely dependent on his efficient use of the natural environment. In the past, he operated on a

theory of superabundance of resources in the environment. It was assumed that his world contained unlimited areas in which to expand, resources to exploit, water to use or pollute, and time to plan for the future. There is now the sudden realization that these assumptions are not true; man must now economize his natural resources and use his manpower, equipment, and terrain more efficiently.

To fully utilize the environment, it is necessary to know the properties of the earth. This knowledge can only be gained by new scientific techniques. New instrumentation is required to permit rapid data acquisition by automated methodology.

Tactical requirements dictate the precise location of operations. The military need for terrain information is usually implicit, and not specified in the official requirements; however, it should be a prerequisite in the evaluation of any prototype weapon or proposed plan.

Pertinent terrain information is vitally necessary for tactical maneuver of ground forces, battle planning, aircraft navigation, target location and analysis, site selection of bases and airfields, strategic planning, and other uses. However, the acquisition of this information is frequently assigned a relatively low priority, and data needs are often obscured by the system approach to weapons development (Sturm, 1967).

1.1 Historical Review

From the time of Homer in 900 BC, the concern for the knowledge of terrain in the form of myth and legend has been described in the records of military campaigns. In the 16th century, Niccolo Machiavelli wrote:

"...and meanwhile learn the nature of the land, how steep the mountains are, how the valleys debouch, where the plains lie, and understand the nature of rivers and swamps. To all this he (the prince) should devote great attention. This knowledge is useful in two ways. In the first place, one learns to know one's country, and can the better see how to defend it. Then by means of the knowledge and experience gained in one locality, one can easily understand any other than it may be necessary to observe; for the hills and valleys, plains and rivers of Tuscany, for instance, have a certain resemblance to those of other provinces, so that from a knowledge of the country in one province one can easily arrive at a knowledge of others. And that prince who is lacking in this skill is wanting in the first essentials of a leader; for it is this which teaches how to find the enemy, take up quarters, lead armies, plan battles and lay siege to towns with advantage" (Machiavelli, *The Prince*, Florence, 1513).

History has not changed the basic concepts of land warfare. Although methods of warfare have become more sophisticated, the objective is still to dominate the territory of the enemy and destroy his will to fight.

The major contributions of earth science applied to the art of warfare have been in cartography, geography, military geology, and engineering.

4.1.1 CARTOGRAPHY

Maps were first developed about 900 BC as a guide to explore the earth's surface. The great conquerors of ancient and medieval time used crude maps in planning and conducting their campaigns. Throughout history, military conquest has stimulated mapmaking and aided science. By 150 BC, cartography combined the achievements of the scientist with those of the explorer and surveyor in presenting a picture of the physical characteristics of the earth's surface. Maps and charts developed into a major source of information for military purposes in the last half of the nineteenth century (Lobeck and Tellington, 1944, p. 1).

4.1.2 GEOGRAPHY

Aristotle founded scientific geography about 350 BC. Mapmaking and later exploration furthered the progress of advancing geographic knowledge until the first modern world atlas was published by Ortelius in 1570. The knowledge of world geography was increasing by the early 1900's, with the exception of the more remote regions (Strahler, 1963, p. 7).

4.1.3 MILITARY GEOLOGY

Terrain features have been used to the disadvantage of enemy forces since 900 BC. In 1826, geology was first applied to warfare in Germany, followed by the U. S. Civil War in 1864—although a number of isolated examples occurred in earlier history when rivers were diverted or mined in war. The first American military geologist advised the U. S. Army on varied terrain problems during the war in the Philippines in 1899. Many countries expanded their interest and application of military geology in the 1930's. The large military organization added a staff of geologists, geographers, and related skills to assist in the planning and conduct of their operations (Erdmann, 1943, p. 1177).

4.1.4 ENGINEERING

Since the first fortifications were designed and constructed in early history, engineering units assigned to all military organizations have been delegated the responsibility to overcome terrain hazards and erect structures to enable the troops and weaponry to combat the enemy more effectively. Such structures were roads, tunnels, bridges, fortifications, gun emplacements, airfields, and dams. Indigenous construction materials were used by developed resourcefulness. Mobile warfare introduced many new problems for engineering ingenuity to provide the required construction, repair, maintenance, and logistic support, particularly in large scale operations (Erdmann, 1943, p. 1176; U. S. Geological Survey, 1945).

4.2 Modern Technology

As war became more complex, the size and range of artillery, missiles, and small-arms fire expanded. The airplane introduced problems of air navigation and precision targeting and bombing. Aerial reconnaissance furnished a fast and easy means of obtaining timely information concerning terrain and the enemy's movements and methods of attack.

With the advent of mechanized warfare in World War I, and improved capability of aircraft and ground forces in World War II, the tactical use of terrain became more critical. Science and engineering developed the means to surmount the major obstacles and minimize the hazards.

The progress made in photo-mapping techniques since the mid-1940's has been phenomenal. The aerial camera has developed as one of the primary surveying instruments. Topographic maps and photographs have been the main source of information in the appraisal of terrain and environmental effects. Supplementary data were added by studying recent large-scale geologic, soils, climatological, and vegetation maps. The introduction of terrain models and diagrams reconstructed from maps and photographs was accepted as a standard procedure for showing details in realistic perspective to the military leaders (Coleman and Lundahl, 1948, p. 453).

Since World War II, the military has used earth scientists and engineers in collaboration with intelligence groups to solve problems relative to military use of terrain. The rapid solutions to terrain problems, the preparation of special maps, and the provision of other requested data to forward combat organizations by these men received widespread praise for their accuracy and value (Committee on Geophysics and Geography, 1953, p. 7).

Present research is developing methods of remote sensing from aircraft and extending such a capability to satellite altitudes. These methods will provide knowledge of global terrain to predict performance of pre-planned activities. Refinement of differentiated signals from active and passive sensors is improving the identification of all natural materials and their properties in a suitable display for efficient system interrogation.

Current technology permits (1) the selection of landforms to support aircraft operations; (2) the identification of areas possessing weak natural materials or structures susceptible to natural or induced landslides; (3) detection of disturbed foliage, vegetation, or other terrain parameters that could provide enemy camouflage; (4) determination of the hazards of ice and snow surfaces and permanently frozen ground features; (5) the location of natural drainage hazards, impassable routes due to flooding or damage; and (6) assessing site stability and the potential occurrence of disasters from catastrophic forces (Van Lopik, 1962, p. 776).

Earth-orbiting surveys, utilizing photographic sensors, offer a unique system for producing topographic and geologic maps. Maps at 1:1,000,000 or smaller could be produced from such data on a global basis. Although much of the surface mapped at 1:1,000,000 needs revision, it would be impractical to complete world-wide mapping at this scale or larger except by orbital remote sensing (Carr and Van Lopik, 1962, p. 6).

An airborne and orbital system would enable the transformation of all map, photo, and quantitized terrain data into digitized form at data bank centers for transmission to forward military units in a matter of minutes to hours. The convenience and versatility of aerial and orbital surveying, mapping, and sensing methods have only commenced to be exploited for use in modern warfare (Mays, Noma, and Aumen, 1965, p. 19).

5. PREVIOUS WORK

Since 1935, U. S. and foreign civilian and military agencies, universities, private companies, and research institutions have conducted intensive studies to develop methods for predicting terrain conditions for military, scientific, and commercial use. The primary federal agencies engaged in research on terrain problems are discussed in Appendix A.

The bibliographic references on the subject indicate the wide range of topical and geographical coverage and gaps in information. Many organizations concentrated on some of these gaps in response to military needs. Recent emphasis has been centered on the classification of terrain parameters from the interpretation of remote sensor data.

Since its founding in 1879, the U. S. Geological Survey (U.S.G.S.) has been one of the leading non-military federal organizations in the scientific study of the earth and use of terrain for military and civilian purposes. For over 150 years, the U. S. Coast and Geodetic Survey (USC&GS) has been making precise measurements of the earth and its waters. Many State agencies have been using earth science and related technology in the construction of airfields, roads, highways, waterways, and installations. State governments also participated jointly with federal agencies in the long-term mapping and locating of natural resources.

5.1 Department of Defense

Since World War II, over 37 DoD agencies have been involved in area analysis, environmental research, and programs related to terrain. Their common objective is to obtain knowledge of the physical and cultural environment in all parts of the world. Of the agencies involved, 13 are in the Air Force, 16 in the Army, and 8 in

the Navy, Advanced Research Project Agency, and Defense Intelligence Agency (DIA). The description of their work pertaining to terrain is beyond the scope of this report. See Appendix A for additional information.

5.2 Other Government Agencies

Eighteen other research groups are distributed largely among the Dept. of Interior, Dept. of Commerce, Dept. of Agriculture, Atomic Energy Commission (AEC), National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and the Dept. of Health, Education and Welfare. These agencies have been performing major efforts in environmental research and testing. DoD has frequently utilized their services.

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II. Terrain Study, Analysis, and Evaluation

I. INTRODUCTION

A study of the natural environment necessitates dividing the total complex into its separate parts. One of these parts-terrain-is as an aggregate of all physical and man-made features of an area. This aggregate includes an exclusive group of primary and secondary factors that characterize specific attributes of the terrain (AFM 88-53, p. 146).

The primary factors are: surface geometry and landforms, composition and engineering properties, vegetation, and hydrology.

The secondary factors are: cultural features and climate and weather.

Different combinations of terrain factors can have similar effects on some of man's surficial activities and have a varying impact on others. Terrain factors do not have permanent critical values for all types of activities. In many cases, a critical value (the point beyond which the activity cannot be satisfactorily performed) will change if it is even slightly modified in form, weight, etc. (Carr and Van Lopik, 1962, p. 3).

Terrain assessment by genetic and physical-attribute examinations can provide reliable information; such information, derived from contact, non-contact, and indirect methods, yields valuable performance-prediction data.

Present methods correlate field-test data and supplementary sources with analagous terrain areas, but most of the available global information is qualitative, not quantitative as desired. At best, the qualitative genetic approach is merely a substitute for detailed, directly measured terrain data (AFM 88-53, p. 124).

2. REGIONAL AND ENVIRONMENTAL ASPECTS

A knowledge of regional information is a necessary background to understanding and analyzing geologic, soil, vegetation, and implied engineering conditions. The characteristics of the local terrain in factor classes (a specific category within a terrain factor) are then determined. A comparison of the features in the region with the local complex reveals facts on materials and their surface and subsurface properties. Landforms, drainage and erosion patterns, and vegetation which can be identified are correlated with features which cannot be directly observed (Belcher, 1948).

Environmental conditions directly affect the existence, development, and alteration of terrain characteristics. The formation and sculpturing of landforms are controlled by the decay of rocks at the surface, the nature of the underground geology, the degree of weathering action, and the influence of the climate. An uneven surface is the result of etching by agents of denudation or deposition of transported materials. Thick, well-bonded-type rocks resist erosion and remain as hills, while the weaker materials form valleys. Running water transports soil and broken material, and the rock waste carried by the water scour and modify stream and river beds. Gravity and wind are other forces which remove material. Along the coastlines, waves undercut cliffs and blocks of rock fall into the sea. Waves batter the fallen blocks into sand, and the tides carry away the sand.

Soil is formed from rock wastes, shattered minerals, and organic matter. It comprises the outermost layer of the earth's crust, and its profile includes the decaying remains of plants and animals, a wealth of living organisms, the roots of living plants, and bacteria.

The environmental temperature and the composition of the rocks in an area determine the character of the soil in that area. Rock wastage is removed unless the climate is conducive to the growth of vegetation that binds the materials in the soil. Removal of vegetation can result in rapid soil loss, and glaciation can completely strip a region of all its soil (Thornbury, 1954, p. 68).

3. TERRAIN CLASSIFICATION AND METHODS OF ANALYSIS

3.1 Classification

In the classification of terrain, the characteristics are described in subjective and objective terms, and data on landform, microrelief, soils, rock, drainage, vegetation, and related properties are incorporated.

The current technology is limited in the quantitative classification of terrain properties for determining the critical values in terms of their effect upon specific military activities. Expedient classifications of the terrain components, based on data obtained from field observations and laboratory analysis, are largely qualitative on individual factors (Carr and Van Lopik, 1962, p. 2).

Qualitatively described terrain with a few measured factor values can provide an index of the regional terrain. Classification by this method is rated on a valid universality of application, degree of simplicity of measurements, repeatability of factor values, mappability or portrayability of data produced by other techniques, and completeness of data.

The most accurate appreciation of terrain is obtained by scientific analysis of the data and a determination of terrain-factor effects on activities. The primary categories used to describe terrain follow.

3.1.1 SURFACE GEOMETRY

Surface geometry is the measurement of the physical forms of features constituting the earth's surface. The basic components can be measured as slope, relief, distribution of topographic highs and lows, plan and profile configurations, and related dimensions.

Landforms that are primary surface features have varying external and internal characteristics, are in various stages of development, and change with environmental conditions. The major landforms are the plains, plateaus, hills and mountains. The secondary features are cliffs, valleys, lakebeds (playas), and alluvial fans (Leet and Judson, 1967).

Landform classification commonly utilized is based upon differences and similarities resulting from variations in the local relief and in the amount of land in slope. Mountains and hills have most of their land in slope and have moderate to high relief while plains and plateaus have surfaces that are predominantly level or gently sloping and have low relief.

There is great diversity in the surface features of the four major types of landforms, and differences within each type result from varied conditions that caused the formation of the original surfaces, the weathering and erosion that have been present, and the variations in slope and local relief.

3.1.2 COMPOSITION AND ENGINEERING PROPERTIES OF TERRAIN

The terrain is a reflection of the surficial (unconsolidated) materials and bedrock (consolidated) materials in an area. Since military operations are dependent upon the characteristics of the unconsolidated portion, that portion is emphasized in this report.

The entire thickness of unconsolidated material overlying the bedrock is considered to be soil. It varies in definition by geologists, agricultural engineers, construction engineers, soil scientists, and others. Several systems of classification are commonly used, based on characteristics and uses (See Figure B-1 in Appendix B).

3.1.2.1 Soil Properties

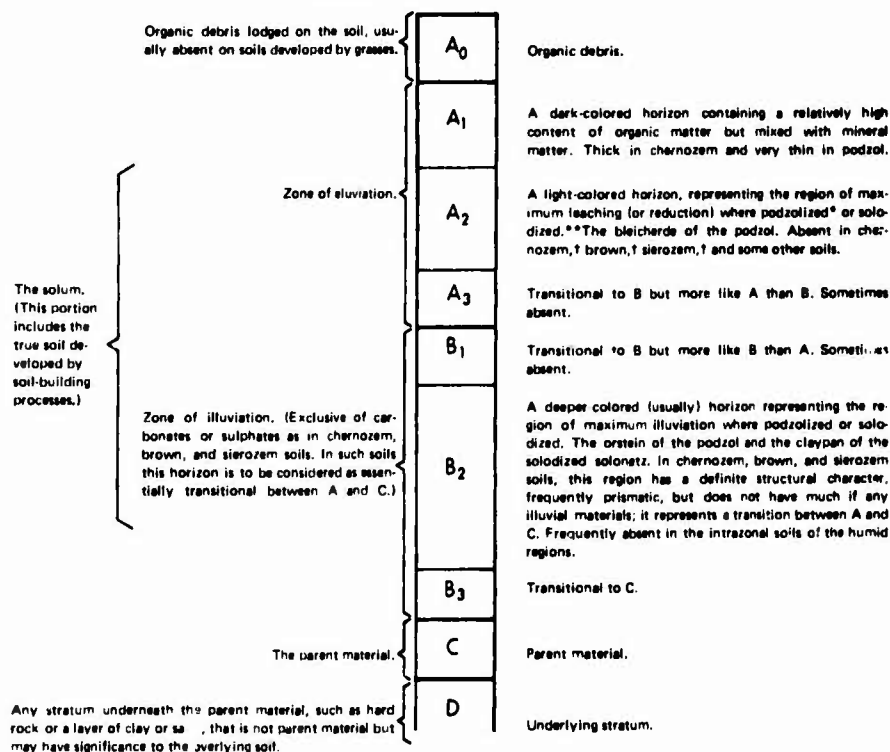
The properties of soil vary with its grain size, structure, moisture content, color, vertical position in a series of distinct layers in the profile, and geographical location. Soil is usually a mixture of varying proportions of particles of different sizes. Each component contributes its characteristics and properties to the composite mixture.

(1) Profile

Many processes of formation occur as soil is formed from disintegrated particles of the earth's crust or parent material. Air and water enter the spaces between the particles, organic matter mixes with the particles, and the soil-formation process begins. Definite layers develop near the earth's surface, and these layers (horizons) differ chemically and physically. A vertical cross-section of these horizons constitutes the soil profile (Figure 1).

From the surface downward, four horizons are recognized and are identified by the letters A, B, C, and D. The upper layer, or A-horizon, is the zone where organic matter accumulates on the surface and where the semi-decayed plant and animal material or humus is found. This is the layer from which water soaking into the ground may remove material by either chemical or physical action. The B-horizon, the second layer, is the zone where material removed from above accumulates. It is usually composed of finer particles and forms a more compact substance than the layer above. The C-horizon consists of broken-up fragments of the parent material. The D-horizon is the underlying, unaltered parent material. Figure 1 compares a typical pedological soil profile with an engineering profile.

THEORETICAL SOIL PROFILE



*Process of water leaching downward through A and B horizons.

**Process of accumulating surface minerals through leaching upward, produced by evaporation in areas of low rainfall causing moisture to be toward the surface.

†Members of great soil groups

COMPARISON OF PROFILE FOR PEDOLOGICAL AND ENGINEERING PURPOSES

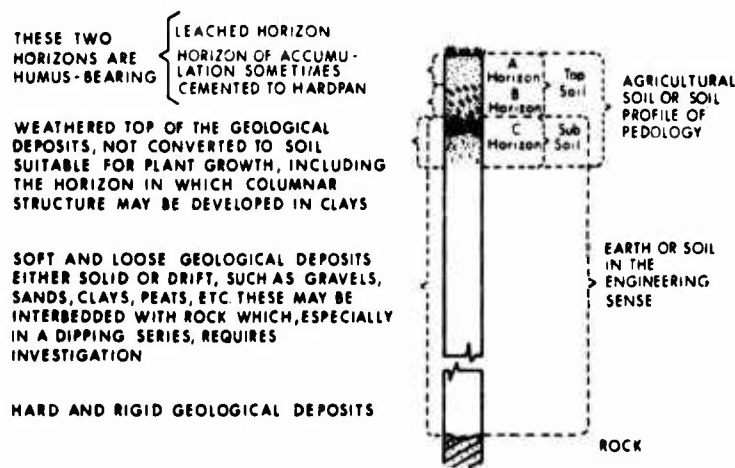


Figure 1. Soil Profile With all Horizons Present for Pedological or Engineering Interpretation

A typical profile is shown as follows:

<u>Horizon</u>	<u>Thickness</u>	<u>Range</u>	<u>Term</u>
A	10-12 In.	2 In. -4 Ft	Topsoil
B	10-12 In.	4 In. -8 Ft	Subsoil
C	Variable	Variable	Mother Soil or Parent Material in Broken Frag- ments
D	Variable	Variable	Underlying, Unaltered Rock Stratum

(2) Texture

The texture of a soil determines its ability to absorb water, heat, and air and its amenability to plant growth. The texture of a soil reflects the predominance of one size of particle or composite mixture of sizes imparting its peculiar properties. The common classes of texture are sand, silt, and clay that vary in size from diameters of 1 mm in coarse sands to a fraction of a millimeter in clays, as seen in Figure 2. Soils may include particles of organic matter.

Individual grains of sand can be distinguished, and they feel gritty to the fingers. Silt particles are difficult to observe, but they feel and look like flour. Clay particles cannot be seen without a microscope.

(3) Structure

The arrangement of a group of particles in a soil is referred to as its structure. A soil tends to be composed of units resembling a geometric-type figure. In sandy soils, the particles do not adhere. Clay forms into lumps or clods. In some soils, the particles combine into rounded aggregates of varying size. The structure of a soil indicates its capability of cultivation.

(4) Color

Color is the most easily observed and significant soil characteristic. It reflects the physical and chemical processes that formed a soil, it may be an indication of its fertility, and it differs with time, location, moisture content, and temperature. The apparent color may demarcate different major soil groups of the world and the limits of each soil horizon. Dark soils are better absorbers of solar radiation than those of light color and tend to be warmer, depending upon the circulation of air and water in them.

Soil colors range in shades or tints from white to black. The most common are dull shades of red, rust, brown, gray, or yellow. These colors represent variations in degrees of hydration and intensities of the oxides of iron. In humid regions,

COMPARISON OF PARTICLE SIZE OF WENTWORTH, USDA, AND USCS SYSTEMS

WENT - WORTH	CLAY	SILT	VERY FINE SAND	FINE SAND	MED SAND	COARSE SAND	VERY COARSE SAND	GRAVEL			
USDA	CLAY	SILT	VERY FINE SAND	FINE SAND	MED SAND	COARSE SAND	VERY COARSE SAND	FINE GRAVEL	COARSE GRAVEL	COBBLES	
UNIFIED	FINES (SILT OR CLAY)			FINE SAND	MEDIUM SAND	COARSE SAND	FINE GRAVEL	COARSE GRAVEL	COBBLES		
SIEVE SIZES											
200 270 140 60 40 20 10 4 1/2" 3/4" 3"											
.001 .002 .004 .01 .02 .04 .1 .2 .4 1.0 2.0 4.0 10 20 40 80											
PARTICLES SIZE, MM											

WENTWORTH SCALE USED IN GEOLOGIC MEASUREMENT OF SEDIMENTS

SIZE	FRAGMENT	TO GET NEXT LARGER SIZE, MULTIPLY BY	APPROXIMATE EQUIVALENT
256 mm	BOULDER		10 in
64 mm	COBBLE	4	2-1/2 in
4 mm	PEBBLE	16	5/32 in
2 mm	GRANULE	2	5/64 in
1/16 mm	SAND	32	.0025 in
1/256 mm	SILT	16	.06 mm
	CLAY		.00015 in
			.004 mm

Figure 2. Common Systems of Measuring Particle Size of Soil

a whitish color may indicate a lack of iron, but in arid regions, this color may denote a concentration of alkalinity or soluble salts and a lack of iron. Black and dark-brown colors often denote a high content of organic matter. Reddish brown is high in iron content, but yellow, brown, and mottled colors of them indicate a lack of iron in the soil constituents or poor drainage of the soils.

(5) Water Content

Gravitational, capillary, and hygroscopic water are the three types of moisture in soils. The type and percent of water in a soil have a great influence on the performance and value of a soil as a subgrade material. Excess moisture often reduces the bearing strength and adversely affects other properties of the soil (Strahler, 1963, p. 439).

(6) Soluble Salts

It is important that the presence and type of soluble salts in a soil be determined, because of their possible deleterious effects on construction materials. Also, soluble salts in a soil indicates that its engineering properties may change in the presence of percolating water.

(7) World Soil Types

Contrasts of topographic relief, parent earth material, climate, and vegetation produce a wide variety of soil types that are difficult to accurately classify on a world-wide basis. However, by classifying broad categories of undisturbed soil types as zonal soil groups, well-developed soil profiles can be established for analogous comparison with regions of similar climate, vegetation, and parent material.

3.1.2.2 Engineering Properties of Soils

The combination of internal friction, cohesion, compressibility, elasticity, capillarity, and permeability properties determines the suitability of soils for engineering use. These properties are influenced largely by the soil type and by its gradation, moisture-density relationships, and composition (Terzaghi and Peck, 1948, p.3).

(1) Structural Strength

The load-supporting capacity of a soil varies considerably with its moisture content and density. Methods for determining the strength of soil range from the use of complex formulas and empirical design criteria to controlled field and laboratory tests. Specialized training and experience are required to evaluate a soil for a specific use at a particular location. General estimates of the strength of various soil types can be obtained from published data, but for large structures, field-test data on the entire foundation area are required (Leggett, 1967, p. 1449).

3.1.3 VEGETATION

Vegetation is a prominent feature of terrain and has a great influence on military operations since it affects mobility, concealment, observation, and construction (Carr and Van Lopik, 1962, p. 56; Finch et al, 1957, p. 483).

For terrain analysis purposes, vegetation cover is subdivided into three major categories (Figure 3):

- a. Dimension - this includes height, crown shape, stem diameter, and root and stem variations.
- b. Physical Properties - the degree of woodiness, deciduousness, leaf characteristics, and spininess.
- c. Distribution - the spacing of stems, coverage of canopy, and arrangement of plants.

Vegetation may serve as a source of construction material, fuel, water, or food. It also is an indicator of climatic conditions, soil type, moisture content, drainage, and other surface and subsurface characteristics which are helpful in explaining the differences between terrain.

3.1.4 HYDROLOGY

A body of water is one of the main terrain factors, and its shape, size, distribution, moisture budget, and dynamic properties are factor classes. Other hydrologic information regarding terrain includes flooding susceptibility and controls, tidal variations, local drainage, and climatology (Strahler, 1963, p. 439).

The water supply in an area is dependent upon the sub-surface structure and materials and the amount, seasonal distribution, and type of precipitation in that area.

The total of all the moisture on or near the earth's surface and in the atmosphere does not vary widely from year to year, but exists in a giant circulatory system known as the hydrologic cycle. The cycle originates primarily with the waters of the oceans and seas that cover about three-fourths of the globe.

The occurrence and migration of subsurface water and the semi-permanence of natural water bodies are based (see Figure 4) on the following sequential processes:

- a. Evaporation of water from large water bodies.
- b. Condensation to produce cloud formations.
- c. Precipitation of rain, snow, sleet, or hail upon land surface.
- d. Dissipation of the rain or melted solids by direct runoff into lakes and streams, by seepage or infiltration into the soil and underlying rock formations, and by direct evaporation.

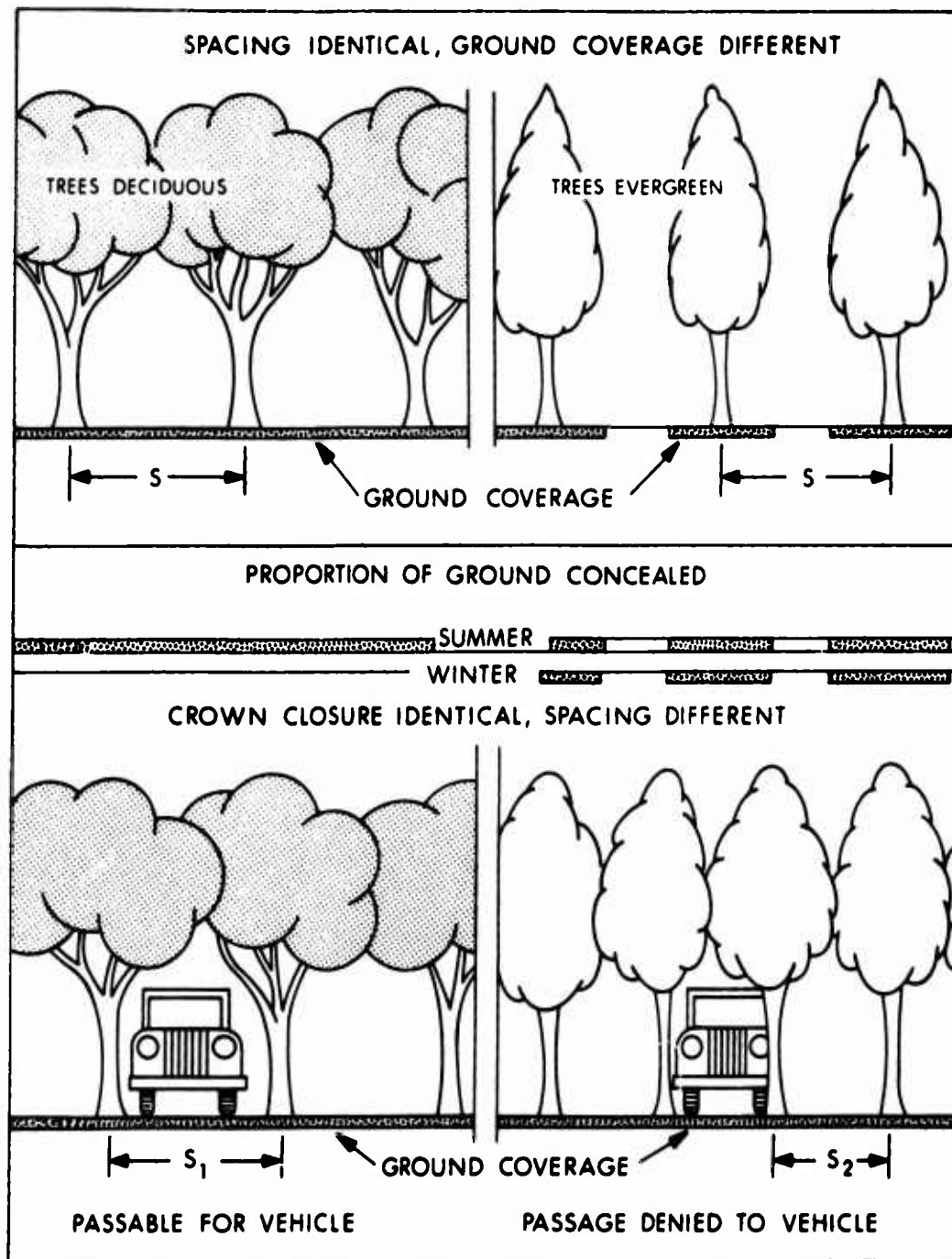


Figure 3. Physical Parameters of Vegetation

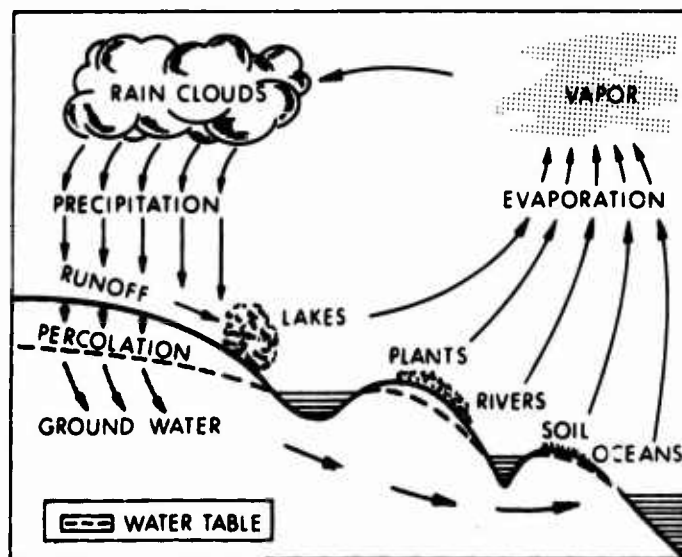


Figure 4. Hydrologic Cycle

e. Movement of water through openings in rocks.

f. Issue of water at the surface through springs, streams, and lakes.

Evaporation from the terrain and transpiration from the vegetation represents the transport of water from the earth back to the atmosphere, the reverse of precipitation. During the period when evapotranspiration exceeds precipitation, the moisture in the terrain profile decreases and results in a drier surface. During periods of excessive precipitation, the moisture index increases, either overcoming a moisture deficiency in the area or creating a surplus. The surplus may result in the formation of new water bodies, glaciers, and snowfields or in the enlargement of the older ones which could lead to flooding conditions (AFM 88-53, p. 90).

The drainage features of various parts of the world display a number of stream patterns. Variations in the pattern are the result of differences in the slope of the land upon which the drainage system developed and differences in the resistance of the underlying rocks to erosion (Figure 5).

The most common drainage pattern, known as dendritic, consists of a tree-like arrangement made up of a main stream and successively smaller tributaries joining it at acute angles; it occurs in regions where the water flows over materials that have relatively similar resistance to erosion. If the stream flows over a regular succession of elongated zones of weak and resistant rocks, such as is formed by folded or faulted structures, a trellis pattern develops. In this pattern, the major streams are arranged in relatively straight parallel lines with tributaries joining at right angles. Single mountain peaks and other places that have

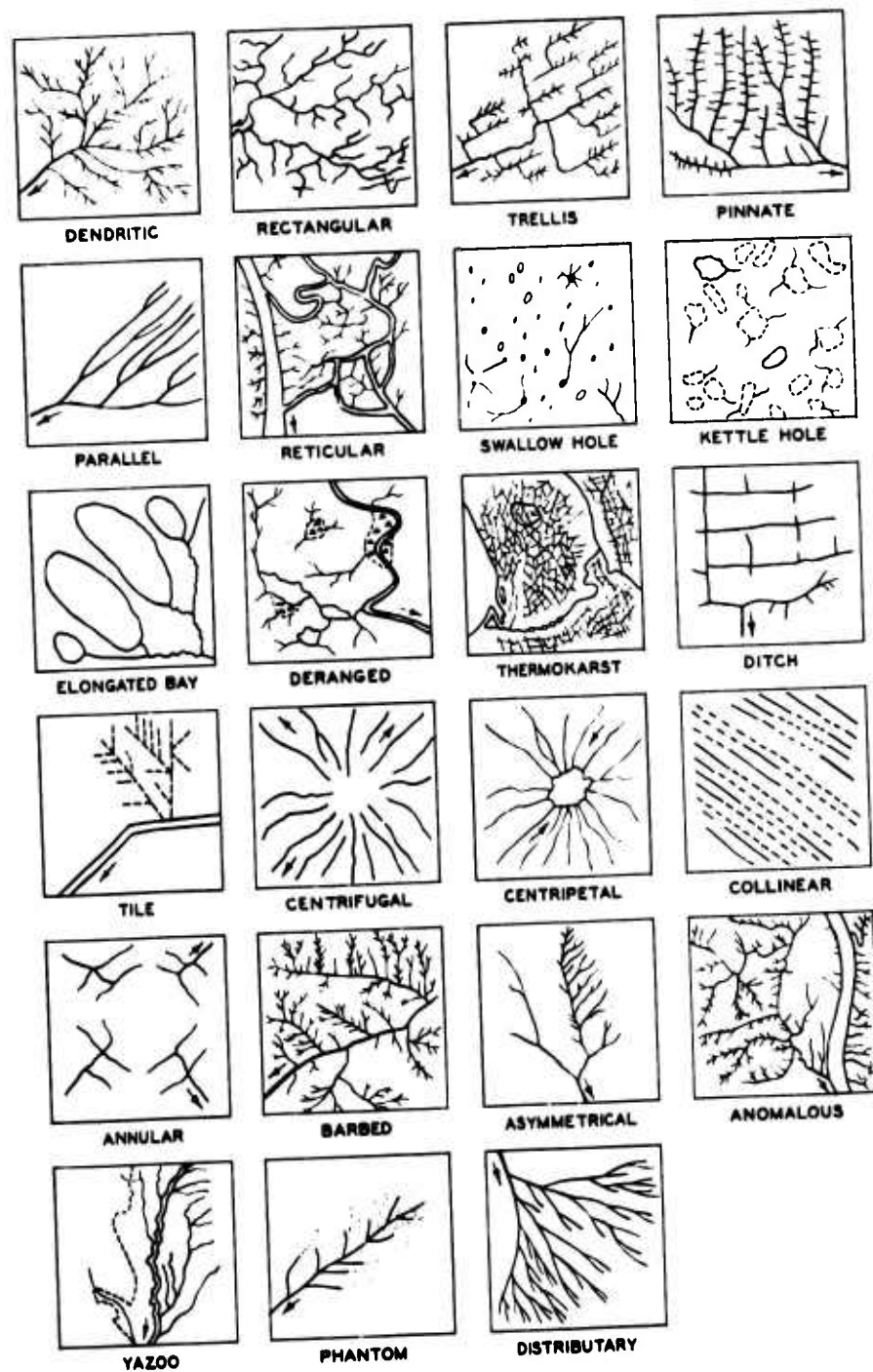


Figure 5. Drainage Pattern Types

a centrally located high area with drainageways extending out from it in all directions have radial patterns. Irregular drainage systems are characteristic of regions that have been covered by continental glaciation.

3.1.5 CLIMATE AND WEATHER

Over a long period, some geographical elements influence the physical and chemical properties of terrain. These elements are: temperature (including radiation), moisture (including humidity, precipitation, and cloudiness), wind (including storms), pressure, evaporation, latitude, altitude, distribution of land and sea, and atmospheric phenomena.

Because these elements vary considerably throughout the world, there are many variations as well as similarities in climate throughout the earth.

Various systems have been formulated to classify climatic types. One noted system, based on the relationship between evaporation and precipitation, was devised in 1931 by C. W. Thornthwaite. He listed five major climatic groups - wet, humid, subhumid, semiarid, and arid - and assigned a rating for "precipitation effectiveness" to each group (Strahler, 1963, p. 327; Air Weather Service Manual 105-3; Curtis, 1966, p. 227).

In 1918, Wladimir Köppen developed a system of classifying the world's climate into 12 primary types according to annual monthly means of temperature and precipitation. His method, frequently modified, is generally accepted by terrain analysts as a suitable systematic and quantitative approach.

3.1.5.1 Major Types of Climate

The Köppen system divided the land areas of the world into 24 groups and utilizes the following 12 classifications to describe the world's climatic types. Figure 6 indicates the geographic locations of these climatic types.

(1) Tropical Rainy Climates (Af, Am)

Rainy tropical climates are characterized by high temperatures and heavy precipitation in all months of the year with no seasonal variation. Other terms used to describe this type are rainy tropics, humid tropical, tropical moist, and tropical rainforest.

(2) Tropical Wet and Dry Climate (Aw)

The type of climate that borders the rainy tropics on their poleward sides has high temperatures through the year and a rainy season followed by one that is distinctly dry. It is also designated by its principal vegetation type as tropical grassland or savanna.

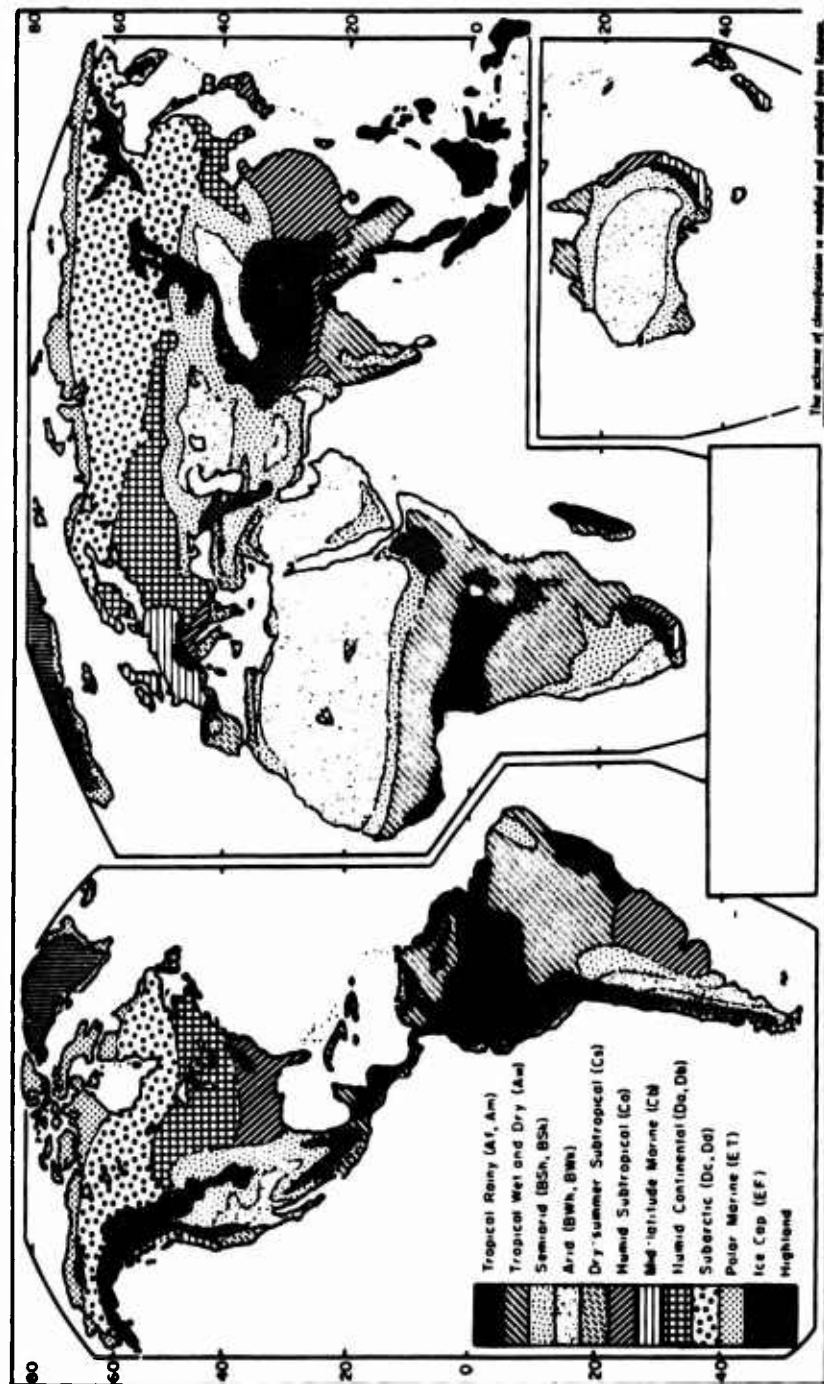


Figure 6. Climates of the Earth (Köppen System)

(3) Semiarid Climates (BSh, BSk)

Broad transitional zones with semiarid climates separate the deserts from the humid climates. Since their one prominent feature is short grass vegetation, these areas are often termed "steppe" climates.

(4) Arid Climates (BWh, BWk)

Arid climates, including deserts, are those greatly lacking in moisture. Many of the arid climates (tropical, subtropical, and mid-latitude arid) have an annual precipitation less than evaporation.

(5) Dry Summer Subtropical Climates (Cs)

This type is characterized by a high percentage of sunshine in all seasons, and by dry, warm to hot summers and mild, rainy winters. Since such conditions are most widespread in the borderlands of the Mediterranean Sea, the climatic type is often termed as Mediterranean or Mediterranean subtropical.

(6) Humid Subtropical Climates (Ca)

Areas with this climatic type are on the eastern sides of continents in the lower middle latitudes and have hot summers, mild winters, and abundant precipitation in the warm season.

(7) Mid-latitude Marine Climates (Cb)

In many coastal regions of the middle latitudes, particularly west coasts, the climate is characterized by mild winters, cool summers, and relatively high precipitation. This type of climate is also designated west coast marine or temperate marine.

(8a) Humid Continental Climates, Warm Summer Phase (Da)

This climate has great differences between the long hot summer and cold winter temperatures, changeable weather in all seasons, and some precipitation.

(8b) Humid Continental Climates, Cool Summer Phase (Db)

The cool summer phase of this climate is similar to the warm summer phase as described in (8). The major differences are that the cool summer is shorter as the result of lower temperatures in the high latitudinal locations.

(9) Subarctic Climates (Dc, Dd)

This climatic type has long cold winters, short summer seasons, and great extremes of temperature. Other terms used to describe it are polar continental, boreal forest, or northern coniferous forest.

(10) Polar Marine Climates (ET)

The Arctic and Antarctic regions have a harsh environment with very low temperatures.

(11) Ice Cap (EF)

The two types of polar climates are polar marine and ice cap. They have similar harsh environments and weather characteristics, but vary often within and between the arctic and antarctic regions. The ice cap climate has severe cold temperatures, high winds, light precipitation, and a short summer-like season with a few days above freezing and sunshine.

(12) Highland

Differences in elevation and in exposure to winds and sunlight result in a great variety of climatic features in highland regions. Mountain climates cannot be easily classified on the basis of similar temperatures and pressures on a world scale. Climates of mountainous regions are frequently termed undifferentiated highland.

3.2 Methods of Analysis

3.2.1 DATA ACQUISITION METHODS

Three methods are used for acquiring terrain data: contact, non-contact, and indirect. These methods are described briefly below and fully in Appendix C (see Figure 7).

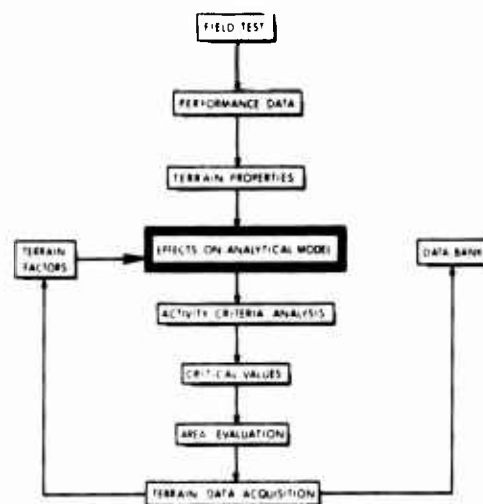


Figure 7. Data Acquisition Cycle

In the contact method, direct measurements of factor and factor class values are made on the ground. This method is the most reliable, since it yields usable quantitative data, but it is costly, time-consuming, and not always feasible.

In the non-contact method, remote-sensing instrumentation is used to obtain images of the terrain or recorded values of emissions from certain terrain properties (Figure 8). Although the non-contact method is easy to use and expedient, the accuracy and reliability of the resultant data are much less, generally, than are those of the contact method. The non-contact method is described in detail in Chapter III.

The indirect method of terrain data acquisition is employed when measured data are lacking and an area is inaccessible. Basically, the method entails employing intuitive scientific deduction to obtain an appropriate analogous analysis. Certain terrain characteristics can be predicted by comparing an unknown area to a known area that is similar in geology, topography, landforms, soils, climate, and vegetation. This method is frequently used in combination with the others to provide supplementary information to an analysis (Grabau, 1967b, p.18; Belcher, 1948).

3.2.1.1 Terrain Evaluation

The rationale of evaluation is largely the development of reasonable conclusions from an analysis and interpretation of measured and inferred data. The conclusions must relate the influence of terrain on a proposed activity whose performance can be predicted in any defined terrain complex (Figure 9).

Terrain studies for military application have the following specific goals:

- a. Terrain Classification, Quantitative (describe, classify, map, and establish analogs)
- b. Effects on Military Activities in Known Areas (available data and specialized experience)
- c. Factor/Effect Relationships (theoretical analysis)
- d. Field Testing of Theoretical Studies (validation of critical values)
- e. Sensors for Determination of Terrain Factor Values (remote sensing from airborne or orbital altitudes)
- f. Prediction of Quantitative Effects in Unknown Areas (elimination of pre-mission reconnaissance)
- g. Data Storage and Retrieval (accumulation of information for prediction)
- h. Selection of Flexible Alternative Conditions (varied response to meet changing tactical situations and environmental factors)

(1) Performance Prediction

The most efficient prediction concerning the success (that is, performance) of a proposed activity is achieved when all the requirements of a proposed activity and all terrain factor values are known prior to the evaluation. The principles

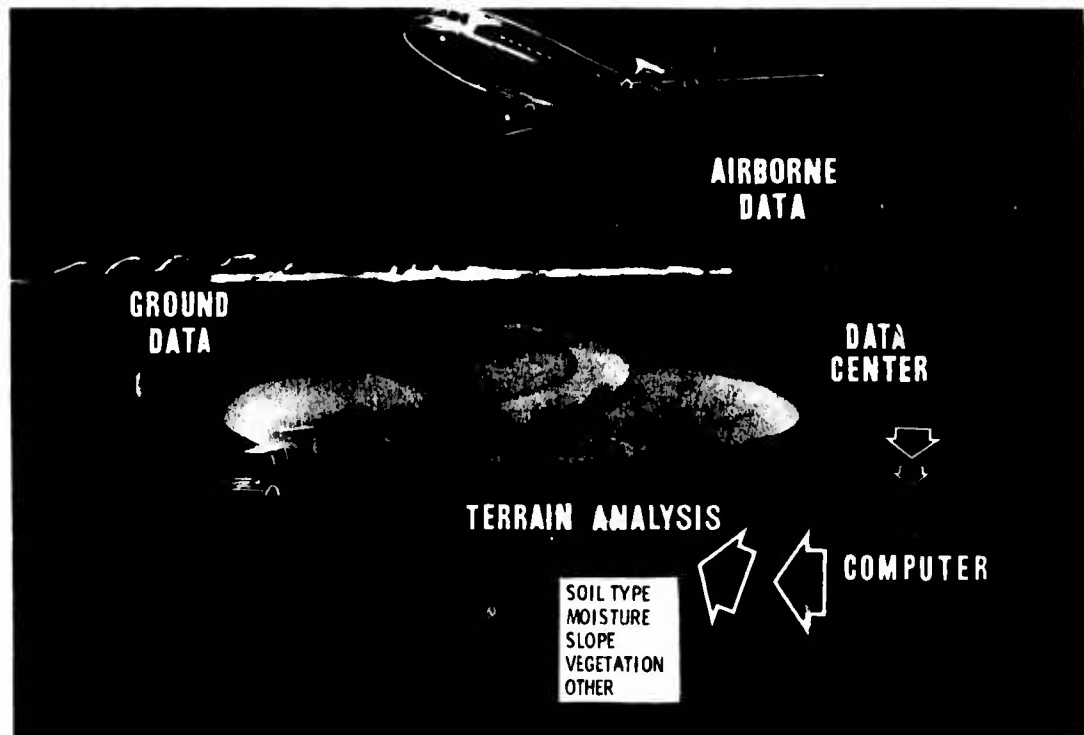


Figure 8. Synthesis of Data From Non-Contact and Contact Methods

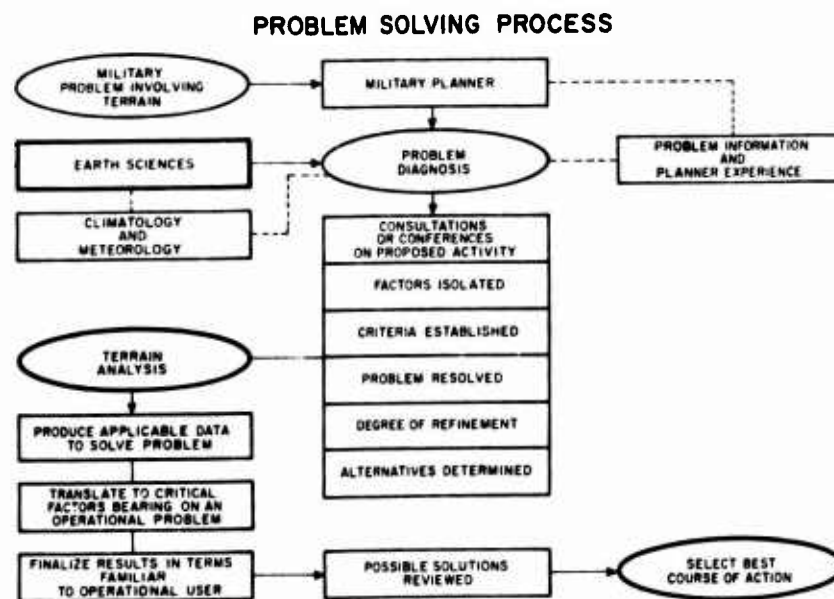


Figure 9. Terrain Evaluation for Military Use

governing an objective, rapid, and accurate evaluation of terrain are: (a) the relationship between the terrain and the activity must be known in mathematical terms in the study and analysis phases; (b) a set of analytical models for each selected terrain factor relevant to the activity must be formulated; and (c) the evaluation must be based on the designated factors in the models and their critical values (Grabau, 1967b, p. 18).

(2) Evaluation and Prediction Procedure

The procedure for obtaining and disseminating evaluation and performance-prediction data is outlined below and shown diagrammatically in Figure 9. The terrain analyst should:

- a. Define and understand the military need and delineate specific activities in mathematical terms.
- b. Isolate the relevant terrain factors and their subclasses and construct a mathematical model of each subclass.
- c. Determine the critical terrain factor class value for each model.
- d. Obtain and analyze all relevant terrain factor data near the site of the proposed activity.
- e. Determine the gaps in the required data, and plan to obtain that data.
- f. Analyze all the information and make preliminary conclusions.
- g. Consult with knowledgeable professionals and/or technicians on any hazy aspect of the total problem.
- h. Review the analysis of source information, evaluate for specific effects on the activity, and make final conclusions and recommendations. Consider vulnerability of terrain to possible enemy action.
- i. Prepare a report covering all major aspects of the problem, and include in it large and medium scale maps, annotated ground and aerial vertical and stereoscopic photos, charts, diagrams, graphs, engineering data, and important references. Radar, infrared, other film (color, camouflage detection), and other imagery would be included.
- j. In cases of major problems, document all important information in detail. The conclusions and recommendations should be brief, clear, complete, and supported by data or information contained in the body of the report. Useful photographic documentation, and other imagery properly annotated, should be included as appendix material.
- k. The team concept of analyzing a problem or activity should be the standard procedure. A special group of three to six professionals or technicians should be assigned the problem, with a target date for completion. The professionals should be from such fields as civil engineering, geology, geography, soil science, botany, ecology, forestry, and photogrammetry.

1. The terrain analyst will emphasize the foregoing steps related to his particular objectives, using the basic concepts of his scientific field, the criteria which they provide, and applying the method of reasoning appropriate to the problem. In the absence of specific data, the interpretation is based on reasoning by analogy. For this step, comparison of the unknown terrain complex with its nearest analogous terrain of known characteristics is the primary point of departure in the analysis.

The possibilities suggested by such comparisons are subjected to independent checks before any final judgment is rendered. Critical examination is made to appraise the correctness of the analogy, to consider possible ambiguities, to explore alternate explanations, and to ascertain the extent to which explanations conform with basic principles and data of the scientific disciplines. Analysis and synthesis of the data compared with the analogous conditions can contribute to a reliable evaluation.

(3) Special Procedures for Site Selection

As a supplemental guidance to the approach outlined in (2), the following steps will provide the required data for effective integration, reduction, and evaluation in response to the varying siting problems.

a. Determine data on: regional and local topography, geology, hydrology, soils, vegetation, climate and weather, and accessibility (roads, railroads, air, water, and ports).

Terrain data of engineering significance includes:

- 1) Regional relief within a 25-mile radius of the potential site with about 20-ft accuracy, local relief within a 5-mile radius with about a 10-ft accuracy, and site area within a 3-mile radius with about 1-ft accuracy
- 2) Soil profile down to 10 ft or bedrock
- 3) Surface and ground water characteristics
- 4) Geological conditions
- 5) Vegetation location and type, root systems, and density
- 6) Meteorological factors
- 7) Accessibility and logistics requirements
- 8) Perimeter defense advantages.

b. Prepare and compile all the data in item a., above, in large, intermediate, and small scale maps appropriate to the type of use and annotate the aerial and ground photography details.

c. Conduct a survey of the site to determine availability of local indigenous construction materials, water supplies (potable and construction), and topographic controls.

- d. Prepare engineering plan of site layout and development.
- e. Compute grading and excavation requirements, estimate effort required to remove obstacles, and plan for protection against serious natural hazards.
- f. Perform final evaluation of all the environmental factors influencing the site utilization.
- g. Compute the total construction effort and resources in terms of personnel, equipment, materials, and time needed to ready the site for use.
- h. Prepare final report in a folio form on the site including recommendations, alternate sites, advice in site preparation, accompanied by properly annotated overlap maps, ground and aerial photographs, and other essential background information.
- i. Check with user to record for future guidance the comparison of predicted site conditions and recommended effort with the final site selection, development, and expended construction effort.

Selection of sites for installations, tactical positions or mobility of weapons and troops, and aircraft and vehicle trafficability generally follow a similar plan of investigation.

3.2.2 CAPABILITIES AND LIMITATIONS OF TERRAIN ANALYSIS

Experience has demonstrated that significant savings of time and effort in terrain interpretation are obtained by a combination of contact and remote-sensing methods. The viewing of terrain in three-dimension, thus presenting it in realistic perspective, is invaluable for improved planning. The non-contact and indirect methods have limitations which degrade an optimum analysis of terrain in completely quantitative terms.

3.2.2.1 Masked Terrain Conditions

One of the major limitations to an accurate evaluation of terrain is that surface materials can mask the diagnostic characteristics of underlying formations. Vegetation, glacial remnants, and wind-blown or water-transported materials are common types of masking deposits. In addition, relic and pseudomorphic landforms produced from different materials, conditions, and geologic processes are unfamiliar varieties and can confuse the interpreter. Current knowledge regarding the origin, distribution, and relationships of many known types of landforms is inadequate, and additional varieties remain to be discovered and studied. Although external characteristics may be diagnostic of internal conditions and underground materials, the interpreter is handicapped unless the surface details of the terrain are evident and simulate the classic examples of landforms.

3.2.2.2 Available Information

Terrain data obtained for other objectives (economic or agricultural purposes, etc.) is available, but it is generally not directly applicable to specific military needs. Photointerpretation used in conjunction with this data could provide some of the necessary details.

3.2.2.3 Quality and Accuracy of Source Materials

The reliability of interpretation is proportional to the availability of large-scale, recent, and accurate maps and photographs (aerial and ground). Ideally, the map and photo scales for microterrain studies should be from 1:2,000 to 1:10,000; for general terrain analysis they should be from 1:15,000 to 1:40,000. Many interpretation difficulties arise from the need to use expedient procedures and maps and photos of unsuitable scale and poor quality. Factors of cost, time, priority, or specific requirements often outweigh the interpreter's preference and limit the reliability of his interpretations.

3.2.2.4 Training and Field Experience of the Interpreter

The level of skill, formal training, and field experience of an interpreter directly affects the quality of his analysis. Many of the subtle phases of interpretation - denoting interpretative skill and confidence - are not developed until a number of successful predictions have been achieved in unknown areas. The common weakness is lack of training in a pertinent scientific discipline.

3.2.2.5 Inadequate Methodology

To overcome existing limitations in the field of terrain analysis, a source of ready and reliable data must be made available to the interpreter. This goal could be achieved by the establishment of a data bank, by continued effort to supply and store new data, and by incorporation of the following types of information:

(1) A Global Atlas of Regional Landforms - Aerial Views

Representative examples of landform types and their variations in all types of geologic, geographic, and climatic environments should be depicted in an atlas. Comparisons of different geographic areas with analogies in accessible areas such as in the United States would be included.

(2) Types of Terrain Features

The characteristics of the terrain from microfeatures to vegetation, soil conditions, bedrock, surface and subsurface drainage, and other related factors such as engineering properties within the global environment should be summarized and illustrated in detail. Such summaries would compare stereographic data of familiar areas with that from unknown areas.

(3) Case Histories of Terrain Studies

Detailed reports on locations that were checked on the ground and the results compared with data obtained through remote sensing would be of great value as background, training, and reference material. Such reports would describe the predictions made, criteria used, source data, and the extent to which predictions were confirmed by ground testing. The reasons for inaccuracies in the interpretation would also be covered. A folio of all site maps, charts, graphs, aerial and ground photographs, and other imagery, plus supporting bibliographic references, would be a part of the documentation.

(4) Increased Use of Illustrations & Annotated Imagery

All reports issued on the investigation of terrain should contain annotated photographic and other imagery showing terrain characteristics. This would contribute to an increase of background information for further reference and analysis.

(5) Further Research

Fundamental research through controlled experiments should be continued on the origin, nature, and distribution of landforms and microfeatures and their properties in different environments. Bare, natural, and cultivated vegetated surfaces should be investigated for clues to specific terrain conditions that can be recognized on aerial imagery (Williams, 1964, p. 98; Neal, 1965, p. 150; Needleman, 1962, p. 70).

As new types and varieties of terrain are studied, variations must be inventoried, scientific complexities must be unravelled, ambiguities resolved, and controlling factors evaluated. This new information could facilitate improved terrain interpretation (Committee on Geophysics and Geography, 1953, p. 26).

4. CRITERIA

Since the critical values of terrain parameters change with each new military application (size of tanks, etc.), a thorough knowledge of the geology of the ground feature and the surrounding terrain is necessary in order to determine the engineering properties. The critical values are based on the quantitative effect that the application will have on the individual natural features.

The criteria established from performance tests, etc., determine such applications as trafficability of aircraft, vehicles, and troops; concealment and cover; availability of water and construction materials; and types of construction problems.

5. VALIDATION

The quality of the terrain evaluation is directly proportional to the usability of the investigated terrain according to performance predictions. Reliability is increased if the predictions are supplemented with adequate measured data. The best approach is to use the data in a check and balance method to eliminate possible limitations in the proposed use of the terrain for each application. Field, laboratory, and sub-surface investigations can either confirm or deny such use. Comparison of unfamiliar terrains with their nearest analogues of known characteristics and performance predictability is the standard practice in lieu of sufficient ground data (Burns, 1960, p. 25; Needleman and Pressman, 1962, p. 190).

III. Remote Sensing

C. E. Molineux

I. INTRODUCTION

In terrain analysis, aerial photography is the most widely used type of remote sensing, and most of the photos obtained are black-and-white, taken on panchromatic film at scales ranging from 1:10,000 to 1:50,000. Such photos, used in conjunction with on-the-ground observations, usually provide the best means of obtaining a ground inventory. To be of maximum usefulness, the aerial photography must have been taken with proper consideration given to film, filter, resolution, time of day, and season of the year. Each land structural element has a critical scale that is optimum for interpretation, and the photo patterns pertaining to the distribution of tones and textures of an image are critically important.

Electromagnetic sensing outside the visible spectrum is not extensively used at this time, but research and development are in process, especially in the imaging infrared and radar regions. As experience is accumulated, such imaging or non-imaging sensors will come into greater use and acceptance.

Non-imaging sensors usually record a phase of electromagnetic radiation emitted or reflected from a surface. The phase may be an absolute quantity in various spectral regions, such as radiometric temperature, or time-distance relations of received radiation, as in microwave or radio-frequency-reflection devices. The relationship may be phase or polarization, absolute reflectivity

values, or similar factors associated with sub-surface conditions determined by the radio-frequency penetration capability of such devices. Gamma-ray sensing, radio-frequency sounding, and swept-frequency radar techniques are examples of this capability.

Some limitations are due to the relationships of the terrain electromagnetic emissivity and the sensor's capability to detect or record the same.

In general it may be said that aerial photography enables estimation and limited measurement of the physical and engineering properties of surficial terrain. Infrared sensing in the 3 to 5 μ wavelength region of the spectrum best indicates cultural or artificial thermal energy sources. Infrared in the 8 to 14 μ region coincides with the broad envelope of natural earth radiation, and enables sensing of surface or near-sub-surface soil conditions that are important for mobility purposes.

Microwave radiometry has much promise for terrain material identification and discrimination and for mapping of sub-surface conditions. Radar techniques have great potential for distinguishing surface materials, determining moisture content and vegetation conditions, and for recording engineering geologic patterns such as outcrops, faults, and stratification. Airborne magnetometry is useful in mapping near-surface igneous material.

To expedite the acquisition of reconnaissance, engineering, and geologic data, remote sensing methods are used. Basically, the method entails acquiring information about an object or phenomena by using an information-gathering device that does not have to come in contact with the object under investigation. The data obtained by remote-sensing devices can be utilized to further our knowledge relevant to the earth and its environment, to solve engineering problems and problems relevant to the exploitation or conservation of natural resources, and to promote national defense. The USAF Scientific Advisory Board (AFSAB) has recently endorsed the need for continuing such application of remote sensing techniques (USAF Scientific Advisory Board, 1966).

Present electromagnetic sensing technology and the ability to operate from platforms above the earth has permitted the development of systems having a greatly increased ability to sense the meaningful characteristics of the earth and its environment. Increased information can be obtained through the use of combinations of sensors, with each individual sensor exploiting a different portion of the electromagnetic spectrum. Infrared, radar, passive microwave, geochemical, spectrophotographic, and spectroradiometric sensor techniques show much promise in providing surface and subsurface information. Much of this information is also needed in target-background, signature-characterization efforts.

With remote sensing devices it is possible to map large areas, obtain information about the physical characteristics of objects or phenomena, and monitor conditions that change with time. Regardless of the application, especially when used in aircraft or spacecraft vehicles, these devices provide a means of acquiring data on environments otherwise inaccessible because of physical limitations or political restraint. In some instances, remote sensors may be the only means of acquiring a certain type of data; in others, they may be the more economical means. The vast potential of satellite sensing has been documented for NASA by the University of Michigan (University of Michigan, 1966a). In addition, non-imaging sensors (including air-droppable devices) can be used to obtain specialized data. Ground-based surveys, when feasible or allowed, may use additional sensors that require contact with the surface to obtain unique data. In the airborne mode, information obtained photographically in the visible portion of the spectrum can be supplemented by data recorded by other sensors used in a multi-disciplinary approach.

Various charts and effectiveness diagrams tabulating the terrain and environment parameters detectable and measurable by pertinent remote sensing techniques have been prepared by organizations conducting such activities. One such comprehensive chart prepared by the U. S. Army Engineer Waterways Experiment Station (USAEWES) is shown as Figure 10. Others are plentiful in the literature. The electromagnetic spectrum, sub-divided to show the generally accepted sensing regions, is drawn in terms of frequency and wavelength in Figure 11.

Countless governmental, industrial, and university organizations are conducting research and development, testing, and determining the applications of remote sensors. Indicative of the general interest and emphasis in this scientific field is a long-term comprehensive study by the University of Michigan, supported by many federal agencies, which has featured periodic Symposia to provide an information exchange medium on the state-of-the-art and applications of all unclassified phases of remote sensing (University of Michigan, 1962, 1963, 1965, 1966b). NASA has published extensively on the use of remote sensing in its earth resource program (Badgley et al, 1967), and an International Symposium on Electromagnetic Sensing of the Earth from Satellites was held in late 1965, sponsored by American Geophysical Union, American Meteorological Society, and the Optical Society of America (Zirkind, 1967). The Michigan Symposium proceedings and the Journal "Photogrammetric Engineering" of the American Society of Photogrammetry (ASP) are highly recommended for presentations of current status and applications.



Figure 10. Remote Methods for Characterizing Environmental Factors

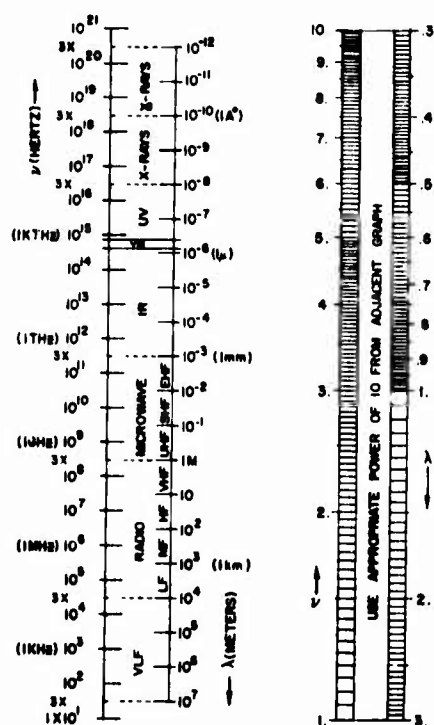


Figure 11. The Electromagnetic Spectrum and Frequency Wavelength Conversion Nomogram

2. AERIAL PHOTOGRAPHY

The principles and uses of aerial photography using conventional black-and-white film are well known and will not be re-stated here. Such photography with panchromatic film uses the complete visible spectrum, except that haze, or minus-blue, filters are occasionally introduced. It provides a high resolution and generally distortion-free visual map of the terrain essentially as the human eye perceives it. In this type of photography most images have the objects of interest recorded in varying shades of gray on the photographic emulsion. The problem of photo-interpretation begins here. In many situations the image is of a familiar object or terrain feature, and its geometric properties (size, shape, shadow, or texture) plus its location, contrast, and relationship to surrounding objects enable ready identification. However, when the object is unfamiliar or exhibits a different or unaccustomed tonal value on the image, the interpreter's judgment and experience becomes critical (American Society of Photogrammetry, 1960, p. 99).

2.1 Resolving Power

For a given film format (W), the smallest detectable elevation feature is dependent on the flight altitude (H) and the resolving power of the camera system (R). This is expressed as $\frac{\Delta H}{H} = \frac{1}{274WR}$ where ΔH , H, and W are in feet and R is the commonly used term of lines per millimeter. This capability is shown for various $\frac{\Delta H}{H}$ combinations using a 9-inch film format in Figure 12. The range of resolution hachured (up to 80 lines per millimeter) represents that presently in the unclassified state-of-the-art of aerial photography (Itek, 1962, p. 50).

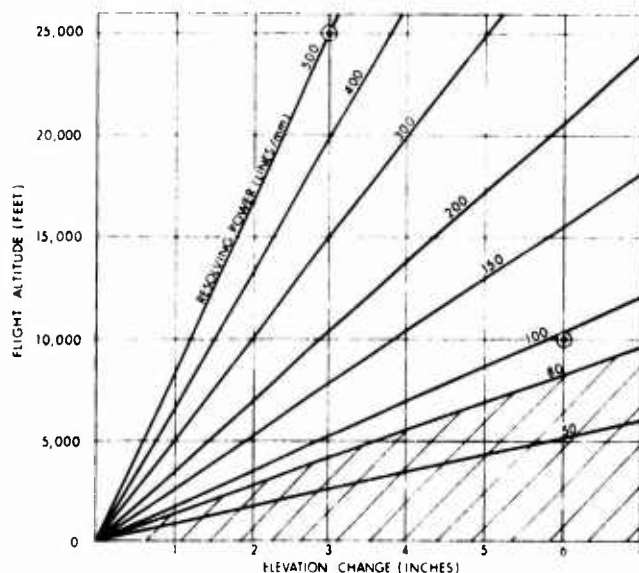


Figure 12. Resolving Power of Photography Varying With Flight Altitude

2.1.1 GROUND RESOLUTION

Photographic interpretation for detail from aerial photography ranges from scales of 1:2,000 to 1:10,000, with ground resolution of object size obtained in terms of inches. In contrast, the common scales for photointerpretation for reconnaissance purposes range from 1:10,000 to 1:40,000, with ground resolution attainable in terms of feet. The common photographic mapping scale is 1:60,000, depending on the use of adequate ground-control points (American Society of Photogrammetry, 1960, p. 773).

The use of aerial color photography greatly extends the criteria that can be used for terrain property identification. Although the human eye-brain combination can only discriminate about 128 shades of gray, it can discriminate several million different colors.

There are many problems associated with the use of aerial color photography, apart from the cost of this film and the necessary processing techniques. The glass covering the camera wells in photographic reconnaissance aircraft are rarely of high optical quality and may act as an image-degrading filter with color tones appearing on the emulsion being different from the natural object colors. The optical properties and color correction of the camera lenses themselves, the quality, amount, and atmospheric absorption of the reflected solar radiation, and the variability of the dyes making up the film emulsion itself are other factors that can contribute to image color variability. The American Society of Photogrammetry has published a "Manual of Color Aerial Photography" that is highly recommended for pertinent information. A voluminous report entitled "Photographic Instrumentation - Science and Engineering" prepared for the Naval Air Systems Command (Hyzer, 1965) gives a thorough coverage of all photographic equipment and applications. The Navy Oceanographic Office (Vary, 1967) has recently conducted a test of the water-penetrating ability of color photography, in flights from 2000 to 30,000 ft altitude. It was found that 100-ft-sq offshore targets could successfully be detected at depths of 65 ft, even in rough water at sun angles from 20° to 40° .

Color photography from satellite altitudes provides coverage of earth areas of unprecedented scope and contrast. An example of this capability is the preparation of tectonic maps of the Middle East at one to one million scale by the North American Aviation Science Center under NASA support (Abdel - Gawad, 1967). These maps, prepared entirely from GEMINI photographs, show faults, shear zones, and geologic structures, often extending for hundreds of miles, that are unrecognizable in lower-scale photography.

Aerial panoramic cameras have been developed and used for over a decade to combine wide-area photographic coverage with very high resolution. They generally have a curved film plane and a high-quality, narrow-angle lens that scans across the flight path of the aircraft so as to "paint" an image of a wide

swath of ground onto the film. The maximum scan angle is 60° either side of the vertical. With a focal length of 12 in., very high altitude photography can be obtained without sacrificing image detail. Since the center of the lens rotates with the scanning arm, the sharpest possible image is always recorded on the film, even at the edges of the format. An example of the scope and high resolution of panoramic aerial photography is shown in Figure 13.

Modifications to aerial color film to eliminate the blue-sensitive layer have recently been proposed to film manufacturers. The standard yellow haze filter, would, therefore, not be needed, and a one-stop increase in exposure would be possible.

2.2 Multispectral Photography

Multispectral, multiband, and spectro-zonal photography are terms applied to the images simultaneously obtained through various filter combinations in narrow-band regions of the visible and near-infrared spectrum. The operating

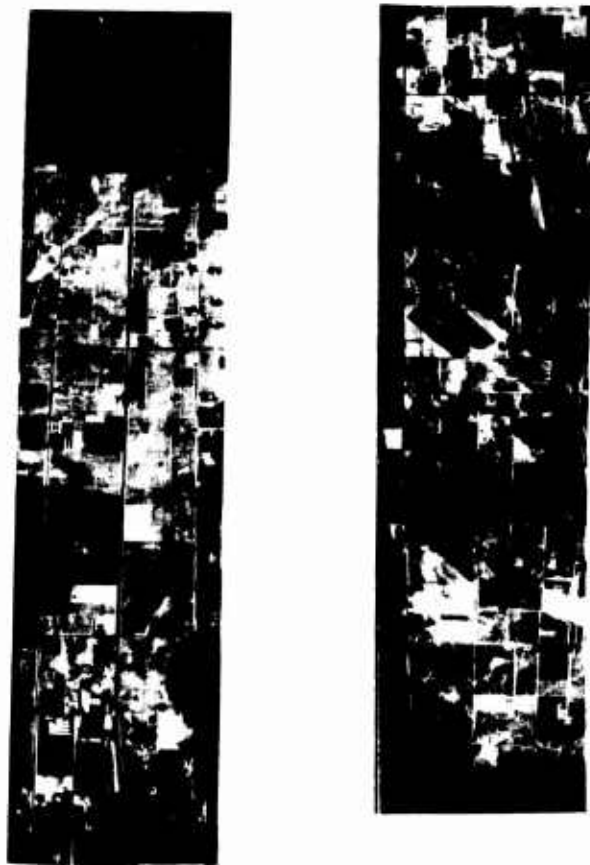


Figure 13. Aerial Panoramic View of Terrain

principle of this technique is that different types or conditions of terrain reflect solar radiation differently throughout the photographic spectrum. By interpretation of the relative brightness or tonal contrast appearing on matched, narrow-band images, changes in soil or vegetation properties and composition or seasonal effects on the terrain can be detected and analyzed. Such information can be obtained in a more quantitative manner from this type of aerial photography than from conventional black-and-white or even color photography.

A nine-lens camera system (Figure 14), originally developed for ARPA nuclear test detection program (Molineux, 1965), has been used extensively by AFCRL and NASA for airborne terrain research programs. This "multiband" camera employs three rolls of film, each traversing three matched lenses equipped with appropriate filters to give a narrow-band input to the film. The part of the spectrum covered is from 400 to 900 m μ , with resolution of approximately 75 lines per millimeter. The resulting nine photographs, taken at one shutter click, are matched within 0.001 in. Six of the images are on two rolls of 70 mm aerial panchromatic film, and the other three are on one roll of 70 mm aerial infrared film. The lenses used are f/2.4, 150 mm with standard gelatin filters that give bandwidths of about 100 M μ .

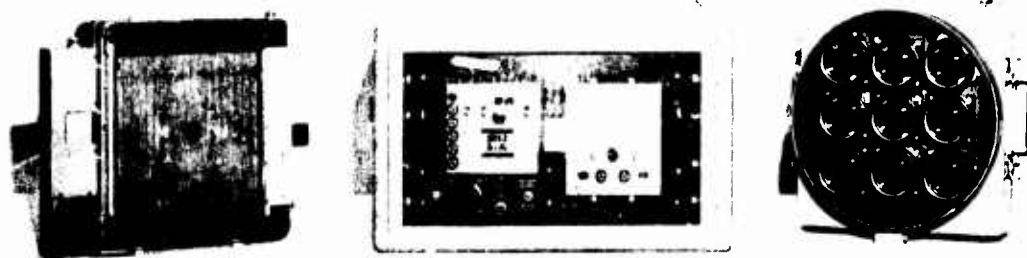


Figure 14. Multiband Camera System

Extension of the camera's capability to gather signatures of terrain properties is provided by the use of horizontally and vertically polarized filters in two of the bands, and an ultraviolet transmitting lens in another band, applied when desired. The camera has image motion compensation, and can be flown at altitudes of from 600 ft to over 25,000 ft. A stabilized mount is desirable to provide vertical control of photographic coverage. A wide range of shutter speeds and apertures are available for use over varying conditions of terrain illumination.

AFCRL's use of the multispectral camera has covered terrain areas ranging from arctic glaciers through lava flows and coastal beaches to desert playas and tropical rain forests, all of interest because of their characteristic reflectance

properties. Analysis involves examination of the nine images from each exposure on a light table modified to display the three rolls of film together. Terrain anomalies or patterns of interest can be identified in terms of their reflectance changes for correlation with known patterns and conditions; selected frames can be used for color enhancement or superposition techniques, if desired. In special cases where very subtle tonal differences are worthy of more analysis, a micro-densitometer can be used to scan the original negative and yield the detailed reflectance values that were registered as gray tones.

The nine bands were originally chosen to provide wide coverage throughout the spectrum. Since some of these may give no additional or otherwise redundant reflectance information, a lesser number of bands may be practical. Other government agencies (Rome Air Development Center, Army Terrestrial Science Center, and National Aeronautics and Space Administration) and many commercial aerial photographic organizations have developed four-band cameras by clustering four separate 70-mm cameras and synchronizing their shutters, which enable worthwhile multispectral photography.

An example of the imagery generated by the nine-lens systems of AFCRL, and the interpretation of the tonal changes evident in contrasting wavelength regions, is shown in Figure 15.

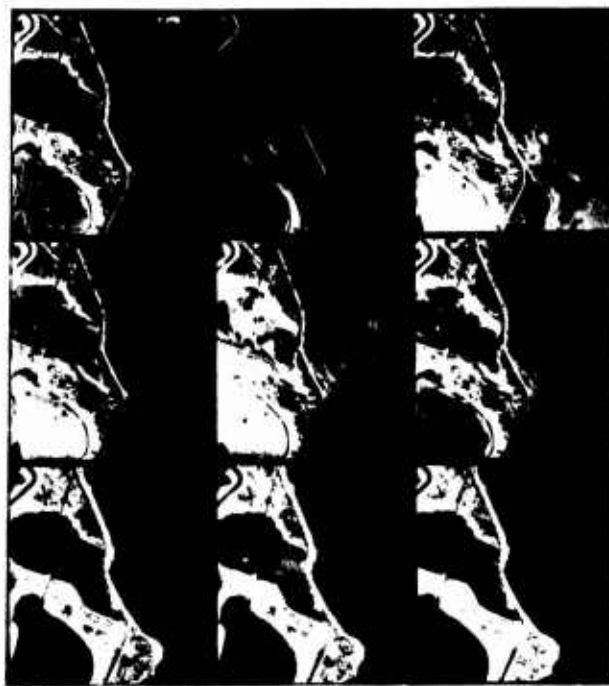


Figure 15. Multiband Photography

2.3 Color-Distortion Photography

"Camouflage Detection" (CD) or Ektachrome Infrared (IR) film is a high-resolution, false-color film that differs from normal color film by having its three sensitized emulsion layers record green, red, and infrared radiation instead of the usual blue, green, and red. It has high color contrast, brilliance, and haze penetration capability. The colors, although appearing false to one's experience, provide a contrast enabling adjacent objects or materials to stand out distinctly. Although the high-resolution values cited by the manufacturer are not generally realized through exposure and processing, the clarity of CD images provides greater detail than comparable color or IR images. Figure 16 illustrates the visible spectral and sensitivity ranges of pertinent films.

The use of color-distortion photography also enables distinction between types and health of vegetation cover. Deciduous green foliage reflects green and infrared radiation, and film processing leaves magenta as the indicator for such vegetation; coniferous foliage is recorded as a darker magenta. Due to changes in IR reflectivity of foliage pigments, dead or diseased leaves are recorded in shades of light magenta to orange. The effectiveness of using CD film for determining vegetation cover properties has been pioneered and established by Dr. Robert Colwell at the University of California (Colwell, 1966).

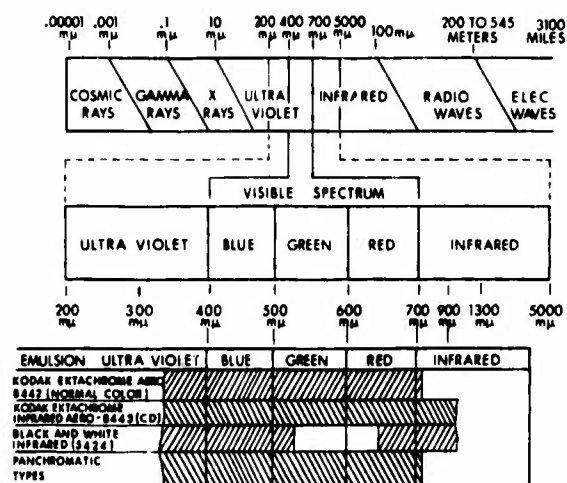


Figure 16. Electromagnetic Spectral Sensitivity Ranges of Films

In addition, the use of color emulsions, particularly CD film, enables very good photographic penetration of water. Underwater terrain contours and obstacles can be recognized and mapped by this CD photography, enabling offshore beach or shallow-water charting for amphibious operations.

Objects in shadow or shade usually are not detectable on normal black-and-white images, but they stand out readily on CD film. Objects of different colors, which usually show the same shades of gray in black-and-white photography, have definite color contrasts when imaged on CD film. This is especially valuable during conditions of low sun angle or in oblique photography where long shadows are produced.

CD photography is best reproduced and evaluated as transparencies, since the full-color values cannot be duplicated on paper prints.

2.1 Polarized Light Photography

In real target-background situations, illumination is by both direct sunlight and diffused skylight. Light reflected from surfaces, in turn, is both coherent and incoherent. Light reflected from most surfaces is considered partially coherent, in that a rough textured reflecting surface is a fairly good diffuser since the surface as a whole reflects diffusely while the many small facets of which it is composed reflect specularly. The expression $\frac{c}{\lambda}$, where c is the rms surface roughness and λ is the wavelength of the incident light, can be stated as a measure of the light-diffusing property of the surface. Multi-reflected light, in the case of a many-faceted rough surface, is randomly polarized. The intensity ratio of multi-reflected to directly reflected light is dependent on the distribution of facet orientation. This ratio generally increases with increasing total reflectance. Hence the degree of linear polarization of light reflected from diffusing surfaces is inversely related to the total reflectance.

The Naval Weapons Center, China Lake, California, has conducted many polarized photography experiments on natural terrain and man-made surfaces. Their experiments verify this relationship and prove that polarization contrasts can be used to detect and discriminate background and target materials, in both direct and diffuse illuminations. Several of their reports present a wide variety of natural materials photographed in both the visible and near-infrared spectrum. It was found that the largest polarization contrast exists in the 500 to 700 and the 800 to 1000 m μ region of the spectrum.

In general it can be stated that polarization contrast, like chromatic and luminous contrast, can be observed for any material, and that a discrimination capability is therefore present in the degree of polarization of light reflected from objects in any scene. Airborne measurements were carried out at NWC using a variety of polarizing filters in aerial cameras, and a polarizing TV camera was used in ground-based experiments.

2.5 Infrared Photography

The use of black-and-white infrared film in aerial cameras has both advantages and disadvantages. This film is designed to be sensitive in the red and near-infrared wavelength region, but it is also sensitive in the ultraviolet region below 530 $m\mu$. So that only the red and infrared portions will be recorded, a Kodak 89B filter is used to eliminate the ultraviolet and almost all the visible portion of the spectrum below 700 $m\mu$.

The difference in black-and-white IR photography as compared to panchromatic is most evident in the recording of water and foliage, as reported from Navy studies (Naval Reconnaissance and Tech. Support Center, 1966). Since water does not reflect or transmit infrared radiation, and the blue portion of the rest of the spectrum reflected from water surfaces is filtered out, water appears very dark or black with respect to land which is a lighter gray tone. Grass, bare earth, and water might all show an equal density or gray tone on panchromatic film. However, IR film will show the grass as light gray and earth as medium gray, enabling ready distinction. Delineation of shoreline contours is an immediately obvious capability.

IR films record healthy, lush vegetation in the lightest tones, while vegetation that does not have enough water reflects less infrared energy and shows as medium tones, due to changes in the relative amount of chlorophyll and pigments.

The filtered infrared sensitivity of this film also makes it useful for haze penetration, since the less-scattered rays are recorded. This infrared sensitivity also provides increased tonal contrast between man-made and natural objects, such as an asphalt runway against an adjacent grass or soil background.

The resolution of black-and-white IR film is noticeably poorer than panchromatic. Most lenses for aerial cameras are designed for visible light and therefore focus the infrared rays behind the normal focal plane, as shown in Figure 17.

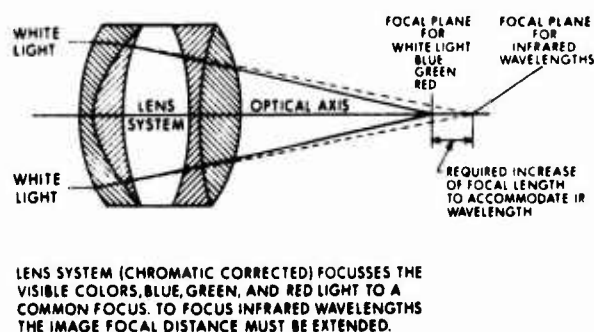


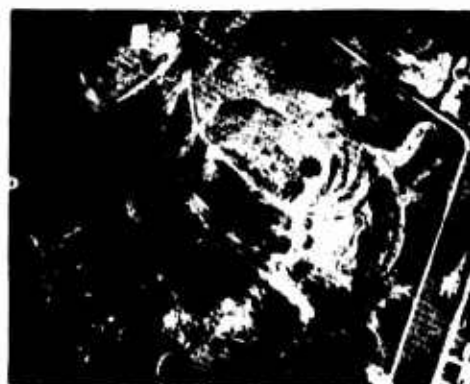
Figure 17. Focus of Infrared Wavelengths With Focal Distance

Refocusing or lengthening of the focal distance is therefore required with IR film. Not all of the IR wavelengths will be brought into the film plane, but a sufficient portion of them will fall into focus to produce an acceptable image. The 89B filter provides a bandpass of 200 m μ to minimize the possibility of degraded images generated by the lens-film combination.

A photometer or exposure meter cannot give reliable values to determine proper IR film exposure, since wavelengths beyond the visible spectrum do not register on these devices. The usual technique is to use the manufacturer's exposure index as modified by the appropriate filter factor. Areas highly reflective in the infrared, such as vegetation, require less exposure than industrial areas. Examples of comparison of simultaneous panchromatic and IR photography are shown in Figure 18.



BLACK AND WHITE IR



PLUS X

Figure 18. Comparison of Visible and Infrared Photography

3. INFRARED SCANNERS

In the last decade, an airborne, electromechanical, imaging, infrared radiometer, generally called an IR scanner, has been widely used for reconnaissance. They are now proving valuable for gathering geophysical data inasmuch as they generate a two-dimensional thermal map indicative of surface or sub-surface parameters.

The earth radiates energy in a spectrum approximating that of a blackbody at 300°K , with a maximum near $9.5\ \mu$ wavelength. It also reflects solar energy whose spectrum approximates a blackbody at 6000°K with a maximum near $0.5\ \mu$. The energy emitted by or reflected from the earth's surface is selectively absorbed by the atmosphere, with only the part that passes through "atmospheric windows" reaching an airborne detector, as shown in Figure 19.

In a scanner these detectors, generally sensitive to radiation between 3 and $5\ \mu$ or between 8 and $14\ \mu$, as shown in Figure 20, convert the radiation into wide-band electrical signals that modulate a light source or cathode ray tube. Recording is generally made on film passing in front of the tube at a rate proportional to the velocity height ratio of the aircraft. Lateral coverage is provided by rotation of a collecting mirror, and forward coverage by the motion of the aircraft. The resulting image gray scale is thus a function of the detected earth surface temperature. Tape recording of scanner output enables preserving a higher dynamic range of imagery for enhanced evaluation.

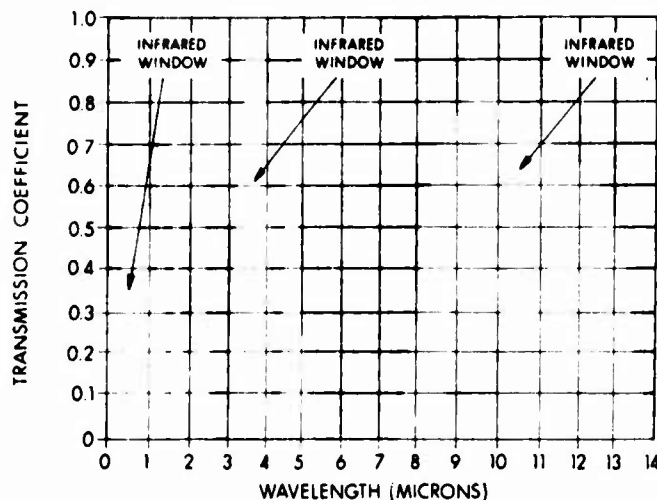


Figure 19. Infrared Transmission Through the Atmospheric Windows

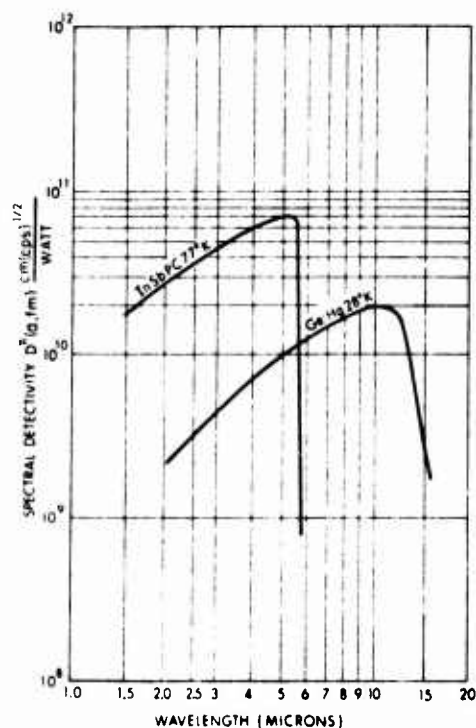


Figure 20. Infrared Detector Sensitivity Variation With Wavelength

Development of infrared scanners was pioneered by the University of Michigan, Texas Instruments, Inc., and HRB-Singer, Inc. Many terrain surveys using infrared scanning are being conducted by AFCRL, USGS, NASA, ONR, and ATSC (CRREL). Examples of such programs are thermal mapping of soil properties, vegetation, fresh- and salt-water ice patterns, volcanic activity, forest fire distribution, crevasses in ice, and recent applications to archaeology. The obvious military reconnaissance and detection programs using this technique are beyond the scope of this report.

Typical infrared scanner imagery obtained by AFCRL for terrain evaluation purposes is shown in Figure 21.

1. ULTRAVIOLET SENSING TECHNIQUES

A generally held opinion is that the absorption of solar radiation by the ozone in the earth's atmosphere causes a nearly complete attenuation of ultraviolet energy. However, experiments have proved that sufficient ultraviolet light may be available for daylight photography using sensitive film and appropriate filters. Also, it has been proved that many terrestrial materials have selective responses to narrow-band ultraviolet illumination.



Figure 21. Typical Infrared Scan Imagery

AFCRL, AFAL, USGS, ATSC, and the Army Tank Automotive Center are government agencies that have performed experimental photography using ultraviolet transmitting filters to distinguish targets and terrain backgrounds. Texas Instruments, Inc., has done similar studies for material discrimination. AFCRL is incorporating an ultraviolet-transmitting lens in its aerial multispectral camera for airborne terrain surveys.

A promising application is being conducted by USGS (Hemphill and Vickers, 1966a) involving use of an ultraviolet video imaging system for detection of luminescent minerals and rocks and for possible discrimination among non-luminescing materials on the basis of selective absorption of energy between 330 and 410 m μ wavelengths. Their scanning system employs an S-11 photomultiplier detector and is filtered to accept only wavelengths shorter than 410 m μ .

Airborne scanning imagery in the ultraviolet has been collected by USGS from up to 15,000-ft altitudes over representative test sites (Hemphill, 1966b) and it shows distinct contrasts between materials and vegetation. Sandstone and carbonate materials with a minimum amount of moisture are particularly reflective in the ultraviolet.

5. PHOTOMETRY AND SPECTROMETRY

Data on the visible and near-infrared spectral reflectance of various elements of the earth's surface are of the utmost value in photointerpretation. These data can permit discrimination of materials by their tonal brightness appearance on aerial photographs. In addition, spectral reflectance measurements from field or airborne sensors, extending into the far infrared in some instances, allow determination of the mineralogy, chemistry, particle size, and surface roughness of materials.

Reflectance measurements are made by a variety of photometers, spectrometers, spectrophotometers, and radiometers, usually filtered for narrow-band outputs.

One of the earliest and still most comprehensive experimental studies of reflectance was published by Krinov in 1953. The National Bureau of Standards long-time work by Keegan and his associates on vegetation reflectance (Keegan et al, 1956; Gates et al, 1965) have been major references in the United States. Since then many organizations (MERDC, ATAC, AFCRL, NWC, and NASA) have conducted extensive measurements of rocks, soil, vegetation, and man-made substances. A chart compiled by the University of Michigan is given in Table 1. The compilation by Steiner and Gutermann (1966) is a valuable survey of Russian data since the original Krinov studies.

Under NASA Support, R. J. P. Lyon of Stanford (Lyon and Patterson, 1966) pioneered the gathering and interpretation of geological reflectance signatures in the 8 to 13 μ infrared region. By matching the measured signatures with pre-determined ones in the memory of a computer, rock composition can easily be identified in field operations. Real-time determination at rates up to seven signatures per second, utilizing a filter wheel, are feasible, permitting sensing from aircraft. A typical group of emissivity signatures gathered by Lyon are shown in Figure 22.

6. RADAR SENSING TECHNIQUES

High-resolution, side-looking radar in the present state-of-the-art can be extremely useful for airborne determination of local geologic features, particularly geomorphic and gross relief patterns. A beam of radar energy provides unidirectional illumination rather than the multidirectional illumination given by atmospherically diffused sunlight. It therefore produces imagery that is composed of a great number of specular reflections, as the relationship of the surfaces to each other has a strong influence on the intensity of the returned energy recorded on the film. Small variations in surface relief thus imaged may express geologic phenomena such as folding, faulting, and drainage channels. Similarly, surface reflective characteristics based on the relationship of surface roughness to the radar wavelength can reveal to the interpreter the probable physical characteristics of the material. Fine materials such as clay, silt, or sand are imaged as a "no return", while coarser material such as rocks, a talus slope, or a lava flow show strongly textured patterns. Examples of such radar images are given in Figure 23, with interpretative captions, as reported by Autometrics Corp. (Bienvenu and Pascucci, 1962; Moore, 1966).

Table 1. Reflectance of Terrain Conditions

Type	Reflectance %	Peak Wavelength λ (μ)
Water Surfaces		
Inland Waters	3-10	0.4810
Oceans	3-7	0.4810
Bare Areas and Soils		
Snow	70-86	0.4810
Ice	75	0.5795
Limestone	63	0.5790
Calcareous Rocks	30	0.5790
Granite	12	
Mountain Tops (Bare)	24	0.5816
Sand	18-31	0.5616
Clay Soil	1.5-15	0.5828
Ground Bare (Rich Soil)	7.5-20	0.5832
Field (Plowed)	20-25	
Vegetative Formations		
Coniferous Forest	3-10	0.5744-0.5758
Deciduous Forest	10-15	0.5719-0.5858
Meadow (Dry Grass)	3-8	0.5758
Grass (Lush)	15-25	0.5719
Field Crops	7-15	0.5858
Man Made		
Buildings (Cities)	9	0.5828
Concrete	15-35	

Although the resolution and definition of side-looking radar images are much poorer than aerial photography, radar has many operational advantages over the latter. Returns can be obtained through any weather conditions except heavy rain; the day- and night-scanned images are equally good; returns can be obtained from high altitude and at high speeds; coverage extends many miles to either side of the aircraft; and the scale is built into the system.

There are two types of imaging radar, the noncoherent or real aperture type of system that uses a large antenna, and the coherent or synthetic aperture type employing a relatively small antenna along with an elegant signal processor. Both are generally used in a direct side-looking aspect. With noncoherent radar,

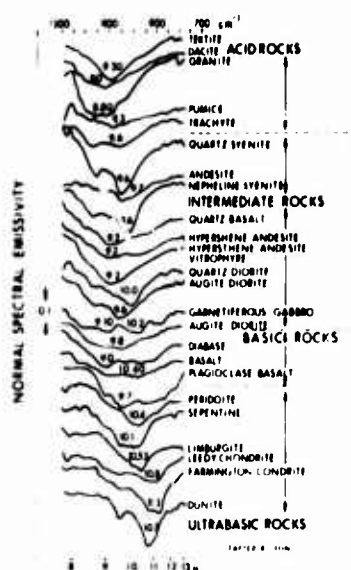


Figure 22. Spectral Emissivity of Common Rocks
(Lyon and Patterson, 1966)

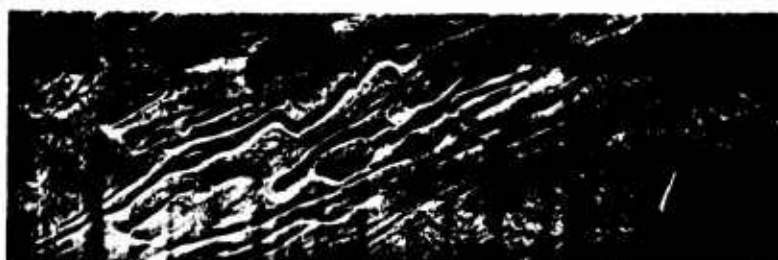


Figure 23.
Radar Imagery

resolution is determined by the antenna beamwidth; with coherent radar, resolution is achieved by the processor's ability to separate targets closely spaced in azimuth by virtue of their time-displaced doppler histories.

Synthetic aperture imaging systems function as follows: The aircraft carries a small side-looking antenna producing a fairly broad beam that scans the terrain by virtue of aircraft motion. The terrain is illuminated at an appropriate sampling frequency by either a narrow pulse or a pulse-compression waveform, depending on the resolution and range requirements. The reflected signal, after intermodulation with the coherent transmitter reference, is stored. Successive terrain-signal samples are then processed in a manner analogous to the coherent weighted summation carried out by a large antenna array. The actual signal processing is usually carried out by optical methods involving film as the storage medium; however, real-time systems have been built using a storage tube as the memory and electronic circuitry for the matched-filter processing. The resolution of a synthetic aperture radar, in contrast to most sensors and optical devices, is independent of range as long as an adequate signal-to-noise ratio exists.

Radar imaging provides location as well as magnitude of the back-scattered return. Because imaging systems operate over a rather restricted portion of the RF spectrum and towards the higher end (typically X and K bands), more is determined about the geometry of a radar target as opposed to its properties as a radar reflector.

Most modern side-looking radar systems are classified as to their specifications and operating parameters, and their use for reconnaissance and target detection purposes is well known and beyond the scope of this report.

A non-imaging four-band radar system has been used by the Army Engineer Waterways Experiment Station for several years in investigations of the radar power return as functions of soil properties. The system comprised K-, X-, C-, and P-band frequencies beamed on soil samples from a 50-ft elevation at various incident angles, as shown in Figure 24. Test conclusions were that such radar



Figure 24. Army WES Experimental Radar System

sensors can provide information on surface water and moisture content of deep homogeneous soil samples. In addition, a swept-frequency radar system can locate ground or surface water. Research investigations are now being conducted for boom-mounted instruments carried on ground vehicles transversing natural terrain.

Stereoscopic or three-D radar is still in the research stage, and several commercial electronic organizations are in the process of developing feasible systems.

Such newer developments have not downgraded the use of high-definition radar-scope photography for studying the earth's surface. Detailed analysis of such imagery has been reported by Texas Instruments (Feder, 1960) and by Acadia University (Cameron, 1965); their analysis shows marked delineation of fracture patterns, folds, and faulting, and distinct erosional patterns.

Optical radar, laser radar, opdar, and lidar are terms applied to the use of narrow-band or coherent light propagation and return similar to conventional radar. Many organizations are conducting research on these techniques, but to date they are used mainly for detection and ranging purposes. Identification and measurement of earth properties and characteristics by such coherent-light beam is still an application awaiting further study.

6.1 Pulsed Radar Techniques

Instantaneous airborne determination of the thickness or layering of terrain material, especially floating ice, is feasible by use of high-resolution, monocycle radar. The analogy is to seismic-reflection prospecting using a single acoustic pulse, in that a single electromagnetic pulse (monocycle) is radiated into the terrain and thickness determined by analysis of the reflected returns.

When a monocycle is transmitted, a portion of the energy is reflected at the air-surface interface; the remainder is transmitted through the medium, and some of this is again reflected at the next interface. The latter might be a layer of soil having a different density or moisture content, such as the water table, the top of bedrock or permafrost, or the ice-water interface of floating ice sheets. Matching of the relative pulse amplitude and time delay to patterns prepared for the known physical properties of the medium being surveyed enables determination of the thickness or layering depth.

The period of the pulse is determined by the resolution required or the frequency range desirable. In general the lower frequencies can penetrate more deeply with less scattering, but at the same time are limited in time resolution for return signal interpretation. Pulses with central frequency of 400 megacycles and periods of several nanoseconds have successfully been used for this type of terrain sensing.

Barringer Research, Ltd. (Barringer, 1965) developed and tested such a system, using shock-excited antennas on a ground vehicle boom as shown in Figure 25, which accurately determined the thickness of the lake ice to within 10 percent.

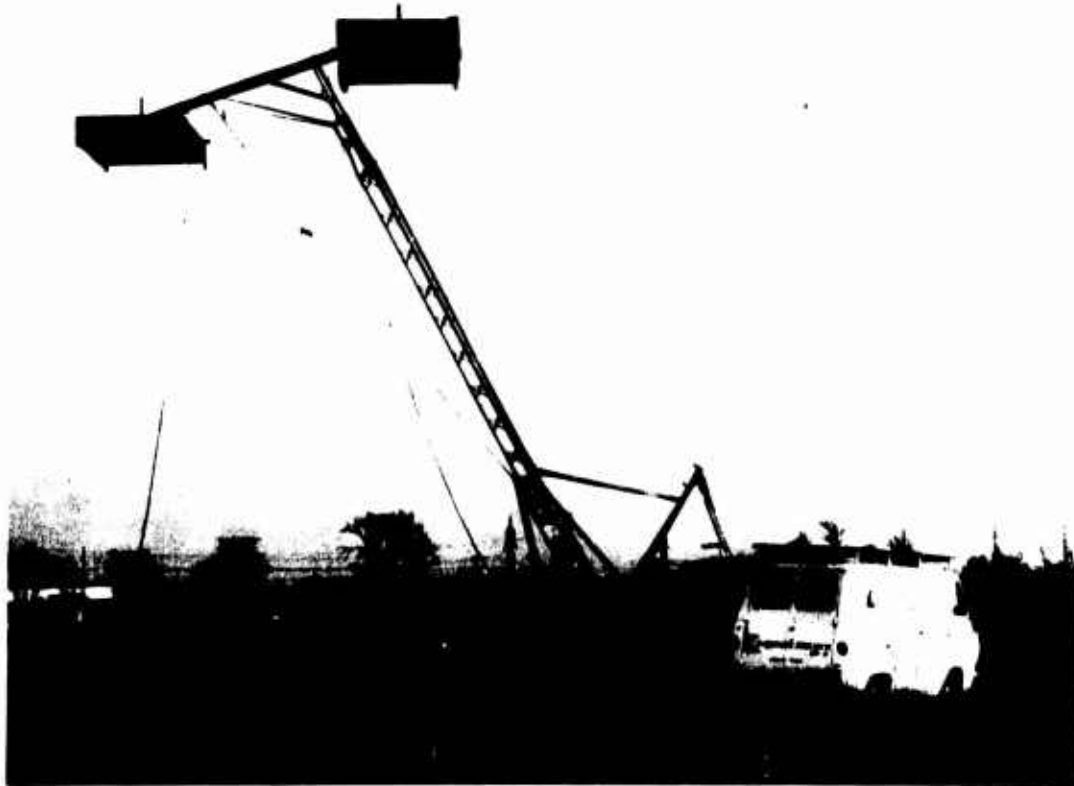


Figure 25. Pulsed Radio Wave Method

Thickness and layering measurements of soils were less successful, due to the complex dielectric constant and conductivity relations within a soil mass. Additional tests indicated that variable-frequency radar operating at frequencies between 100 and 300 MHz, together with coincidence and correlation analysis of the complex pulse returns by computer techniques, would provide this capability. Barringer Research, Ltd. has recently developed an airborne version of this system for NASA that is awaiting verification tests. The Army Engineer Waterways Experiment Station has continued the work on the variable-frequency concept, using 300 MHz

frequencies on multi-layer soil samples. Absolute values of the soil dielectric constant were determined and the thickness of soil layers measured, even though the reflected power dropped to less than one percent due to surface roughness scattering or vegetation attenuation. Field tests by a ground vehicle-boom configuration are now being conducted.

The Adcole Corporation, under contract to the Army Terrestrial Science Center, has successfully continued the ice-thickness measurements, using a monocy- cle radar system from a helicopter (Meyer, 1966). Fresh-water ice masses up to a meter thick were measured, even with one-half meter of snow cover.

6.2 Radar Scatterometry

Radar scatterometry is an active remote-sensing technique pioneered by Dr. R. K. Moore at the University of Kansas under NASA sponsorship (Moore, 1966). It measures the radar scattering coefficient of surfaces having different roughness and material. Applications to measuring sea state and ice roughness were established, and indications of terrain texture and moisture content, both at the surface and somewhat beneath it, were observed. Scatterometry is feasible with wavelengths from fractions of a micron (using lasers) to tens of meters. The normal range for radar scatterometers is from a few millimeters to a few meters wavelength. This range by comparison is wider than from violet light to the longest infrared wavelength commonly in use.

Signals generated by a radar transmitter are re-radiated from the ground and received back at the radar location. If the ground surface is a perfectly smooth plane or sphere, a specular reflection results. Such surfaces almost never exist in nature, hence radar return is almost always a scattering process, enabling measurement of the scattering or reflectivity coefficient. The most favorable angle of incidence of an airborne radar scatterometer is near zero (normal incidence), as with larger angles the range is so great that signal return becomes too small for processing.

Normally, the radar scatterometer cannot discriminate individual small elements of the surface, but must look at a sum of the returns from many such elements. Processing of the data enables compilation of the differential scattering cross section that describes the average properties of a particular surface type.

Conclusions from experimental data gathered by the University of Kansas and Ohio State University with airborne radar scatterometers are that relatively smooth surfaces, such as the ocean, give strong returns near the vertical but the returns fall off rapidly with angle. Surfaces having the same geometry as the sea surface, but smaller reflection coefficients, such as deserts, have scattering coefficient curves with the same shape but smaller absolute magnitude. Surfaces

rough compared with wavelength, such as forests, or, for very short wavelengths, rough gravels, have smaller scattering coefficients near the vertical than the smoother surfaces. However, their scatter changes little with angle, so that near grazing the return from the rough surface is much greater than that from the smooth surface.

Both experimental observations and theory indicate that returns near the vertical are due to larger scale fluctuations in the surface than the returns near grazing angle of incidence. Detailed curves for specific materials have been prepared, including vegetated surfaces. Radar scatterometers provide their own illumination and can, therefore, discriminate among returning signals that are not dependent on self-emission or randomly incident sources reflected from the surface.

7. IMAGERY ANALYSIS TECHNIQUES

Skilled interpretation of sensor imagery, particularly photography but also including infrared-scanner and side-looking radar imagery, is the standard and most widely used method for identifying and evaluating earth surface features. The variation of the individual ability and experience of photointerpreters obviously affects imagery analysis, and efforts to improve upon such often subjective techniques are a necessity. Photointerpretation has generated a great variety of coding keys of terrain and cultural features, signatures, and backgrounds. However, these keys are used mainly to help an interpreter discriminate targets from the terrain background, whereas the objectives of remote sensing, as indicated in this report, are to provide knowledge of the properties of the "background" itself.

The University of Michigan is conducting (for the Air Force Avionics Laboratory) a target-signature program wherein they will compile, tabulate, and evaluate as much electromagnetic sensor imagery as possible pertaining to target discrimination and terrain characteristics. The NASA Manned Spacecraft Center in its Earth Resources program has also accumulated a vast library of sensor records of the character and composition of landforms and features of the earth's surface.

Many techniques are in the process of development, test, and application to ease the problems of manual interpretation of large amounts of sensor imagery and returns. Recording on magnetic tape allows a larger dynamic range of input signals and facilitates later processing of such imagery for enhancement of detail and contrast. The use of thermoplastic tape, pioneered by the General Electric Company, allows real-time recording up to densities of 1700 lines per inch with picture elements of 8000 per line (AFAL, 1966). The recording is done by an electron beam writing on a strip of 70-mm thermoplastic tape.

Electronic instrumentation for scanning imagery now permits the presentation in a graphical form of the gray-scale tonal values along the scanned traverse. Such waveform segments can be presented as statistical parameters associated with the various terrain types or characteristics recorded on the image. Many commercial and university groups have published descriptions and uses of such instrumentation for pattern-recognition objectives.

The color enhancement or color-additive technique is an excellent tool in photographic imagery analysis, particularly with multispectral images. Using this technique, for example, a negative is prepared from band 1 and a positive from band 2. By superimposing these, a complete cancellation is achieved except — a highly significant point — for those areas where a color difference exists in nature. A more sophisticated step is to prepare various combinations using many bands, such as a red, a blue, and a yellow band. In each case the film records emphasize color difference and subdue color likeness. When these records are cascaded and printed as a single unit or with additive printing onto a final color positive, the resulting image brings out features indistinguishable in any of the original film records. The appearance is that of a camouflage-detection image, and it emphasizes the otherwise subtle tonal differences discerned by the camera.

Optical data processing is a relatively new method that enables extraction of detail and contrast from photographic negatives. The development of fiber optics and the laser has sparked many applications of digital optical systems to data processing, pattern recognition, and analog computation. A major advantage of digital optical systems is their high storage density. Such systems enable the obtaining of many successive two-dimensional Fourier transforms of any given light-amplitude distribution, such as would be represented in aerial photographs of the earth's surface. The applications of optical data processing to geologic imagery interpretation and enhancement is currently under study for AFCRL by the University of Michigan. The appreciation of the imaging properties and vast storage density of holograms is an outgrowth of these experimental studies of reconstruction and analysis of imagery. However, lack of qualitative measurements and limiting conditions of image reconstruction have handicapped the use of holography, except in the laboratory.

Change detection, or the analysis of differences between two sets of imagery taken of the same area at different times, can show such factors as seasonal effects on terrain, growth of vegetation, and the sequential morphology of landforms, in addition to the militarily important changes in man-made or cultural features. Photographic or electronic images can be scanned, rectified, manipulated, and correlated by existing techniques, and evident changes can be automatically compared and recorded.

The Army Engineer Topographic Laboratory has developed an "automatic mosaicker" that produces rectified transparencies from imagery and compares them for change-detection purposes, rejecting extraneous factors such as clouds and shadows. Vertical images obviously have the greatest potential for treatment and analysis by this technique. Further extension of the change-detection concept to the "moving target indicator" are well developed and generally used in radar and active sensor reconnaissance and will not be treated in this report.

8. PASSIVE MICROWAVE RADIOMETRY

All objects emit electromagnetic energy due to the random thermal agitation of the electrons within them. The intensity of this radiation depends on the temperature of the object, the frequency at which it is measured, and certain of its physical properties such as dielectric constant, magnetic permeability, electrical conductivity, and surface characteristics. An object may also absorb or reflect any electromagnetic radiation that is incident upon it. The radiometric temperature of an object thus not only is dependent on its emissivity and own temperature but also on its reflectivity and the temperature of the sky environment being reflected.

The radiometric energy emitted from an object or material can be measured at great distances. In the microwave and millimeter wavelength regions the power emitted varies directly with its temperature and inversely with the square of the wavelength. At a given frequency and polarization the emissivity and reflectivity of a material are functions of its surface roughness and the angle of incidence of the radiometer antenna. The region of a solid object that contributes to its observed radiometric temperature extends from the surface downward to a depth depending on its dielectric constant and conductivity. Different frequencies can therefore be said to have different penetrations. Materials such as water or metals have high reflectivities and generally exhibit cold radiometric temperatures (150°K). Conversely, good absorbers such as dry soils or vegetation show high radiometric temperatures (290°K).

Passive microwave radiometric sensing of the apparent temperature of natural terrain and objects upon it is a previously neglected technique. With the development of new analytical methods, advanced instrumentation, and data processing techniques, this sensing method can now be effectively employed for ground-based and airborne earth-science studies. Raytheon Corp., North American Aviation, Inc., and the Jet Propulsion Laboratory of the University of California have used microwave sensing for several years and reported extensively on its applications.

Probably the most comprehensive application of passive microwave sensing of the properties of terrain is being conducted by the Space General Division of Aerojet General Corporation in a tri-service-supported study (Kennedy et al, 1967; Kennedy and Edgerton, 1967). From a boom on an extensively instrumented trailer, a three-frequency microwave radiometer with both vertical and horizontal polarization capability was successfully used to determine the moisture content, layering, and distribution of soils, water, ice, snow, and rocks. An example of the discrimination of soil types on the basis of their radiometric temperatures thus obtained is shown in Figure 26. Soil moisture content can be identified to a 1 percent accuracy by this technique.

Airborne passive microwave radiometric sensing is also a valid technique. Test flights of one of the Space General Division's radiometers over the terrain previously studied have closely verified the previous measurements. Icebergs and floating sea ice were detected by the U. S. Coast Guard for several years, using microwave equipment developed by Sperry Rand (Roeder, 1967).

Microwave thermal imaging of terrain is still a technique awaiting advanced equipment development. Space General conducted experiments using a 3.2-mm (94 GHz) radiometer (Chalfin and Ricketts, 1966). The output, as recorded on magnetic tape, was processed by a computer and plotted to yield half-tone images. Although appearing crude to the eye trained for photographic-image analysis, they showed gross terrain features that closely corresponded to visible-light photographs. The contrasts between reflectors and absorbers was strong, and in heavy fog, where visible and infrared photographs showed practically nothing, a useable image was produced by the radiometer.

9. VAPOR AND TRACE MATERIAL SENSING

Remote sensing of odors, gases, and vapors has recently been applied for personnel detection by the "people sniffer" developed by the Army Limited War Laboratory, and successfully used in Viet Nam. Another obvious use of such a technique is the conduction of air pollution studies. The measurement of vapor concentration by remote sensing is also potentially useful for geophysical exploration. Geothermal and volcanic activity often give rise to emanations of sulphur dioxide and halogens in the air, which can readily be of significance as indicators of sources of power, heat, and minerals, as well as potential hazards to military or geophysical installations.

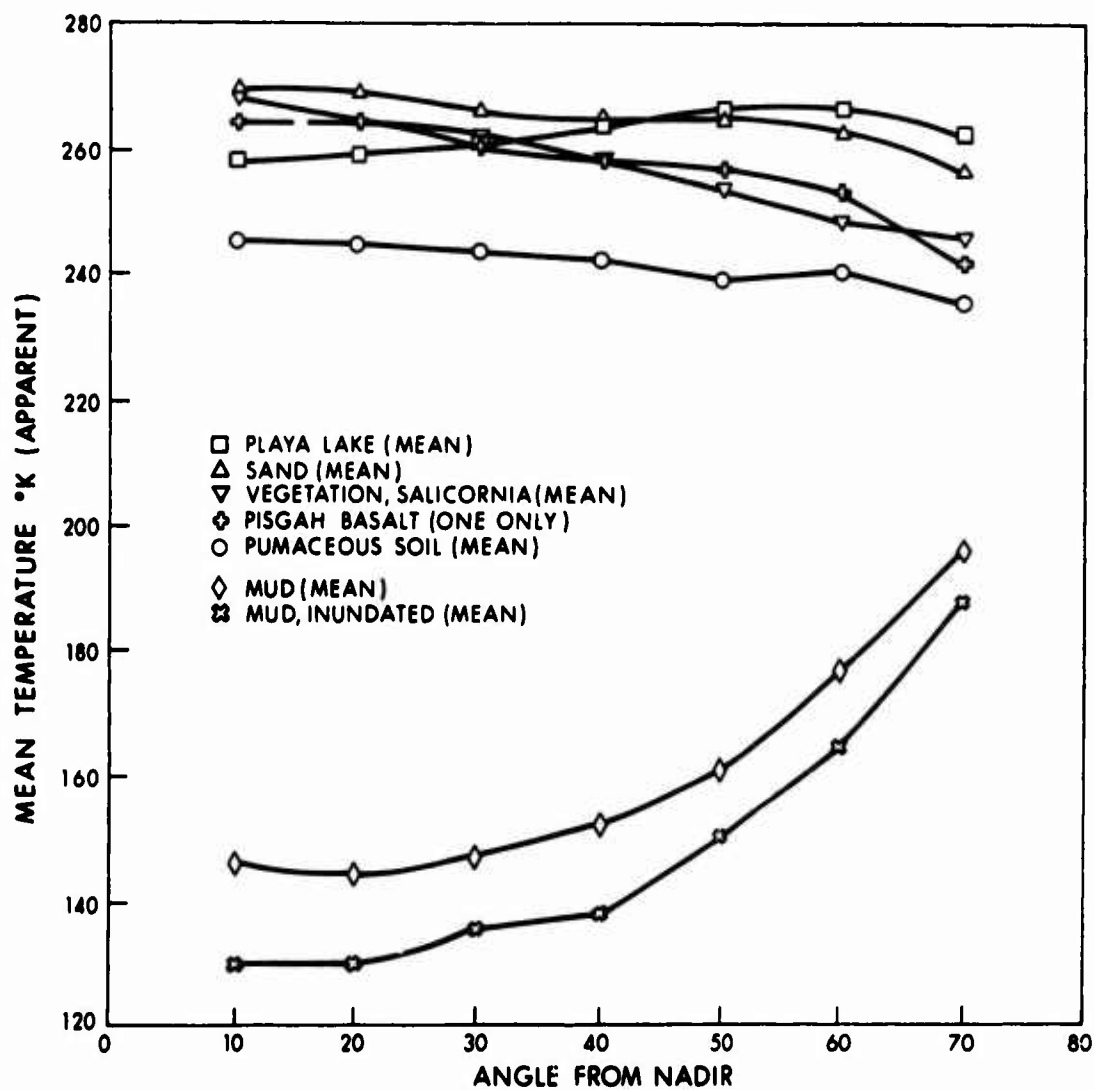


Figure 26. Passive Microwave Data on Various Natural Materials

Oxidizing ore deposits similarly generate vapors that might be detectable. The association of detectable iodine with deposits of marine origin, such as oil field brines, may be exploited. Iodine is also concentrated in marine organisms and plant life by a factor of 10^5 as compared to seawater. Such sensing of marine life could have important economic applications in the future.

Barringer Research, Ltd. developed and tested instrumentation for the remote sensing of vapors; the instrumentation has a sensitivity in the one part per billion range (Barringer and Shock, 1966). The design is based on a conventional spectrometer with its exit slit replaced by a "spectrum correlation" recording mask. These masks are pre-prepared for known gases or vapors and used to cross-correlate the maxima and minima absorption bands of incident light from the gas being sampled. Laboratory tests have verified the sensitivity of the instrumentation and the feasibility of detecting and identifying low concentrations of sulphur dioxide, mercury, and iodine. An airborne unit has been built for NASA. It features an automated mask changer which programs the device for a number of specific vapors to be sensed and identified. Very high sensitivity for monotomic vapors can be obtained, due to the strong and narrow absorption lines they produce in a spectrometer.

The Army Ballistic Research Laboratory developed techniques for the rapid interpretation and discrimination of characteristic chemical vapor signatures by computerized pattern analysis. Such a system might be used with suitable sensors in low-flying aircraft to collect information about ground sources of such material.

10. LASER APPLICATIONS

So that low-light-level TV or scanning sensors can be used at night to view terrain or targets, laser illumination techniques are under development and even now being tested in actual operations. Such lasers radiate mainly in the infrared region. Problems foreseen are the need for stabilized systems to overcome aircraft buffeting by turbulence and the possible degradation of laser illumination by dust, smoke, or clouds. Also, the high repetition rates of a laser illuminator require more reliable and better cooling systems than do less sophisticated scanning assists.

A laser line-scanning camera used as a hightime reconnaissance sensor has been extensively tested (Stein, 1967). Such a sensor uses a laser beam scanned at right angles to the aircraft flight direction as a light source to illuminate the terrain below. The laser returns, varying as a function of the terrain reflectivity, are recorded on film with very high quality imagery resulting. Such a system eliminates the need for flash cartridges or other giveaways of the position of the photographic aircraft.

11. AIRBORNE PROFILE RECORDERS

The microtopography or surface roughness of terrain is of obvious importance in planning or conducting military operations. Natural obstacles such as bushes, boulders, or gullies complicate the evaluation of normal slope variations. When Arctic regions are considered, the ever-present pressure ridges and the irregularities of sea ice, glaciers, and ice fields are natural hindrances to wheeled vehicle traffic. Other needs for airborne surface roughness measurement are information on sea state conditions, wave heights, beach slopes, etc.

For many years, combinations of radar and barometric altimeters were used for relative terrain height measurements. These devices, commonly called airborne profile recorders, use the principle of radar reflection over aircraft-to-terrain distances, corrected for aircraft altitude deviation from some barometric datum surface. A reference is established by flying at a pre-set barometric altitude over a terrain feature of known elevation. Further flying over an area of interest will enable applying the aircraft altitude deviation to the radar height record to give the terrain profile. Primary limitations are accuracy (about $1 \text{ ft} \pm 0.5 \text{ percent}$ of flight altitude) and beam size (15° half angle). Present narrow-beam airborne profile recorders are estimated to have an accuracy of $\pm 20 \text{ ft}$ at altitudes up to 30,000 ft, while illuminating an area 500 ft wide.

A recent joint development of Aero Service Corp. and Spectra-Physics, Inc. has provided an operational laser altimeter with greatly improved accuracy and resolution performance (Jensen and Ruddock, 1965). This device incorporates an improved barometric pressure sensor with a CW helium-neon gas laser generating 50 mW of diffraction-limited light at 6238 Å. The beam generated is about 1 in. wide, resulting in terrain height resolution of 2 in. in the vertical plane and less than 1 ft in the horizontal at 1000 ft altitude, and within 2-5 ft vertical resolution at 15,000 ft altitude. Flight tests conducted under the auspices of the Army Engineer Waterways Experiment Station verified the exceptional ability of this device for terrain profiling. A limitation to all-weather use of this laser altimeter is the severe attenuation and scattering of the light beam by water vapor.

12. GAMMA-RAY SENSING

The gross natural gamma radioactivity of common sediments has been used for many years in mineral and oil exploration and in the interpretation of geologic structure. Marine shales have abnormally high radioactivity, whereas other rock types such as anhydrites, pure sandstones, and limestones have very low radioactivity.

The principal natural materials contributing to background gamma radiation are the uranium, thorium, and potassium decay series. Different soils and their parent rock material show varying and characteristic contents of these chemically different natural radioactive elements, which reflect the physics and chemistry of the rock in addition to the effects of weathering in soil production. In general, these element contents of igneous rocks increase with increasing acidity or silica content. These concentration ranges are tabulated in Table 2.

The U. S. Geological Survey (Moxham, 1960) has extensively explored mapped total gamma radio-activity patterns throughout the United States, using airborne scintillation counters. Major oil companies have done similar work in smaller areas. The recent development of practical, total-absorption, gamma ray, spectral-measuring equipment for field use has enabled much refinement of soil and rock identification by this technique.

The Army Engineer Waterways Experiment Station has conducted detailed laboratory investigations to determine soil parameters useful in estimating trafficability (USAEWES, 1967). Their results indicated that photopeak counts of the radioisotopes of primary interest were proportional to the moisture content of the soil samples; however, ratios of these photopeaks were nearly independent of moisture content, although different for each soil type tested. From this data, it would appear that geological formations, such as loess and shales, can be distinguished from limestone and sandstone material, and that this technique is a powerful tool for estimating soil moisture content. Airborne tests using a large array of gamma ray detectors were recently conducted to verify the extension of this sensing method for remote measurement.

13. AIRBORNE EM SENSING

Since a high proportion of the earth's sub-surface is covered by a mantle of soil, ice, weathered rocks, transported alluvium, glacial debris, dense vegetation, or water, airborne "prospecting" for subsurface deposits of minerals or strategic resources is limited to those deposits which have a surface expression. Airborne magnetic surveys are effective in outlining many types of intrusive and extrusive rocks, even when they are buried under deep overburden. However, these surveys are limited in defining the sedimentary geology wherein valuable ground water, non-magnetic metallic deposits, industrial minerals, construction materials, and oil resources may be residing.

Associated parameters such as conductivity, which can be sensed from aircraft, can provide useable clues to sub-surface deposits. The majority of metallic ores such as copper, nickel, lead, zinc, silver, and gold contain sufficient sulphides

Table 2. Radioactive Elements in Igneous Rocks and Sediments

RADIOACTIVE ELEMENTS IN IGNEOUS ROCKS			
Rock	Thorium (ppm)	Uranium (ppm)	Potassium (%K ₂ O)
Silicic Intrusive (Granites & Syenites)	1-25	1-6	1.5-6.0
Silicic Extrusive (Rhyolites & Trachytes)	9-25	2-7	
Basic Intrusive (Gabbros & Diabases)	0.5-5	0.3-2	0.4-3.0
Basic Extrusive (Basalts & Andesites)	0.5-10	0.2-4	
Ultrabasic Intrusives (Peridotites & Dunites)	low	0.001-0.03	0.1-1.0
RADIOACTIVE ELEMENTS IN SEDIMENTS			
Rock Type			
Clastic Rocks			
Common Shales	2-47	1-13	0.9-6.7
Orthoquartzites	0.7-2	0.2-0.6	0.9-2.6
Black Shales	2.8-28	1.4-80	0.9-6.7
Residual Rocks			
Bauxites	8-132	1.5-22	very low
Bentonites	6-44	1.0-21	very low
Precipitated Rocks			
Carbonates	0.1-7	0.1-6.5	0.1-0.6
Salt Beds	0.4-0.5	1-5	up to 30%
Chert	0.1-1.6	0.01-0.9	0.07-0.4

to provide them with a large conductivity contrast with surrounding rocks. The development of low-frequency, electromagnetic, inductive, airborne sensing systems has recently been exploited for commercial exploration. Present capabilities permit detection from several thousand feet altitude and signal penetrations up to 700 ft depth.

The U. S. Geological Survey is currently using an induced-pulse-transient EM system in an aircraft. This system radiates a short electromagnetic pulse that induces eddy currents in conductive bodies (Barringer, 1962). The pulse has a repetition rate of 380 pulses/sec, and is generated from a large horizontal loop antenna strung across the aircraft. The time-varying decay transients of the eddy currents are received in a stable high-drag "bird" towed behind the aircraft. The amplitudes of these received signals are sampled after selected time delays and their ratios define the shape of the characteristic decay curve associated with the degree of conductivity.

Initial use by the Canadian Geological Survey has indicated the ability of the system to detect gravel deposits, which could be important aquifers, lying in glacial clays (Collett, 1965). Computer analysis is being applied to study conductivity stratification in the ground. Results indicate that differentiation of areas of sulphide mineralization from those of other ionic conductors is feasible.

11. AIRBORNE MAGNETOMETERS

The airborne magnetometer has been used since 1946 in petroleum and mineral exploration, with some 20 million square miles of survey flown covering a large portion of the earth's surface. The military services have used airborne magnetometers for reconnaissance of submarines and land-vehicle targets. Gradual improvements in instrumentation have been made, but 1 gamma has generally represented the limit of attainable resolution.

Recently the rubidium vapor magnetometer was developed. Although originally designed to measure the magnetic field in space probes, it has had immediate use as an airborne device for oil exploration. The resolution of this device is 0.1 gamma, enabling more detailed mapping of the total magnetic field, which in turn reflects variations of the sedimentary structure and basement complex of the earth. The system can be located in a towed-bird configuration or mounted in a tail-boom "stinger" on aircraft. Data are presented on a strip chart in analog form, with the linear scale calibrated directly in gammas for easy compilation of area maps.

Further application of this new device has resulted in the magnetic gradiometer (Aero Service Corp., 1967), an ultra-sensitive tool for direct measurement of the vertical gradient of the earth's magnetic field. This system comprises two

simultaneously recording rubidium or cesium vapor magnetic sensors flown from or on an aircraft and separated by a fixed vertical distance. Sensitivity of measurement of the vertical gradient is in ten-thousands of a gamma per foot. In comparison to the total field map, the gradiometer more closely defines and differentiates earth structure effects and increases the amplitude of local anomalies while attenuating regional effects.

These new magnetometers also have application to the detection of buried objects, when used in ground-vehicle surveys. Arms caches, pipe lines, underground communication cables, etc., are susceptible to detection by this method, and it has been used recently in a presently inconclusive attempt to detect tunnels in Vietnam. Previous applications in detecting buried materials for archeological purposes have been reported.

15. GRAVITY SURVEYS

While airborne or surface measurement of the variations of the gravitational field over terrain areas cannot directly reveal the surface properties of such areas, these variations are often indicative of the geological formation beneath. In general, without delving into complex theories of gravity-earth structure relationships, it can be said that gravitational anomalies are related to the densities of underlying material. The average density of granitic rocks is about 2.7 gm/cc; for poorly-sorted fans and alluvial debris it is 2.4 gm/cc, and for silts, clays, or other fine material it is 2.0 gm/cc. Detailed surface gravity surveys may, therefore, give useful information on basement topography, the depth and extent of basin or fill material, the presence of faults as inferred from steep gravity gradients, and ~~barriers~~ to or channels for ground-water movement. In addition, sub-surface cavities or voids can be easily detected, since they appear as "negative" gravity anomalies of substantial size and extent (Romberg, 1961).

Because of the higher altitude and speed of coverage, airborne gravimetric surveys have far less capability to distinguish the density of terrain areas. However, experimental airborne gravimetric surveys are often used by commercial petroleum companies to outline large geologic structures, such as salt domes, that could be oil-bearing formations. Other large-scale regional features such as deep crustal rifts, major deep-seated igneous rock intrusions, and massive ore deposits may similarly be detectable, using the recently developed gravity gradient sensors of extremely high sensitivity (0.1 mgal).

16. ACOUSTIC SENSING

Acoustic sensing techniques are generally typified by the use of sonar to identify the location and spatial configuration of underwater objects such as submarines, mines, reefs, or structures. Some application has been made to sounding the bottomside of floating ice from submarines. However, airborne use of acoustic sources as sensors of terrain properties is generally infeasible. Limiting factors include the scattering of the sound through the intervening atmosphere, the wide-beam coverage of such a source, the scattering of a possible return, and the lack of acoustic coupling for propagation of sound waves through unconsolidated soils.

Sonar mapping of ocean bottom sediments and their distribution has been successful, using acoustic sources from a ship. Information on landforms adjacent to lakes, fjords, or rivers might be gained from a knowledge of the erosional materials deposited as bottom sediments. Sonic techniques deployed from a hovering helicopter having the necessary electric power capacity might also be used. One such commercial system generates a 0.5 msec acoustic pulse with extremely high peak pressure and a frequency of 1000 Hz. The reflected pulses are recorded on a moving chart to provide a continuous vertical profile of bottom characteristics. Analysis of reflection losses, ranging from 10 percent for hard sand to 90 percent for mud, might aid in determining the type and density of the parent material.

17. SEISMIC EXPLORATION METHODS

Seismic techniques obviously cannot be used in an airborne mode, but they do have application for ground-based terrain surveys. The seismic refraction method can be used to determine the depth to interfaces such as the water table, permafrost, bed rock, or sub-surface formations offering a distinct change in the propagation velocity of seismic waves. Delineation of deep-lying deposits is possible and qualitative relationships between seismic velocity and hydrologic parameters such as porosity and density have been established. Mapping of buried aquifers is therefore practical.

Now available are compact portable seismographs that utilize a hammer blow against a steel plate on the ground as an energy source. This eliminates the need for drill holes and explosives, and has greatly enlarged the utility of operation.

Some identification of the type of near-surface material is possible from computation of the wave velocity obtained by a thorough seismic refraction survey (Linehan, 1951). Dry, wind-blown sand or fine gravels have velocities varying from 1500 to 2500 ft/sec; heavier gravels with small amounts of clay binder run

up to 4000 ft/sec; while velocities from 4500 to 6000 ft/sec represent more compact gravels or those within the water table. Varved clays show a constant velocity of 5000 ft/sec, while values from 6000 to 9000 ft/sec usually represent a hard pan or till material that is heavy gravel and clay, often cemented together by iron rust or oxidation.

Rock velocities are not as reliable indicators of type, but in general low seismic velocities are associated with less dense or lower strength rocks.

18. ELECTRICAL RESISTIVITY MEASUREMENTS

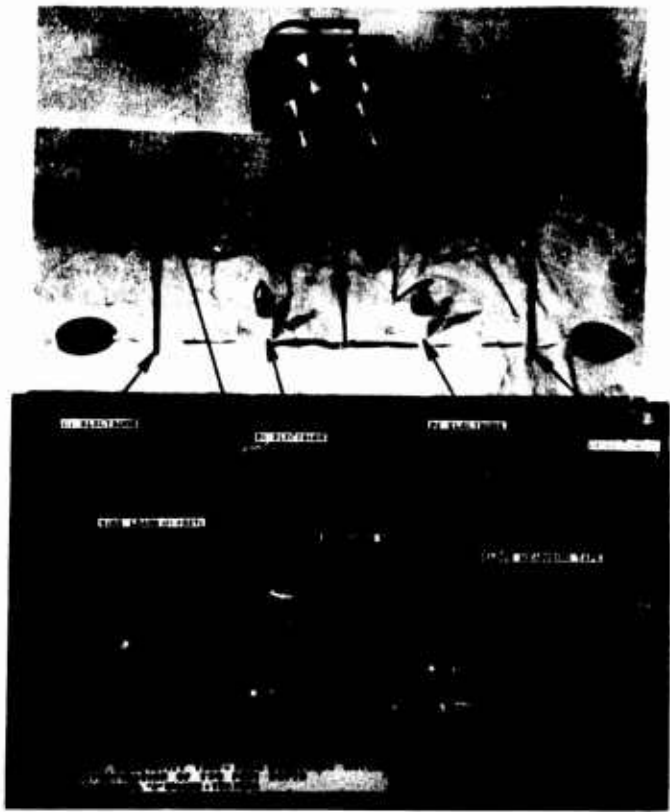
Sensing of terrain properties by analysis of electric current propagation through the ground is a well-established exploration technique. Active transmission methods are generally used in resistivity measurements, while passive recording of telluric currents also provides information on sub-surface conditions. It is not feasible to generate or record such currents from the air, so these techniques would have no application in airborne sensing. However, field exploration using ground vehicles might well use electrical methods.

All surface and sub-surface materials have to some degree the ability to conduct an electrical current. The moisture within the earth's materials and, more particularly, the impurities in this moisture provide an avenue for the current flow. It is natural for the harder, denser, rock layers (containing less moisture and perhaps less impurities than the clays and silty layers) to have higher resistivities than fine-grained clays or silt. Salt water is a very good conductor of current flow. Hence, a geologic layer such as shale or clay, laid down under marine action, usually has a very low resistivity. Such materials can be located beneath weathered or leached-out materials overlying them.

Usually, any hard, dense layer of parent rock will have a resistivity that is different from its weathered components. Because of these and other characteristics, trial and calibration must be made over exposed or identifiable formations of each material to produce the type curves needed to evaluate data obtained from exploration.

The distance between the electrodes is a function of the depth of the area surveyed, as shown in Figure 27. By increasing the spacing, the test can be carried deeper, and any deep formation, such as solid rock, having generally higher resistivity than the surface layer, will be indicated by a rapid rise of the plotted curve. Tabulation and interpretation of measured resistivities can establish relationships of these to porosity, texture, salinity, and mineral content of terrain, in addition to defining the depth of bed rock, the water table, or permafrost layers.

INSTRUMENTATION



THEORY

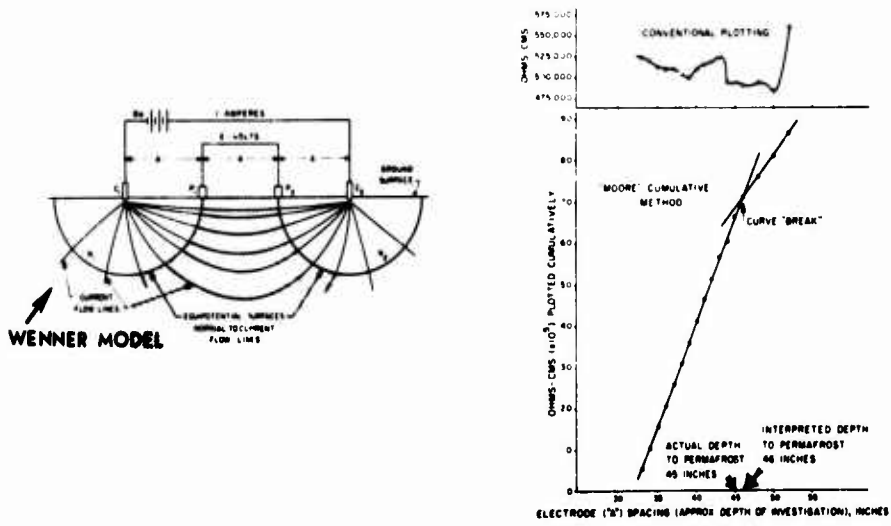


Figure 27. Theory and Instrumentation of Electrical Resistivity

19. DROPPABLE SENSORS

To overcome problems of ground surveys, AFCRL (Molineux, 1955) and WES (1957-1963) developed several devices for airborne determination of soil strength, using projectiles dropped or fired from aircraft. Such an instrument, called an aerial penetrometer, is essentially an aluminum cylinder that looks like a small rocket; it is approximately 2.5 ft long, 2 in. in diameter, and weighs less than 2 lb. The original model was dropped from propeller-driven aircraft and had a spring mechanism to measure the impact. If the penetration resistance is greater than the pre-set level, a flare is released through the hollow barrel and rises to several hundred feet altitude as a visible "go-no-go" indicator. Figure 28 shows an exploded view of this device.

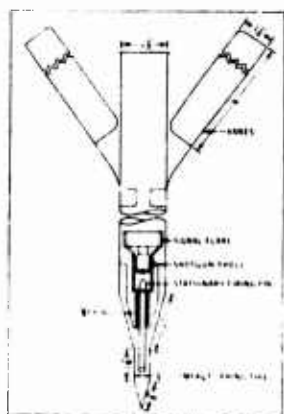


Figure 28. Assembly of Aerial Penetrometer

For tactical reconnaissance missions, an additional development by AFCRL facilitated an improved means of deployment and indication. This penetrometer can be ejected in quantities up to 10 in a pre-selected sequence from tip-tank launchers on jet aircraft at speeds of approximately 450 knots and altitudes of 1000 ft above the terrain. For multiple deployment the firing sequence is 0.5 sec apart, with the penetrometers thus landing about 300 ft apart. Ejection is by an electrically detonated charge contained within the launching system; the penetrometers are inert. They are nearly buried in their own holes, depending on the soil strength encountered, and are expendable. Soil hardness is indicated by the appearance of a self-contained light bulb visible through the vertically impacted cylinder. The launching mechanism shoots the penetrometers downward and backward at a component velocity sufficient to cancel the forward speed of the aircraft, so that the penetrometer hits the ground at 350 ft/sec directly under the spot where ejection takes place.

The penetrometer is aerodynamically stable with pop-out vanes governing its fall, which takes about 1.5 sec from ejection to impact. The strength-indicating mechanism is adjustable to allow determination of soil hardness through a range of values that might be required by various aircraft landing loads.

Development is now underway by AFCRL for another aerial penetrometer, operating on a depth of penetration principle, that is more pertinent to determination of relative strength differences in pre-selected areas. This device consists of two parts whose different weights cause them to separate on impact and transmit their relative displacement by radio telemetry.

The device, cylindrical in shape, has fins at the top to serve as an antenna and to provide aerodynamic stability. The cone-shaped bottom surface consists of the point of the penetrating cone and rod surrounded by a conical ring that is the impact surface of the penetrometer shell. It is about 24 in. long and less than 4 in. in diameter.

Relative displacement is transmitted by successive cutting of electrical wire pickups spaced along the shell length. Each cutting causes an increase in resistance of the circuit modulating the transmitter output, so the frequency of the tone signal increases with each cut. The depth of penetration is indicated by the number of step increases in the signal frequency; the uniformity of deceleration is indicated by their spacing. The signal from each penetrometer can be distinguished by an identifying code from a pre-set grouping of pickups. Figure 29 shows the configuration of this new development.

WES is currently developing and testing an air-dropped oscillator or dielectric penetrometer to penetrate or lie on the surface of the terrain for measurement and telemetry of the dielectric constant and conductivity of soils (USAEWES, 1966c). These parameters can be correlated to soil type and water content.

NASA has also conducted feasibility studies and testing of impact-type devices for determining the hardness of terrestrial surfaces (McCarty et al, 1964).

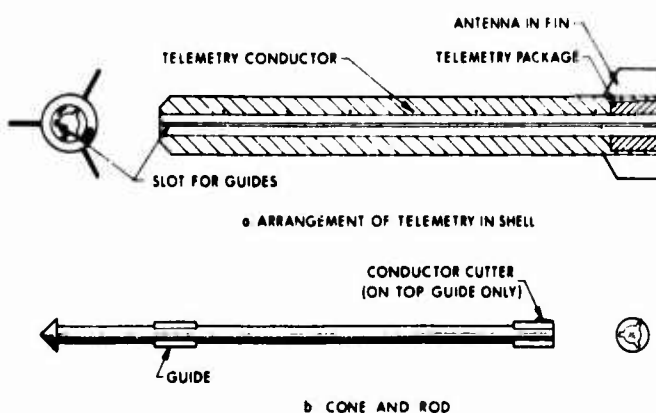


Figure 29. Modified Aerial Penetrometer With Telemetry Capability

20. IMPLANTED OR ROVING SENSORS

Implanted or air-dropped sensors for determining and monitoring meteorological conditions are well-developed and extensively used; the "Grasshopper" weather telemetry station is an example of this type sensor. Counterpart devices for monitoring sea state are in use by the Navy. Similarly, implanted sensors for determining hydrologic data are frequently used by the Army Engineers and the Department of the Interior.

A development effort sponsored by AFCRL at the Army Engineer Waterways Experiment Station resulted in an automated sensing station that can obtain and telemeter data on soil moisture, soil strength, and local weather variables from a remote site to a central headquarters (USAEWES, 1965). Purpose of the system is to provide information on landform conditions that might be affected by seasonal or climatic variations.

Soil moisture can be measured by electrical resistance sensors with a digitized microammeter readout or, preferably, by a neutron soil-moisture meter which would not be sensitive to possible effects of soil chemical composition on its resistance. Soil strength is determined by a hydraulic-loaded penetrometer operating at a constant penetration rate through a 2 ft depth. Obstruction would cause abandonment of the probe cycle and repetition at an adjacent location. The strength data can be recorded at the receiving station as an X-Y plot of force versus depth. Values of wind speed and direction, surface air and soil temperature, and precipitation falling on the site are also obtained and telemetered. The system can be actuated on a pre-programmed basis, on demand, or whenever rainfall occurs signalling a possible change in site properties of concern.

The station can either be permanently implanted or employed on a small track-laying vehicle that is self-propelled by battery power and guided with a cable attached to a central control mast about which the vehicle spirals. Telemetry can be by teletype or by radio link. All measuring sensors are transistorized, with automatic selection by logic circuits in the control unit. The teletype, in addition to paper-printing the data, also stores it on punched paper tape for possible future computer operations. The station and sensing system is capable of unattended operation for long periods of time at remote locations under extremes of temperature conditions. Figure 30 shows this penetrometer/vehicle system.



Figure 30. Remote Controlled Roving Ground Penetrometer Monitoring System

21. AIRBORNE SENSING LIMITATIONS

It is recognized that many limitations exist for full employment of types and arrays of airborne sensors. Many of these limitations are caused by the atmosphere intervening between the sensor and the terrain, such as air turbulence, absorption or attenuation of solar radiation by water vapor or ozone, cloud cover and rain, and lack of natural illumination for night photography. However, as the sensing wavelength increases, atmospheric absorption of the available energy generally decreases.

Some restrictions are due to the sensors themselves, including photographic resolution, non-linearity or distortion of camera film, and altitude or slant range limitations. Sensor operation in aircraft also presents problems of temperatures or pressure effects on the equipment, aircraft vibration, and requirements for size, configuration, electric power, and antenna placement. Degradation of photography through non-optical glass is another problem.

Still other limitations to efficient sensing and imagery interpretation are caused by the terrain and its topography. These include vegetation cover, surface scattering, shadowing, and man-made camouflage.

Some or most of these limitations can be overcome by proper design and planning of the sensing systems and operational missions, but they must always be considered.

22. DATA GATHERING VEHICLES

Useful terrain and environmental data can be obtained all the way from the earth's surface outward to space, ranging from sensors implanted below ground to manned or unmanned satellites.

The use of automated surface-based systems telemetering their data to a central headquarters has been well established. The gathering of seismic, gravity, magnetic or electrical data on earth properties by surface measurements is standard practice. Placing sensors on ground-vehicle booms or on platforms, towers, or arches enables obtaining "remote" surface data pertinent to the individual sensing technique.

The sensing vehicle most widely and successfully used is, of course, the aircraft. This vehicle combines the advantages of range, speed, and repetitive coverage with its capacity for containing large weights and volumes of sensing instrumentation and self-power generation. Sensing aircraft have ranged from helicopters and small observation planes through multi-engine reconnaissance aircraft to the supersonic X-15 type from which much photography has been obtained. Many governmental agencies (USGS, AFCRL, U. S. Department of Agriculture, and NASA in particular) have aircraft permanently instrumented and used for terrain property sensing. In addition, many commercial organizations have aircraft devoted to the mission of testing, verifying, and applying remote sensing instrumentation. Also, many universities, especially those conducting sponsored research in the earth sciences, operate well-equipped aircraft for data gathering assignments.

High-altitude balloons offer an intriguing potential for photographic or other sensing of terrain, as they provide a stable, vibration-free, and relatively controlled platform with slower passage over the ground than either aircraft or rockets reaching comparable altitudes.

Much earth photography has been obtained from past sounding rockets such as the Viking and Aerobee, and the Mercury series of satellite flights started a vast library of earth photographs obtained from space. The GEMINI series in particular has provided considerable information on terrain characteristics and mapping.

IV. Applications

I. INTRODUCTION

The success of a military air or ground operation is frequently dependent upon the proper utilization — that is, application — of terrain. The elements and parameters of the terrain that are pertinent to its proper utilization include its dimensions, composition, form, and dynamics. The terrain factor-effect relationships are, of course, not known for all military activities and must be determined by controlled performance testing. The ability to select an alternate terrain is necessary to meet any changing tactical situation or environmental elements.

Relevant military applications pertinent to terrain analysis include: strategic and tactical planning, air and ground navigation, and guidance, geodetic control, and target location; reconnaissance, surveillance, and detection of activities including perimeter intrusion, tunnels, and nuclear tests; intelligence; mapping and charting; site selection of bases, airfields, missile silos, roads, and surface and underground facilities such as command and control centers; location of sources of power and construction materials; aerospace craft and vehicle trafficability; analogous area analysis; design of weapon systems and destruction effects; surface modification and soil stabilization; prediction warning and protective measures against terrain movement and natural catastrophic events (earthquakes, volcanisms, landslides, floodings, tidal waves, and major erosive actions); and inducing actions

to degrade the capability of an enemy by causing landslides, flooding, and the instability of structures by inducing loss of strength in terrain foundations materials.

2. MODEL CRITERIA

Adequate quantitative terrain data incorporated into performance-prediction mathematical models are required for each terrain application. Essential lacking data would then be easily identified for required input to the model (WES, TR3-726, Vol. 1).

When the critical value limits of the terrain factors selected for input to the model change, the model must be modified. The data obtained from pilot-performance testing of the activity on terrain determines the critical values that are fed into the model concept.

Performance results are introduced into the analytical model to determine design criteria. These criteria are then translated into factor values representative of global environmental characteristics and are reflected in the design of new equipment and system components.

3. SELECTED TYPES OF APPLICATIONS

The applications described below are typical, since they relate to common operational problems. They are: trafficability, surface modification, analogous areas, and site selection.

3.1 Trafficability

The maneuverability of vehicles and aircraft on natural surfaces is based on the pedologic, geologic, hydrologic, physiographic, climatic, vegetative, and bearing strength properties of the terrain. An evaluation of all these elements of a terrain contributes to the rapid assessment of the conditions that will affect trafficability (U. S. Army WES, 1954, p. 9; U. S. Army WES, 1961, p. 10; AFM 88-51, p. 92; Pressman, et al, 1961; Needleman, 1962).

A terrain is considered trafficable when the forward thrust of a vehicle overcomes the rolling resistance at a specified rate of speed (Burns, 1960, p. 15). Certain soils in a comparatively dry state can be trafficable for many vehicles and aircraft (Womack, 1965).

Predicting the speed of vehicles along a planned route is dependent upon adequate available pertinent factor value data.

3.2 Surface Modification

Most surfaces require some modification for operational use; these modifications can be achieved through mechanical or chemical means. Standard construction procedures and equipment can prepare any surface for use by removing obstacles, substandard soil, vegetation, and rock horizons in the profile, and replacing them with suitable local indigenous materials (Needleman, 1961, p. 38). The properties of a soil may be improved by compaction, moisture control, blending of added materials, and stabilization. In the case of airstrips, the placement of landing mats and plastic membranes over a reinforced soil is widely practiced. A combination of these methods and concrete or asphalt surfacing is the optimum approach to improve a natural surface for a great deal of traffic (AFM 88-52, p. 175; U. S. Army WES, Misc. Paper 3-605, p. 3).

3.3 Analogous Areas

The use of accessible analogous terrain for conducting studies and tests substitutes for the inability to conduct such activities at the scene of anticipated operations. The comparison of similar areas requires the establishment of the factor classes upon which the analogies will be based. Although no area is entirely coincident, it is possible to identify areas that are nearly similar in the majority of the factors. These areas may have had an identical geologic and climatic history influence a similar development of their soil, vegetation, and topographic characteristics, resulting in approximately equal terrain factor values (Van Lopik, and Kolb, 1959, p. 3; Wood and Snell, 1960, p. 15; Curtis, 1966, p. 134).

In a case study of analogous areas in an arctic environment, 46 terrain sub-factors were considered for a determination of a suitable military test site.*

Research, development, engineering, and testing on selected sites in the U.S. that are analogous to other world environmental conditions are standard procedure in programs sponsored by Department of Defense agencies. The lack of completely analogous test sites results in some inaccurate performance data, but a range of values can be deduced to indicate the limits of each factor class in the design parameters (Stoertz, 1961, p. 7; Grabau, 1967a, p. 4). Worldwide conditions

* The factors may be characterized by slope or relief; elevation; vegetation type, density/height, tree trunk diameter; soil profile; rock type, strength, and structure; depth of thaw; depth of frost; depth, thickness, and continuity of permafrost; depth to water table; soil shearing strength; snow cover depth and density; river depth and velocity; stream width and bottom conditions; flooding; seasonal icings; slides and mudflows; earthquakes, volcanic activity; thermal factors (ground temperature, freeze-thaw index, and mean annual temperature); and miscellaneous environmental factors between terrain and climate (duration of darkness, blowing sand and dust, blowing and drifting snow and ice crystals).

are analyzed to develop optimum design criteria and provide a minimum number of limiting conditions for maximum utilization (Van Lopik and Kolb, 1959, p. 11).

3.1 Terrain Studies

So that alternate choices are available in the event of contingency action, the military is conducting continuing terrain studies throughout the world. This is being done so that extensive pre-mission reconnaissance will be minimized.

3.4.1 SITE SELECTION

The investigation of the earth's surface and subsurface for the location of airfields, roads, radar and missile sites, storage depots, and other facilities on all types of terrain (soil, snow, ice, permafrost, coral, laterite, etc.) is essential to successful global operations. The tactical situation in limited wars invariably demands the deployment and operational use of sites with marginal conditions in remote areas (Needleman, 1962, p. 69).

The terrain requirements for a specific mission determine the type of data needed for analysis. Each terrain factor in the model is evaluated for the application. Figure 9 outlines these sequences and shows the approach in arriving at recommended solutions for the decision-maker or commander.

4. APPLIED EARTH AND RELATED SCIENCES

The scientific areas that offer an insight into regions lying above and below the surface of the earth are geology, geodesy, geography, hydrology, glaciology, soil mechanics, soil science, soil engineering, geomagnetism, seismology, oceanography, ecology, biology, and electronics (AFM 88-53, p. 1; Strahler, 1963, p. 1; Strahler, 1960, p. 287; Berkner, 1962, p. 2180).

The data on the parameters peculiar to each application are correlated with data from these interrelated disciplines to draw reasonable conclusions from observed phenomena. Unfortunately, reports are usually issued in the major field of interest, incorporating only the terrain data applicable to that field of interest.

5. TERRAIN ENGINEERING

Engineering history is marked by failures of structures such as dams, bridges, tunnels, reservoirs, highways, and airfield runways due to weak foundation materials, faulty design, or excessive loading on the structure and associated earthwork construction (AFM 88-53, p. 191).

Of the various terrain features that commonly present engineering problems, rivers present the most severe problems. Plains and plateaus, on which most large operations take place, do not present as many severe problems. Hills and mountains are general obstacles and only suitable for small operations (AFM 88-53, p. 146).

Flood control and construction of foundations over permafrost, coral, or laterite present special problems. The construction of underground installations in consolidated and unconsolidated materials necessitates different techniques and equipment (Nat. Acad. of Sci., 1963).

As the effects of climate are more pronounced in an arid, tropical, or arctic environment, compared to a temperate zone, construction in these areas present unique problems.

5.1 Natural Resources for Military Operations

Indigenous construction materials and a useable water supply are essential for successful military applications. Purification of the water may be necessary when pollution, salinity, or minerals are found in the source of supply (AFM 88-53, p. 270).

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V. Research and Development Status

1. INTRODUCTION

The acquisition of subsurface data, particularly by remote methods, is not keeping pace with the requirements for quantitative terrain information (underground sites). Modern ground-test techniques can be used to expeditiously determine the suitability of a terrain, in any environment, for various uses, but airborne techniques have not yet been fully developed for operational use.

Gaps in our knowledge concerning the static and dynamic behavior of natural materials are being studied, and laboratory and field experiments are being conducted to evaluate the theoretical results.

Comparative methods of analyzing terrain parameters of analogous areas and the formulation of rigorous mathematical terrain models of global environments are attaining increased accuracy for operational utility. Key terrain characteristics can be evaluated, but the analysis of microfeatures requires supplementary sources of information from ground data, indirect measuring techniques, photogeologic analysis, and photogrammetric processing. Computer assistance is necessary to permit the rapid interpretation of terrain data and requires the development of programming methods for reducing data to a suitable matrix format (Figure 31).

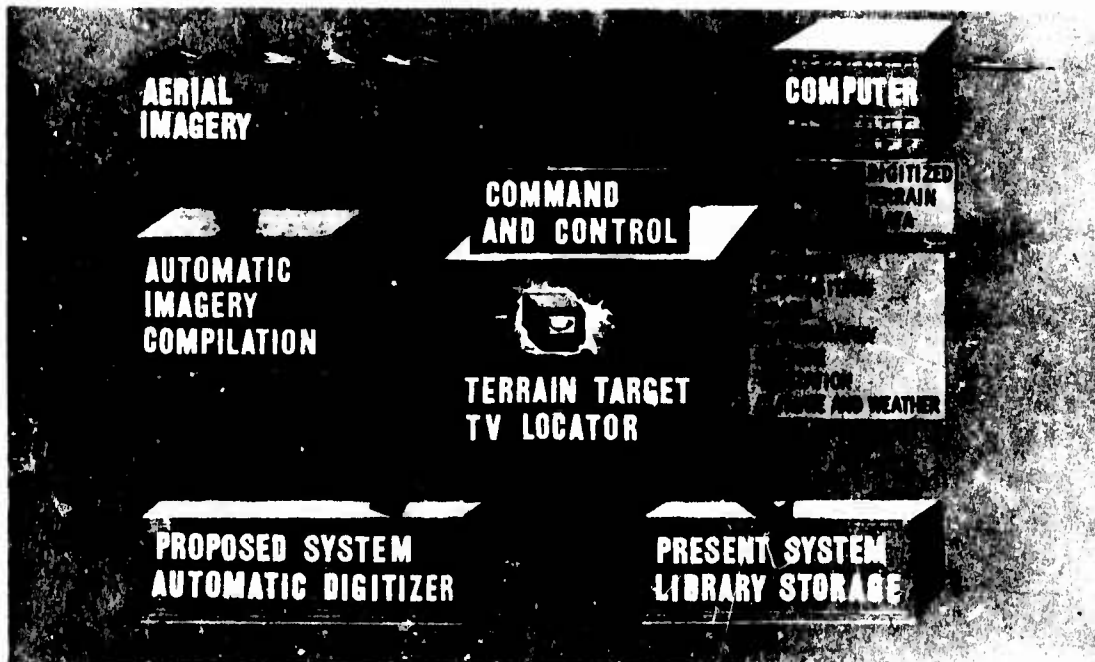


Figure 31. Simulated Terrain Data Processing Approach

Terrain characteristics and the properties of soil, ice, and snow have been intensively studied by the Air Force, Army, and Navy. Terrain in polar, temperate, and desert environments was the major research interest in the past, but present research is concentrating on vegetated surfaces and landforms in a tropical environment, especially on the identification and measurement of the effects of vegetation on military operations and the exploitation of natural terrain.

2. CLASSIFICATION OF THE ENVIRONMENT

Techniques are being developed for classifying geographic areas and their respective subordinate physiographic regions in more quantitative terms, so that their effects on military operations can be evaluated. Such data are the basis for comparing one area with others that are similar in the majority of environmental parameters (Strahler, 1963, p. 326).

The Army's Waterways Experiment Station (WES), Terrestrial Sciences Center (ATSC), and Natick Laboratories (USANL) are improving methods for classifying and correlating the environments with the terrain. Sites in a particular environment are selected in accessible terrain and are representative of other areas

of the world where there is a possibility of future military activity. The terrain factors are analyzed and the resultant data utilized to optimize equipment design (Wood and Snell, 1960, p. 2; Grabau, 1967a, p. 3).

3. TERRAIN RESEARCH

Problems relative to the identification of terrain parameters and instrumentation and methodology for measuring those parameters are being studied by AFCRL, AFWL, ATSC, USANL, USAEWES, and ONR. These organizations are shifting a portion of their concentration from contact to remote sensing techniques for obtaining terrain data.

Data obtained from contact and non-contact methods are correlated and synthesized for application to military activities. As each study produces data for a particular use, an intensive analysis is done from a narrow perspective.

A comprehensive terrain research program of military significance has not been undertaken, although a number of efforts by DoD and their contractors have produced valuable data. These investigations resulted in the development of several terrain classification systems, but some gaps still exist and additional research is warranted. Some of these gaps are presently being studied by many organizations in the following areas.

3.1 Geology

Studies of geologic processes are being made to determine the static and dynamic properties of individual landforms and materials. This type of information is being applied to problems that include site selection of airfields, stability of underground structures and miscellaneous types of facilities, rapid excavation for the construction of military installations, location of natural hazards and power sources, and crustal studies for the detection of underground objects and communications.

3.2 Geophysics

Research on seismic methods for monitoring the earth's interior is being carried out in an effort to improve our ability to detect underground nuclear explosions. With improvements in seismic techniques and the necessary instrumentation, other tactical applications are possible (Bates, 1962, p. 2207; AFCRL, 1967, p. 280). Detailed gravimetric, magnetic, seismic, and geothermal studies will enable us to predict eruptions of volcanoes, to better understand the mechanisms involved in volcanic eruptions, and to utilize the energy associated with volcanoes, such as geothermal steam (Kiersch, 1964, p. 18).

The determination of site stability by geologic, gravimetric, and seismic methods offers great promise for monitoring earth movements on a continuous basis. With such a monitoring system, precautionary measures could be taken to prevent personal injury and damage to facilities from earthquakes and tsunamis (sea waves) (U. S. Coast and Geodetic Survey, 1964, p. 72).

3.3 Geodesy

Geodetic knowledge from improved ground, airborne, and orbital surveying techniques will redefine the shape of the earth, interrelate all points of the earth for better mapping and navigation accuracies, and refine astronomic and terrestrial constants for inertial guidance and new navigation systems. The areas of increased knowledge will include more accurate data on: undulations of the geodetic ellipsoid network of the earth; deflections of the vertical gravity component; the composition, thickness, warping, and rigidity of the crust, mantle, and the core of the earth; the movements of large land masses; the precise location of the magnetic and geographic poles; and response of crust to tidal accelerations, degree of crustal isostatic equilibrium, oceanic swell and tide cycles; all major gravity anomalies and equipotential surfaces up to satellite altitudes (Williams, 1963, p. 3; AFCRL, 1965, p. 135; AFCRL, 1967, p. 289).

Star catalogues are being refined to more accurately show their positions and motions. Research regarding the precise determination of astronomical constants is being continued. The moon and its precise librations are being studied, and large scale mapping, sufficient for precise reference in space and planetary exploration, is progressing (Williams, 1963, p. 4; Strahler, 1963, p. 71).

3.4 Geomagnetism

Studies of the earth's magnetic field (main field and transient magnetic variations) are continuing. The main field category includes magnetic surveys, magnetic charts, secular changes, rock magnetism, magnetic anomalies, and studies regarding its origin. The transient variations of the lunar, solar, and magnetic field are being investigated to develop more accurate world navigation charts (AFCRL, 1960, p. 10-1).

Correlations of magnetic field measurements from rockets, earth satellites, and space probes with those obtained on the ground is expanding our knowledge of the geomagnetic field and the internal composition and structure of the earth (Strahler, 1963, p. 142).

4. SOIL MECHANICS

Research is directed toward the maximum utilization of soils for military construction purposes.

Efforts are planned to advance the understanding of the static and dynamic characteristics of soils under varied loads. Methods are being developed to predict the profile and engineering properties of soils in order to determine the needs for final site selection and utility. Accompanying these efforts is the search for improved sonic, electrical, electromagnetic, seismic, and radioactive techniques for rapidly measuring soil properties. Soil models and analog techniques are being applied to predict the trafficability of global terrain. Research will be continued on the response of soils and rocks to high-energy impulses (Tsai, 1967, p. 33).

5. REMOTE SENSING

Ultraviolet, polarization, and passive microwave sensing techniques are being studied to provide interpretable imagery of terrain data. (Figure 8).

New applications of existing techniques are being developed, and the instrumentation is continually being improved. Radar scatterometry, multi-spectral photography, and passive microwave thermal imaging are representative areas that have been improved by advanced instrumentation development (USAF Scientific Advisory Board, 1966, p. 12).

Research toward the development of a semi-automated terrain-data-interpretation process has recently been initiated. Pattern recognition, spectral discrimination, and mapping by computer printout of terrain characteristics are potential areas of application needing much further investigation. Advances in fiber optics may enable an automated generation, presentation, and comparison of the terrain data with imagery presently available. The tape recording of sensor outputs permits automated enhancement, storage, and contrast comparisons that far exceed the dynamic range of present photographic film (Van Lopik, 1962, p. 777).

The continued growth and refinement of a data bank of target and background signatures is sorely needed. Such reference information will guide the test, interpretation, and application of new imaging sensors by providing ranges of exposure settings for optimum sensor use. Discrimination of land contours, spatial extent, and spectral reflectance of material composition, using such data bank information, could enhance the detection and interpretation of natural backgrounds and penetrate possible masking or camouflage of targets.

The use of sensors in orbiting platforms is a new technique that is still in its infancy, but the vast potential of space photography has already been demonstrated by NASA. Research directed toward the use of other kinds of sensors in orbiting platforms should now be initiated in order to exploit their potentials. The repeated coverage of wide geographic areas of the earth's surface by orbiting sensors would be of obvious benefit for assessing changing conditions, seasonal, climatic, and otherwise.

6. SCIENCES OF MARINE ENVIRONMENT

Advances in oceanography (studies in marine gravimetric, magnetic, seismic, heat-flow, and the specialized interrelated disciplines of traditional science — geology, chemistry, biology, and physics) are refining theories on the earth's history and internal structure (Strahler, 1963, p. 292).

The potential fields of applications to be derived from studies in ocean technology are aircraft landing sites on floating sea ice, underwater missile sites, underwater storage and tank fields, salt water conversion processes, scientific waste disposal, trans-ocean pipelines, nuclear damage in water areas, predicting and inducing tsunami waves, mineral recovery and extraction, seafood farming, submarine navigation, etc. Methods for preventing beach erosion and harbor and waterways over-sedimentation are being investigated.

7. COMPUTERIZATION OF DATA

Data on terrain factor values will be computerized and used in controlled laboratory experiments, followed by field tests in varied environmental and terrain conditions. The data obtained from these tests will permit rapid analysis for comparison with the established criteria of specific uses (Anstey, 1960, p. 4).

Efforts are being made toward establishing guidelines for acquiring earth-science data that will be amenable to mathematical processing. Past records include errors that will remain until replaced by new data.

As a research aid, computer technology is a much more efficient use of geo-science libraries than the inadequate bibliographic procedures. For many years a need has existed for the automated tabulation of references and scientific data. Many libraries are awaiting the results of present research studies before incorporating such computer methods. The increasing volume and complexity of the scientific literature of military importance indicates the need for continued research in this area to improve data retrieval methods (Pangborn, 1967, p. 18; Miesch, 1967, p. 13).

VI. Conclusions and Recommendations

I. CONCLUSIONS

The success of global military operations is based upon the tactical exploitation of terrain in all environments. As terrain is a common denominator of earth science and the art of warfare, a multi-disciplinary understanding of terrain parameters in quantitative terms is necessary in modern technology. An efficient system of acquiring, quantifying, interpreting, and evaluating such data on a global basis is absolutely essential. The significance of terrain parameters varies with the use, but the instrumentation and methodology to collect the information are similar.

A combination of ground, airborne, and future orbital scientific techniques can be used to develop a "quick-response" type of capability for obtaining ground data and predicting use of terrain for specific military purposes. This capability could be further enhanced by the computerization of geoscience information and the development of methods for retrieving selected data for rapid synthesis and evaluation.

Advanced warfare concepts and recent conflicts have emphasized the inadequacy of our quantitative global terrain data. With our limited data, we are unable to perform certain operations on a routine, efficient, rapid, and automated basis. This problem has been partially solved by the introduction of electronic skills,

but problem areas still exist, particularly obtaining data below the surface of the earth. Scientific and technological gaps are only gradually being identified, delineated, studied, and surmounted by additional research and development, but research funds are limited. The only exception to this austere support occurs in the category of priority programs in narrow fields when requirements are established for special applications. The current state of knowledge is in the form of an incomplete foundation upon which new scientific information must be added from productive research, development, and test efforts.

Military-sponsored applied research has achieved some technologic progress in semi-automated terrain-analysis capabilities, but the progress has been slow and expensive. This approach has involved the use of research performed by private contractors. Certain problems remain to be solved for improved capability.

Microterrain data are not recorded for many parts of the world, and available data are plotted on small-scale maps that are inadequate for conducting all types of military operations. Critical terrain factor values for specific uses are difficult to predict without adequate measured data. This type of precise information currently must be obtained by ground methods of investigation. Remote sensing methods from aircraft and possibly from orbital altitudes could provide the necessary quantitative information, if an optimum terrain investigating system and advanced analytical techniques were developed.

Terrain problems that should be investigated by remote sensing technology are: bearing strength as a function of moisture, climate, vegetation, soil, and related parameters; resolution of microrelief; identification of type and determination of properties of complex soils (laterites, permafrost, coral); location of adequate water supplies; site selection for natural landing areas; detection of clandestine nuclear tests; determination of weapons effects; occurrence of natural catastrophic events above and below the surface (landslides, volcanic eruptions, tsunamis, earthquakes); micromovements; and rock failures in underground structures, affecting weapon system accuracies.

Although conventional aerial photography is presently the most reliable sensor for providing geometrical measurements and locations of terrain features, it is not possible to examine subsurface features directly from any film and filter combinations. Stereoscopic viewing of such photography can reveal much qualitative information on the microfeatures. Photography has a higher resolution of ground characteristics by an order of magnitude greater than current radar or infrared systems flown at comparable altitudes (Neal, 1965).

New films, improvements in photographic resolution and contrast, and techniques for recording spectral information from the near-ultraviolet through the near-infrared are providing methods for identifying terrain characteristics.

At wavelengths longer than 0.9μ , imaging on film is not presently possible. Various infrared, radar, and microwave line scanners can supplement photography to generate imagery interpretable in terms of terrain properties. Parameters such as surface planes of weakness (jointing, faulting, fracturing), lateral variations in soil moisture and ground water, and soil or rock types are susceptible to identification and discrimination from such imagery. To date, this interpretation is not reliable, but research and development regarding the origin and distortion of images with time, weather, aspect angle, or polarization will reduce the ambiguities in the interpretation.

The interpretation of remote sensor records has not kept pace with the development of the individual sensors. Development of the capability to correlate terrain properties with the characteristics of images or the electromagnetic energy levels received is progressing. The premise that each material has characteristic signatures at differing wavelengths, varying with the physical state of the material, is accepted in the scientific community. Identification of the materials and their engineering properties through diagnostic spectral characteristics analysis, supported by a minimum of valid and reliable "ground truth" data for correlation, will achieve a milestone in terrain-analysis technology.

With further research and development in computerized techniques, remote sensing will enable an economical compilation of the engineering properties of terrain for any area susceptible to overflight.

The development of an automated terrain-data-gathering and efficient display system cannot be achieved without adequate support to perform the basic and applied research needed for a modern level of competence.

The report has stressed the importance of the quality of terrain input data, the adequacy of an evaluation model, and the appropriateness of performance data in research, development, testing, and engineering. The recommendations listed below are designed to pinpoint those areas requiring more intensive investigation to alleviate the gaps in the advancement of terrain-analysis technology. Such objectives can be attained only by having complete knowledge of the pertinent terrain parameters and factor values. In the cases where data are lacking, an efficient and rapid information acquisition system is essential for an improved military capability.

2. RECOMMENDATIONS

2.1 Future work should develop an integrated method for describing the surface configuration of landscape patterns and correlating them with airborne sensor data.

2.2 Further study should be made regarding: the type of terrain data that can be derived from imagery for photogrammetric use, the correlation of "in situ" terrain characteristics with sensor imagery obtained from an airborne or orbital system.

2.3 A major effort should be directed toward quantifying terrain parameters for computer storage, retrieval, reduction, and data analysis in digital or analog form (Beckett, 1962; Wood and Snell, 1960, p. 11).

2.4 Work should continue on the development of a classification system for all types of terrain, water bodies, and hazards. The data should be in matrix format and applicable for varied military uses and for the conductance of analogous area studies (Beckett and Webster, 1965).

2.5 Assemble an atlas of indexed representative global landform and microrelief features with accompanying air and ground photos, other related imagery, and large-scale topographic, geologic, vegetation, and soil maps (Bredahl and Kiefer, 1957; Kiefer, 1957). Expand and update the "USAF Index to Aerial and Ground Photographic Features Throughout the World," dated 30 September 1946, Supplement No. 1, 2 January 1949, including newly discovered variations of landforms.

2.6 Continue performance tests of aircraft and ground vehicles on controlled natural surfaces to produce factor values for military mobility on natural terrain (Johnson, 1962; Tsai, 1967; Air Force Flight Test Center, 1963).

2.7 Implement a program for measuring, under controlled experimental conditions in the laboratory and field, the spectral reflectance properties of all types of earth materials, to determine atmospheric and visibility parameters influencing the reflectance measurements.

2.8 Continue the growth and refinement of a "target-signature" data storage repository (bank) containing data on the reflectance properties of specific terrain materials needed for the interpretation of sensor imagery obtained from laboratory, field, and airborne or spaceborne sensor platforms.

2.9 Continue efforts to develop automated methods for pattern recognition, spectral or spatial discrimination, image contrast enhancement, computer print-out of mapped imagery, and digital format for storage of sensor data.

2.10 Test the various sensors at balloon, rocketborne vehicle, and satellite altitudes to establish their capabilities and/or limitations.

2.11 Apply the available techniques of terrain analysis to siting of all major military installations, to provide the maximum engineering data, efficiency, and economic benefits.

3. SUMMARY OF KEY CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

Terrain is a common denominator of earth science and art of warfare.

Global terrain data are incomplete or lacking.

Ground and airborne data-acquisition techniques are available.

Orbital techniques are experimental.

Present and potential applications are numerous.

Remote sensing offers much promise in earth science research and development.

3.2 Recommendations

Develop better criteria for terrain evaluation.

Refine methods of measuring microterrain features and critical factor values.

Develop sensors with improved resolution for interpretation of microterrain factors.

Develop orbital methods of high resolution terrain sensing and data telemetry.

Develop automated methods of data storage, retrieval, processing, reduction, interpretation, and handling.

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References

- Abdel-Gawad, M. (1967) Geologic Exploration and Mapping from Space, North American Aviation Science Center
- Aero Service Corporation (1967) New tool for exploration: Gradiometer, Search, 2 (No. 3)
- Air Force Avionics Laboratory (1966), Airborne Thermoplastic Real-Time Recorder Display, AFAL-TR-66-317, Wright-Patterson AFB, Ohio
- Air Force Cambridge Research Laboratories (1960) Handbook on Geophysics, Revised Edition, Bedford, Mass.
- Air Force Cambridge Research Laboratories (1965) Report on Research at AFCRL for the Period July 1963-June 1965, AFCRL-65-595, Bedford, Mass.
- Air Force Cambridge Research Laboratories (1967) Report on Research at AFCRL for the Period July 1965-June 1967, AFCRL-68-0039, Bedford, Mass.
- Air Force Flight Test Center (1963) Project Rough Road Alpha; Take-Off and Landing Capabilities of C-130B, JC-130B, NC-130B (BLC), C-123B, and YC-123H Aircraft on Off-Runway (Unprepared) Surfaces, Tech. Report FTC-TDR-63-8, Edwards AFB, Calif.
- American Geological Institute (1960) Glossary of Geology and Related Sciences; With Supplement, 2nd Edition, National Academy of Sciences, National Research Council, Wash., D. C.
- American Society of Photogrammetry (1960) Manual of Photographic Interpretation, George Banta Co., Menasha, Wisc.
- Anstey, R. L. (1960) Digitized Environmental Data Processing, U. S. Army Quartermaster Research and Engineering Center, Research Study No. RER-31, Natick, Mass.
- Aviation Engineer Force (1956) Airfield Design Criteria, 4th Edition, USAF, Wolters AFB, Texas.

References

- Badgley, P. C., Childs, L., and Vest, W. L. (1967) The application of remote sensing instruments in earth resource surveys, Geophysics, XXXII
- Barringer, A. R. (1962) New approach to exploration - the INPUT airborne electrical pulse prospecting system, Mining Congress Journal
- Barringer, A. R. (1965) Research Directed to the Determination of Subsurface Terrain Properties and Ice Thickness by Pulsed VHF Propagation Methods, AFCRL-64-936, Final Report, Contract AF19(628)-2998, Barringer Research Ltd.
- Barringer, A. R., and Schock, J. P. (1966) Progress in the remote sensing of vapours for air pollution, geologic, and oceanographic applications, Proceedings, Fourth Symposium on Remote Sensing of Environment, University of Michigan, 779-791
- Bates, C. C. (1962) Detection and identification of nuclear explosions underground (Project VELA UNIFORM), Proceedings of the Institute of Radio Engineers, Geoscience Issue, 50 (No. 11): 2201-2207
- Beckett, P. H. T. (1962) Punched cards for terrain intelligence, The Royal Engineers Journal, 76 (No. 2): 185-194
- Beckett, P. H. T. and Webster, R. W. (1965) A Classification for Terrain, Military Engineering Experimental Establishment, Interim Report No. 872, Christchurch, Hampshire, England. AD809686
- Belcher, D. J. (1948) Determination of soil conditions from aerial photographs, Photogrammetric Engineering, 14: 482-488.
- Berkner, L. V. (1962) Geoscience and geoengineering, Proceedings of the Institute of Radio Engineers (IRE), 50 (No. 11): 2180-2182
- Bienvenu, L. and Pascucci, R. (1962) Engineering Geology from Side-Looking Radar Records, Autometric Corporation
- Bredahl, A. R. and Kiefer, E. P. (1957) A Classification System for Unprepared Landing Areas, Air Research and Development Command (AFSC), ARDC-TR-57-20, Final Report, Contract AF18(600)-1609, Planning Research Corp., Los Angeles, Calif. AD115606
- Burns, C. D. (1960) Validation of Soil-Strength Criteria for Aircraft Observations on Unprepared Landing Strips, Technical Report No. 3-554, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.
- Cameron, H. L. (1965) Radar and Geology, AFCRL-65-202, Final Report, Contract AF19(628)-4005, Acadia University.
- Carr, D. D. and Van Lopik, J. R. (1962) Terrain Quantification, Phase I; Surface Geometry Measurements, Air Force Cambridge Research Laboratories, Final Report, Contract AF19(628)-481, Texas Instruments, Inc.
- Chalfin, G. T. and Ricketts, W. B. (1966) 3.2-mm thermal imaging experiments, Proceedings, 4th Symposium on Remote Sensing of Environment, University of Michigan, 859-865.
- Coleman, C. G. and Lundahl, A. C. (1948) Symposium: military photographic interpretation, Photogrammetric Engineering, 14 (No. 4):453-521.
- Collett, L. S. (1965) The measurement of the resistivity of surficial deposits by airborne pulsed electromagnetic equipment. Paper presented at Society of Exploration Geophysicists

References

- Colwell, R. N. et al (1966) A Multispectral Photographic Experiment Based on Statistical Analysis of Spectrometric Data, School of Forestry, University of California
- Committee on Geophysics and Geography (1953) Selected Papers on Photogeology and Photo Interpretation, Dept. of Defense Research and Development Board, Report No. GG 209/1, Washington, D. C.
- Curtis, C. E. (1966) Terrain Analysis and Related Studies Within Tropic Environments: Southeast Asian Region, Surinam, and the Mali Republic, Air Force Cambridge Research Laboratories, Final Report, Contract AF19(628)-4166, Aero Service Corp., Philadelphia, Pa., AD812514L
- Erdmann, C. E. (1943) Application of geology to the principles of war, Geological Society of America Bulletin, 54: 1169-1194
- Feder, A. M. (1960) Interpreting natural terrain from radar displays, Photogrammetric Engineering, XXVI: 618-630.
- Finch, V. C., Trewartha, G. T., Robinson, A. H., and Hammond, E. H. (1957) Physical Elements of Geography, McGraw-Hill Book Co., New York, N. Y.
- Flint, R. F. (1961) Glacial Geology and the Pleistocene Geology, John Wiley & Sons, New York, N. Y.
- Gaffey, J. T. (1967) Foundations in expansive soils, The Military Engineer, 59 (No. 392): 410-412
- Gates, D. M. et al (1965) Spectral properties of plants, Applied Optics, 4: 11-20
- Grabau, W. E. (1967a) A Suggested Procedure for the Selection and Description of Reference Test Areas, U. S. Army Engineer Waterways Experiment Station, Misc. Paper No. 4-921, Vicksburg, Miss.
- Grabau, W. E. (1967b) Terrain analysis for military geographic intelligence, Army Research and Development Newsmagazine: 18-20
- Hemphill, W. R. (1966a) Interpretation of Ultraviolet Imagery of the Meteor Crater, Salton Sea, and Arizona Sedimentary Test Sites, Technical Letter NASA Supplement 39 and 39A, U. S. Geological Survey
- Hemphill, W. R. and Vickers, R. (1966b) Geological Studies of the Earth and Planetary Surfaces of Ultraviolet Absorption and Stimulated Luminescence, Technical Letter NASA Supplement 33A, U. S. Geological Survey
- Hurley, P. M. (1959) How Old is the Earth?, Doubleday & Co., Inc., Garden City, N. Y.
- Hyzer, W. G. (1965) Photographic Instrumentation Science and Engineering, Naval Air Systems Command
- Itek Corp. (1962) Photographic and Photogrammetric Methods of Terrain Analysis for Determination of Aircraft Landing Sites, Air Force Cambridge Research Laboratories, AFCRL-62-644, Final Report, Contract AF19(628)-277, Bedford, Mass. AD282536
- Jensen, H. and Ruddock, K. A. (1965) Applications of a laser profile to photogrammetric problems. Paper presented at American Society of Photogrammetry.

References

- Johnson, A. I. (1962) Methods of Measuring Soil Moisture in the Field, U. S. Geological Survey Water Supply Paper 1619-U, Washington, D. C.
- Keegan, H. J. et al (1956) Spectrophotometric and Colorimetric Record of Some Leaves of Trees, Vegetation and Soil, U. S. National Bureau of Standards Report No. 4528, Boulder, Colorado
- Kennedy, J. M. et al (1967) A Study of the Theory and Measurements of the Microwave Emission Properties of Natural Materials, Technical Report SGC-829R-5, Space General Corporation
- Kennedy, J. M. and Edgerton, A. T. (1967) Microwave radiometric sensing of soils and sediments. Paper presented at Annual Meeting of the American Geophysical Union, Washington, D. C.
- Kiefer, Ralph W. (1967) Landform features in the United States, Photogrammetric Engineering, 33 (No. 2): 174-182.
- Kiersch, G. A. (1964) Geothermal Steam; Origin, Occurrence, Characteristics, and Exploitation, Air Force Cambridge Research Laboratories, AFCRL-64-898, Final Report, Contract AF19(628)-293, Cornell Univ., AD611808
- Krinov, E. L. (1953) Spectral Reflectance Properties of Natural Formations, Technical Translation TT-439, National Research Council of Canada
- Legget, R. F. (1967) Soil: its geology and use, Geol. Soc. Am. Bull., 78: 1433-1460
- Leet, L. D. and Judson, S. (1967) Physical Geology, Prentice-Hall, N. J.
- Linehan, D. (1951) Seismology Applied to Shallow Zone Research, Special Technical Publication No. 122, American Society for Testing Materials
- Lobeck, A. K. and Tellington, W. J. (1944) Military Maps and Air Photographs, 1st Edition, McGraw-Hill Book Co., New York, N. Y.
- Lyon, R. J. P. and Patterson, J. W. (1966) Infrared spectral signatures - a field geological tool, Proceedings, 4th Symposium on Remote Sensing of Environment, University of Michigan, 215-230.
- Mays, R. R., Noma, A. A., and Aumen, W. C. (1965) Digitizing graphic data, U. S. Army Map Service. Paper presented at Annual Meeting, American Congress on Surveying and Mapping, Washington, D. C.
- McCarty, J. L. et al (1964) Application of Penetrometers to the Study of Physical Properties of Lunar and Planetary Surfaces, NASA-TN-D-2413, Langley Research Center, NASA.
- Meyer, M. A. (1966) Remote sensing of ice and snow thickness, Proceedings, 4th Symposium on Remote Sensing of Environment, University of Michigan, 183-192.
- Miesch, A. T. (1967) Geologic data; some comments on quality, Geotimes, 12 (No.9): 12-14.
- Molineux, C. E. (1955) Remote Determination of Soil Trafficability by the Aerial Penetrometer, Air Force Cambridge Research Laboratories, AFCRL-TN-55-223, Air Force Survey in Geophysics, No. 77, Bedford, Mass.
- Molineux, C. E. (1965) Multiband spectral system for reconnaissance, Photogrammetric Engineering, XXXI
- Moxham, R. M. (1960) Airborne radioactivity surveys in geologic exploration, Geophysics, 25 (No. 2)

References

- Moore, R. K. (1966) Radar Scatterometry - An Active Sensing Tool, CRES Report No. 61-11, University of Kansas
- National Academy of Sciences (1963) Proceedings of Permafrost International Conference, 11-15 November 1963 at Purdue University, Lafayette, Indiana, Building Research Advisory Board, Publication No. 1287, Washington, D. C.
- Naval Reconnaissance and Technical Support Center (1966) Camouflage Detection and Black and White Infrared Films for Tactical Aerial Reconnaissance, NAVRECONTECHSUPPCEN, 201/66-U
- Neal, J. T. (1965) Geology, Mineralogy, and Hydrology of U. S. Playas, Air Force Cambridge Research Laboratories, AFCRL-65-266, Environmental Research Paper No. 96, Bedford, Mass.
- Needleman, S. M. (1961) Soil science studies at Centram Sø (Lake), northeast Greenland, 1960, Polarforschung Symposium on Geophysics on Greenland, Munster, W. Germany, 1 Nov 1960, 33-41
- Needleman, S. M. (1962) Arctic Earth Science Investigations, Centram Sø (Lake), Northeast Greenland, 1960, Air Force Cambridge Research Laboratories, AFCRL-62-695, Air Force Survey in Geophysics No. 138, Bedford, Mass.
- Needleman, S. M. and Pressman, A. E. (1962) Site location in the arctic region by airphoto analysis, The Military Engineer, 54 (No. 359): 188-191.
- Pangborn, M. W., Jr. (1967) Recent developments in geoscience libraries, Geotimes, 12 (No. 9): 17-19.
- Pressman, A. E., Stitt, R. L., Montanari, J., and Blesch, R. R. (1961) Terrain Analysis of Ice-Free Land Sites in Arctic Canada, Air Force Cambridge Research Laboratories, AFCRL-61-206, Final Report, Contract AF19(604)-6182, Aero Service Corp., Philadelphia, Pa.
- Roeder, R. S. (1967) Airborne Measurements with the AN/AAR-33 Radiometric Search Set, Sperry Microwave Electronics Company
- Romberg, F. E. (1961) The Detection of Subsurface Voids by Gravimetry, Air Force Cambridge Research Laboratories, AFCRL No. 1014, Final Report, Contract AF19(604)-8348, Texas Instruments, Inc.
- Stein, K. J. (1967) RCA developing laser beam camera unit, Aviation Week and Space Technology, 84-90
- Steiner, D. and Gutermann, T. (1966) Russian Data on Spectral Reflectance of Vegetation, Soil, and Rock Types, Final Technical Report, Department of Geography, University of Zurich
- Stoertz, G. E. (1961) Analogs of Fort Greeley and Fort Churchill Terrain in Central East Greenland, U. S. Army Engineer Waterways Experiment Station, Project 8-70-09-400, Military Evaluation of Geographic Areas, U. S. Geological Survey
- Strahler, A. N. (1960) Physical Geography, John Wiley & Sons, New York, N. Y.
- Strahler, A. N. (1963) The Earth Sciences, Harper & Row, New York, N. Y.
- Sturm, T. A. (1967) The Air Force Scientific Advisory Board, Its First Twenty Years, 1944-1964, Air Force Historic Division, U. S. Govt. Printing Office, Washington, D. C.
- Terzaghi, K., and Peck, R. B. (1948) Soil Mechanics in Engineering Practice, John Wiley & Sons, New York, N. Y.

References

- Thornbury, W. D. (1954) Principles of Geomorphology, John Wiley & Sons, New York, N. Y.
- Tsai, K. (1967) Strength Response Parameters of Natural Soil Surfaces and Their Application to the Landing Problem of Aircraft, Air Force Cambridge Research Laboratories, AFCRL-67-0583, Scientific Report No. 1, Contract AF19(628)-5873, Princeton University, Princeton Soil Engineering Series No. 10.
- University of Michigan (1962) Proceedings of the 1st Symposium on Remote Sensing of Environment, Report 4864-1-X, Institute of Science and Technology
- University of Michigan (1963) Proceedings of the 2nd Symposium on Remote Sensing of Environment, Report 4864-3-X, Institute of Science and Technology
- University of Michigan (1965) Proceedings of the 3rd Symposium on Remote Sensing of Environment, Report 4864-9-X, Institute of Science and Technology
- University of Michigan (1966a) Peaceful Uses of Earth-Observation Spacecraft, Report 7219-1-F (3 volumes), Institute of Science and Technology
- University of Michigan (1966b) Proceedings of the 4th Symposium on Remote Sensing of Environment, Report 4864-11-X, Institute of Science and Technology
- U. S. Air Force (1952) Geology and its Military Applications, (U. S. Army Technical Manual 5-545, August 1952) AFM-88-53
- U. S. Air Force (1954) Control of Soils in Military Construction, (U. S. Army Technical Manual 5-541, Sept. 1954), AFM-88-52
- U. S. Air Force (1958) Materials Testing, (Revision of U. S. Army Tech. Manual 5-530, 12 Dec. 1957), AFM-88-51
- U. S. Air Force Scientific Advisory Board (1966) Report of the USAF Scientific Advisory Board Geophysics Panel Ad-Hoc Study Group on Remote Sensing and Evaluation of Terrain Data
- U. S. Army Corps of Engineers Waterways Experiment Station (1952) Landing Strip Evaluation, Vicksburg, Miss. (Report not numbered)
- U. S. Army Corps of Engineers Waterways Experiment Station (1954) Trafficability of Soils; Tests on Natural Soils with Self-Propelled Vehicles, 1949-1950, Technical Memorandum No. 3-240, Supplement No. 10, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1954) Trafficability of Soils; Soil Classification, Technical Memorandum No. 3-240, Supplement No. 11, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1960) The Unified Soil Classification System, Volume I, Technical Memorandum No. 3-357, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1961) Trafficability of Soils; Soil Classification, Technical Memorandum No. 3-240, Supplement No. 16, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1963a) Forecasting Trafficability of Soils; Airphoto Approach, Volumes I and II, Technical Memorandum No. 3-331, Report No. 6, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1963b) Studies of Aerial Cone Penetrometer, Technical Report No. 3-463, Vicksburg, Miss.

References

- U. S. Army Corps of Engineers Waterways Experiment Station (1963c) Soil Stabilization Requirements for Military Roads and Airfields in the Theater of Operations, Miscellaneous Paper No. 3-605, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1965) Telemetry of Soil-Moisture and Weather Variable, Misc. Paper No. 5-711, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1966a) Radar Responses to Laboratory Soil Samples, Technical Report No. 3-693 (Report No. 2), Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1966b) Feasibility Study of the Use of Radar, Technical Report No. 3-727, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1966c) Report of Conference of the Board of Consultants on Remote Terrain Analysis by Electromagnetic Means, Miscellaneous Paper No. 791, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station, (1967) Terrain Analysis by Electromagnetic Means, Tech. Rept. No. 3-693, Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1967) Laboratory Investigation in the 0 - 2.82 MEV Gamma Ray Spectral Region, Technical Report No. 3-693 (Report No. 3), Vicksburg, Miss.
- U. S. Army Corps of Engineers Waterways Experiment Station (1967) Mobility Environmental Research Study; A Quantitative Method for Describing Terrain for Ground Mobility, Technical Report No. 3-726, Volumes I-III, Vicksburg, Miss.
- U. S. Coast and Geodetic Survey (1964) Preliminary Report, Prince William Sound Alaskan Earthquakes, March-April, 1964, U. S. Dept. of Commerce, Washington, D. C.
- U. S. Geological Survey (1945) The military geology unit of the U. S. Geological Survey and Corps of Engineers, U. S. Army. Paper presented at Annual Meeting of Geological Society of America, Pitts. 1945, Washington, D. C.
- Van Lopik, J. R. (1962) Optimum utilization of airborne sensors in military geography, Photogrammetric Engineering, 28 (No. 5): 773-778
- Van Lopik, J. R. and Kolb, C. R. (1959) A Technique for Preparing Desert Terrain Analogs, U. S. Army Engineer Waterways Experiment Station, Technical Report No. 3-056, Vicksburg, Miss. AD217639
- Vary, W. E. (1967) Preliminary Results of Tests with Aerial Color Photography for Water Depth Determination, U. S. Naval Oceanographic Office
- Williams, O. W. (1963) A Compendium of Papers in the Fields of Geodesy and Planetary Geometry Prepared at AFCRL during 1962, Air Force Cambridge Research Laboratories, AFCRL-63-867, Bedford, Mass.
- Williams, O. W. (1964) A Compendium of Papers in the Fields of Wave Propagation and Geotechnics Prepared at AFCRL During 1963, Air Force Cambridge Research Laboratories, AFCRL-64-998, Special Report No. 17, Bedford, Mass.
- Womack, L. M. (1965) Tests with a C-130E Aircraft on Unsurfaced Soils, U. S. Army Engineer Waterways Experiment Station Miscellaneous Paper No. 4-712, Vicksburg, Miss. AD613170

References

- Wood, W. F. and Snell, J. B. (1960) A Quantitative System for Classifying Landforms, U. S. Army Quartermaster Research and Engineering Command, Technical Report No. EP-124, Washington, D. C.
- Zirkind, R., Editor (1967) Proceedings of Symposium on Electromagnetic Sensing of the Earth from Satellites, Polytechnic Institute of Brooklyn, New York

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Bibliography

I. TECHNICAL PUBLICATIONS

- Air Force Cambridge Research Laboratories (1962) History of AFCRL for the Period January 1961-June 1962, AFCRL-62-714, Bedford, Mass.
- Air Proving Ground Command (1955) Final Report on Evaluation of Forward Air-Strip Criteria, Project No. APG/TAT/141-A, Eglin AFB, Florida
- American Society of Photogrammetry (1952) Manual of Photogrammetry, George Banta Co., Menasha, Wisc.
- American Society for Testing Materials (1958) Procedures for Testing Soils, Philadelphia, Pa.
- Anstey, R. L. (1965) Physical Characteristics of Alluvial Fans, U. S. Army Natick Laboratories, Technical Report No. ES-20, Natick, Mass.
- Anthony, A. L. (1962) Investigation of Photographic Mapping Detail and Data Encoding, U. S. Army Engineer and Research and Development Laboratories, Contract DA-44-009-Eng-4777, New York University
- Bader, H., VanSteenburgh, and Tyree, D. M. (1967) Arctic Research, The Arctic Institute of North America, Office of Naval Research Contract Nonr-3996(01)-NR-307, 105, Washington, D. C.
- Barnes, D. F. (1960) An Investigation of a Perennially Frozen Lake, AFCRL Air Force Survey in Geophysics No.124, Bedford, Mass.
- Beckett, P. H. T. and Webster, R. W. (1965) Field Trials of a Terrain Classification System; Organization and Methods, Military Engineering Experimental Establishment, Report No. 873, Christchurch, Hampshire, England. AD 809687
- Beckett, P.H.T. and Webster, R. W. (1965) A Terrain Brief, Military Engineering Experimental Establishment, Report No. 931, Christchurch, Hampshire, England. AD809694

Bibliography

- Belcher, D. J. (1945) The engineering significance of soil patterns, Photogrammetric Engineering, 11 (No. 2): 115-148.
- Belcher, D. J. (1953) The engineering significance of landforms, Proceedings of Highway Research Board No. 2 in Bulletin No. 13, National Academy of Science, Washington, D. C.
- Belcher, D. J. (1959) Microforms and features, Photogrammetric Engineering, 25: 773-778.
- Belcher, D. J., Gregg, L. E. and Woods, K. B. (1943) The Formation, Distribution, and Engineering Characteristics of Soil, Purdue University Research Series No. 87, Highway Bulletin No. 10, Lafayette, Ind.
- Black, R. F. (1954) Permafrost; a review, Geological Society of America Bulletin, 65: 839-856.
- Brooks, A. H. (1921) The use of geology on the western front, U. S. Geol. Survey Bulletin 128D: 85-124.
- Bucher, W. H. (1933) The Deformation of the Earth's Crust, Princeton, Univ. Press
- Burns, C. D. (1955) Evaluation of Forward Airstrip Criteria for Soil Strength, Miscellaneous Paper No. 4-104, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.
- Burns, C. D. (1963) Aircraft Operations on Unsurfaced Soil, Soil Measurements and Analyses, Project Rough Road Alpha, Technical Report No. 3-624, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.
- Byerly, P. (1942) Seismology, Prentice-Hall Co., Inc., New York, N. Y.
- Cain, S. A. and Castro, G. M. (1959) Manual of Vegetation Analysis, Harper and Bros., New York, N. Y.
- Cameron, H. L. (1953) Air-photo interpretation in natural resources inventories, Photogrammetric Engineering, 19 (No. 3): 481-486.
- Carr, D. D., Becker, R. E., and Van Lopik, J. R. (1963) Terrain Quantification, Phase II; Playa and Miscellaneous Studies, Air Force Cambridge Research Laboratories, AFCRL-63-793, Final Report, Contract AF19(628)-2786, Texas Instruments, Inc.
- Casagrande, A. (1947) Classification and Identification of Soils, Graduate School of Engineering, Harvard University, Cambridge, Mass.
- Challinor, J. (1962) A Dictionary of Geology, Oxford University Press, New York, N. Y.
- Chambers, J. V. (1961) An Environmental Comparison of Southeast Asia and the Island of Hawaii, U. S. Army Quartermaster Research and Engineering Command Research Study Report No. REP-38, Natick, Mass.
- Chapman, C. A. (1962) A new quantitative method of topographic analysis, American Journal of Science, 250: 428-452.
- Chorley, R. J. (1957) Climate and morphometry, Journal of Geology, 65: 628-638.
- Chorley, R. J. (1959) The geomorphic significance of some Oxford soils, American Journal of Science, 257: 503-515.

Bibliography

- Clements, T., Merriam, R. H., Mann, J. F., and Stone, R. O. (1955) An Evaluation of Types and Scales of Aerial Photographs for Use in Arid Regions, Air Force Contract AF33(616)-2175, University of So. California AD87638
- Clements, T., Merriam, R. H., Stone, R. O., Eymann, J. L., and Reade, H. L. (1957) A Study of Desert Surface Conditions, U. S. Army Quartermaster Research Dev. Command, Technical Report No. EP-53, Univ. of So. Calif.
- Clements, T., Mann, J. F., Stone, R. O., and Eymann, J. L. (1963) A Study of Windborne Sand and Dust in Desert Areas, U. S. Army Natick Laboratories Technical Report No. ES-8, Natick, Mass.
- Coates, D. R. (1957) Use of specially made maps in morphometric studies, Geol. Survey Bulletin, 28 (Part 2): 1710.
- Coates, D. R. (1959) Influence of scale in geomorphic map analysis. Paper presented at AAAS 126th Annual Meeting, Chicago, Ill.
- Colwell, R. N. (1946) The estimation of ground conditions from aerial photographic interpretation of vegetative types, Photogrammetric Engineering, 12: 151-161.
- Cornell, Univ. (1951) A Photo-Analysis Key for the Determination of Ground Conditions; Landform Reports, Office of Naval Research Contract, Technical Report No. 2, Volumes 1-6, Ithaca, N. Y.
- Crain, C. N. (1965) Semi-Annual Technical Summary Report on Project Duty; A Methodological Study of the Physical Environment, U.S. Army Research Office Contract under ARPA Order No. 415, University of Denver, AD458545; Report No. 5. AD470379.
- Daly, R. A. (1940) The Strength and Structure of the Earth, Prentice-Hall, Inc. New York, N. Y.
- Davies, W. E. (1961) Surface features of permafrost in arid areas, Geology of the Arctic, 2: 781-787, Univ. of Toronto Press, Toronto, Canada.
- Davies, W. E., and Krinsley, D. B. (1961) Evaluation of Arctic Ice-Free Land Sites Kronprins Christian Land and Peary Land, North Greenland 1960, Air Force Cambridge Research Laboratories, Air Force Survey in Geophysics No. 135, Bedford, Mass.
- Davis, C. K. and Neal, J. T. (1963) Description and airphoto characteristics of desert landforms, Photogrammetric Engineering, 29: 621-631.
- Davis, C. M. (1962) Analysis of Geographic and Climatic Factors in Coastal Southeast Asia, U. S. Army Quartermaster Research and Development Command, Natick, Mass. (Contract DA -19-129-QM-1655), AD275476
- Deere, D. U. and Miller, R. P. (1966) Engineering Classification and Index Properties for Intact Rock, Air Force Weapons Laboratory, Technical Report No. AFWL-TR-65-116, Contract AF29(601)-6319, University of Illinois
- Deetz, C. H. (1943) Cartography, U. S. Coast and Geodetic Survey Special Publication No. 205, 2nd Edition, U. S. Government Printing Office, Wash., D. C.
- Desjardins, L. (1943) A rapid method of drafting an accurate map from vertical aerial photographs, Photogrammetric Engineering, 9 (No. 3): 172-175.
- Dietz, R. S. (1947) Aerial photographs in the geologic study of shore features and processes, Photogrammetric Engineering, 13: 537-545.
- Dietz, R. S. (1964) Origin of continental slopes, American Scientist, 52 (No. 1): 50-69.

Bibliography

- Dirmeyer, R. D., Jr. (1945) Military applications of photogeology, The Military Engineer, 37 (No. 240): 392-397.
- Dobrin, M. B. (1960) Introduction to Geophysical Prospecting, 2nd Edition, McGraw-Hill Book Co., New York, N. Y.
- Dunton, E. C. (1967) Modification and Flight Testing of Airborne Gravity Measuring System Instrumentation, Air Force Cambridge Research Laboratories, Final Report, Contract AF19(628)-4025, Barkley and Dexter Laboratories.
- Dwornik, S. E. et al (1959) Microrelief-physiography-land use-relationships, Geol. Soc. of America Bulletin, 70: 1804.
- Dwornik, S. E. and Webb, P. K. (1961) Microrelief Studies as a Guide to Mine Detector Design, U. S. Army Engineering Research and Development Laboratories, Report No. 1692-RR, Ft. Belvoir, Virginia.
- Eardley, A. J. (1951) Structural Geology of North America, Harper Bros., New York, N. Y.
- El-Ashry, M. R. and Wanless, H. R. (1967) Shoreline features and their changes, The Military Engineer, 33 (No. 2): 184-189.
- Ewing, C. E. (1960) Research and Development in the Field of Geodetic Science, Air Force Cambridge Research Laboratories, AFCRL-TN-60-435, Air Force Survey in Geophysics No. 124, Bedford, Mass.
- Ewing, M. and Donn, W. L. (1961) Pleistocene climate changes, Geology of the Arctic, 2: 931-941, University of Toronto Press, Toronto, Canada.
- Fenneman, N. M. (1931) Physiography of Western United States, McGraw-Hill Book Co., New York, N. Y.
- Fenneman, N. M. (1938) Physiography of Eastern United States, McGraw-Hill Book Co., New York, N. Y.
- Fenton, C. L. and Fenton, M. A. (1952) Giants of Geology, Doubleday Co., Garden City, New York.
- Field, R. M. (1951) Geology, 4th Edition, Barnes and Noble, New York, N. Y.
- Fischer, W. A. (1955) Photogeologic instruments used by the U. S. geological survey, Photogrammetric Engineering, 21 (No. 1): 32-39.
- Fischer, W. A. (1958) Color aerial photography in photogeologic interpretation, Photogrammetric Engineering, 24 (No. 4): 545-549.
- Fleming, J. A. (1939) Terrestrial Magnetism and Electricity, McGraw-Hill Book Co., New York, N. Y.
- Fletcher, R. J. (1964) The use of aerial photographs for engineering soil reconnaissance in arctic Canada, Photogrammetric Engineering, 30 (No. 2): 210-219.
- Fletcher, J. O. (1966) Origin and Early Utilization of Aircraft-Supported Drifting Stations, the RAND Corp., Santa Monica, Calif.
- Flint, R. F. (1961) Glacial and Pleistocene Geology, John Wiley & Sons, New York, N. Y.
- Folson, F. (1962) Exploring American Caves, Revised Edition, Collier Books, New York, N. Y.
- Free, E. E. (1911) The Movement of Soil Material by the Wind, U. S. Dept. of Agriculture, Bureau of Soils Bulletin No. 68, Washington, D. C.

Bibliography

- Freitag, D. R. (1965) Wheels on Soft Soils; An Analysis of Existing Data, U. S. Army Engineers Waterways Experiment Station, Technical Report. No. 3-670, Vicksburg, Miss.
- Frost, R. E. (1953) Factors limiting the use of aerial photographs for analysis of soil and terrain, Photogrammetric Engineering, 19 (No. 3): 427-436.
- Frost, R. E. et al (1953) A Manual on the Airphoto Interpretation of Soils and Rocks for Engineering Purposes, Purdue University.
- Frost, R. E. (1960) Aerial photography in arctic and subarctic engineering, Journal of the Air Transport Division, Proceedings of American Society of Civil Engineers, 86 (No. AT 1): 27-56.
- Gamow, G. (1941) Biography of the Earth; Its Past, Present, and Future, Viking Press, Inc., New York, N. Y.
- Gamow, G. (1962) Gravity, Anchor Books, Garden City, New York, N. Y.
- Geiger, R. (1950) The Climate Near the Ground, Harvard University Press, Cambridge, Mass.
- Gilbert, G. K. (1914) The Transportation of Debris by Running Water, U. S. Geol. Survey Prof. Paper No. 86.
- Gilbert, P. R. (1968) The numerical map, The Military Engineer, 60 (No. 395): 194-196.
- Goldberg, G. M. (1962) The derivation of quantification of surface data from gross sources, Surveying and Mapping, 22: 537.
- Grenke, W. C. (1965) Observing, Analyzing, and Forecasting the State of the Ground, U. S. Army CE Waterways Experiment Station, Contract Report No. 3-112, Contract DA-22-079-eng-354, Wilson, Nuttal, Raimond Engrs., Inc., AD616616.
- Griffiths, T. M. (1964) A Comparative Study of Terrain Analysis Techniques, U. S. Army Research Office (Durham), Technical Paper No. 64-2, Contract DA-31-124-AROD-79, University of Denver, AD 450591.
- Grim, R. E. (1962) Applied Clay Mineralogy, McGraw-Hill Book Co., New York, N. Y.
- Grimes, C. K. (1957) Development of a Method and Instrumentation for Evaluation of Runway Roughness Effects on Military Aircraft, NATO Advisory Group for Research and Development, Report No. 119.
- Gutenberg, B. et al (1951) Internal Constitution of the Earth, Dover Publications, New York, N. Y.
- Hale, B. W. and Look, C. E. (1962) Underwater microcontouring, Photogrammetric Engineering, 28 (No. 1): 96-98.
- Hambridge, G. (1941) Climate and Man, Dept. of Agriculture 1941 Yearbook of Agriculture, U. S. Government Printing Office, Washington, D. C.
- Hamilton, R. A. Editor (1958) Venture to the Arctic, Pelican Books, Inc., Baltimore, Md.
- Hammond, E. H. (1958) Procedures in the Description Analysis of Terrain, Office of Naval Research, Contract Nonr-1202(01), University of Wisconsin AD202198.

Bibliography

- Happ, S. C. (1955) Engineering geology reference list, Geol. Soc. of Am. Bulletin, 66 (No. 8).
- Harrison, J. C. (1962) The measurement of gravity, Proceedings of the Inst. Radio Engineers, 50 (No. 11): 2302-2312.
- Harrison, W. L., Jr., and Chang, B. (1966) Analogs: For Soil Strength Prediction, U. S. Army Tank Automotive Center Land Locomotion Laboratory, Technical Report No. 9267 (LL108), Warren, Mich.
- Hartshorn, J. H. et al (1961) Investigation of Ice-Free Sites for Aircraft Landings in East Greenland, 1959, Air Force Cambridge Research Laboratories, Air Force Survey in Geophysics No. 127, Bedford, Mass.
- Heiland, C. A. (1942) Geophysics in war, Colorado School of Mines Quarterly, 37 (No. 1).
- Heiskanen, W. A. and Vening Meinesz, F. Z. (1958) The Earth and Its Gravity Field, McGraw-Hill Book Co., New York, N. Y.
- Hemphill, W. R. (1958) Small-scale photographs in photogeologic interpretation, Photogrammetric Engineering, 24 (No. 14): 562-567.
- Hemphill, W. R. and Danilchik, W. (1968) Geologic interpretation of a gemini photo, Photogrammetric Engineering, 34 (No. 2): 150-154.
- Highway Research Board (1941) The Appraisal of Terrain Conditions for Highway Engineering Purposes, Bulletin No. 13, Washington, D. C.
- Highway Research Board (1945) Classification of soils and subgrade materials for highway construction, Proceedings, 25, Washington, D. C.
- Highway Research Board (1946) Engineering Use of Agricultural Soil Maps, Bulletin No. 22, Washington, D. C.
- Highway Research Board (1950) Soil Exploration and Mapping, Bulletin No. 28, Washington, D. C.
- Highway Research Board (1951) Engineering Soil Survey Mapping, Bulletin No. 46, Washington, D. C.
- Highway Research Board (1952) Mapping and Subsurface Exploration for Engineering Purposes, Bulletin No. 65, Washington, D. C.
- Highway Research Board (1953) Engineering Applications of Soil Surveying and Mapping, Bulletin No. 83, Washington, D. C.
- Highway Research Board (1957) Agriculture Soil Maps, Status, Bulletin No. 22R, Washington, D. C.
- Highway Research Board (1968) Highway Research in Progress, Parts I-III, (January 1964-October 1967) Highway Research Information Service, National Research Council, Washington, D. C.
- Hittle, J. E. (1949) Air photo interpretation of engineering sites and materials, Photogrammetric Engineering, 15 (No. 4): 589-603.
- Hobbs, W. H. (1911) Characteristics of Existing Glaciers, The Macmillan Co., New York, N. Y.
- Hobbs, W. H. (1935) Earth Features and Their Meaning, The Macmillan Co., New York, N. Y.
- Holm, D. A. (1960) Desert geomorphology in the Arabian Peninsula, Science, 132: 1369-1379.

Bibliography

- Holmes, G. W. and Benninghoff, W. S. (1957) Terrain Study of the Army Test Area, Fort Greely, Alaska, Volumes I, II, U. S. Army Engineer Waterways Experiment Station Project on Military Evaluation of Geographic Areas (8-97-10-004), U. S. Geological Survey
- Horton, R. E. (1945) Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology, Geol. Soc. of Am. Bulletin, 56 (No. 3): 275-370.
- Hosmer, G. L. (1930) Geodesy, 2nd Edition, John Wiley & Sons, New York, N. Y.
- Houbolt, J. C. (1961) Runway roughness studies in the aeronautical field, Journal of Air Transport Division, Proceedings of American Society of Civil Engineers, 11-31.
- Howell, B. F., Jr. (1959) Introduction to Geophysics, McGraw-Hill Book Co., New York, N. Y.
- Hubbert, M. K. (1948) Gravitational terrain effects of two-dimensional topographic features, Geophysics, 13: 226-254.
- Hunt, C. B. (1950) Military geology, Berkey Volume, Geol. Soc. of Am.: 295-327.
- Irving, E. (1964) Paleomagnetism and Its Application to Geological and Geophysical Problems, John Wiley & Sons, New York, N. Y.
- Isaacs, J. D. and Iselin, C. (1952) Oceanographic Instrumentation, National Academy of Sciences Publication No. 309, National Research Council, Washington, D. C.
- Jacobs, J. A., Russell, R. D., and Wilson, J. T. (1959) Physics and Geology, McGraw-Hill Book Co., New York, N. Y.
- Jenkins, D. S., Belcher, D. J., Gregg, L. E., and Woods, K. B. (1946) The Origin, Distribution, and Airphoto Identification of United States Soils, Civil Aeronautics Administration, U. S. Dept. of Commerce, Washington, D. C.
- Jenks, G. F. and Brown, D. A. (1966) Three-dimensional map construction, Science, 154 (No. 3750): 857-864, AD64640
- Johnson, D. W. (1917) Topography and Strategy in War, Henry Holt & Co., New York, N. Y.
- Johnson, D. W. (1921) Battlefields of the World War, Oxford University Press, New York, N. Y.
- Johnson, Q. S. (1958) Athens to Sparta; a comprehensive terrain data handling system, Photogrammetric Engineering, 24 (No. 4): 656-660.
- Kaye, C. A. (1957) Military geology in the U. S. sector of the European Theater of Operations during World War II, Geol. Soc. of Am. Bull., 68 (No. 1): 47-53.
- Kellogg, C. E. (1936) Development and Significance of the Great Soil Groups of the United States, U. S. Dept. of Agriculture, Miscellaneous Publication No. 229, Washington, D. C.
- Kent, B. H. (1957) Experiments in the use of color aerial photographs for geologic study, Photogrammetric Engineering, 23 (No. 5): 865-868.
- Kerr, P. F. (1963) Quick clay, Scientific American, 209 (No. 5): 132-142.
- Kerr, P. F. and Drew, I. M. (1966) Quick-Clay Movements, Anchorage, Alaska, Air Force Cambridge Research Laboratories, AFCRL-66-78, Final Report, Contract AF19(604)-8387, Columbia University, N. Y.

Bibliography

- Kesseli, J. E. and Beaty, C. B. (1959) Desert Flood Conditions in the White Mountains of California and Nevada, U. S. Army Quartermaster Research and Development Command, Contract DA-19-129-QM-565, University of California.
- Kilmer, V. J. and Alexander, L. T. (1949) Methods of making mechanical analyses of soils, Soil Science, 68: 15-24.
- King, C. A. M. (1963) Introduction to Oceanography, McGraw-Hill Book Co., New York, N. Y.
- Kingery, W. D. and Adams, C. M. (1962) Basic Research on Ice and Snow, Air Force Cambridge Research Laboratories, AFCRL-62-1080, Final Report, Contract AF19(604)-5994, Massachusetts Institute of Technology, Cambridge, Mass.
- Kirwan, L. P. (1960) A History of Polar Exploration, W. W. Norton, Co., Inc. New York, N. Y.
- Kolb, C. R. and Shamburger, J. H. (1961) Project OTTER (Overland Train Terrain Evaluation Research), U. S. Army Engineer Waterways Station, Technical Report No. 3-588, Vicksburg, Miss.
- Koepe, C. E. and DeLong, G. C. (1958) Weather and Climate, McGraw-Hill Book Co., New York, N. Y.
- Kozan, G. R. and Pimental, R. A. (1965) Guide Manual for Selection and Use of Dust Palliatives and Soil Waterprooferers in the Theater of Operations, U. S. Army Engineer Waterways Experiment Station, Miscellaneous Paper No. 4-756, Vicksburg, Miss.
- Krumbein, W. C. (1955) Experimental design in the earth sciences, Transactions of American Geophysical Union, 36 (No. 1): 1-11.
- Krumbein, W. C. (1962) The computer in geology, Science, 136 (No. 3522): 1087-1092.
- Krynine, D. P. and Judd, W. R. (1957) Principles of Engineering Geology and Geotechnics, McGraw-Hill Book Co., New York, N. Y.
- Kuenen, P. H. (1950) Stereoscopic projection for demonstration in geology, geomorphology, and other natural sciences, Journal of Geology, 58 (No. 1): 49-54.
- Kuenen, P. H. (1950) Marine Geology, John Wiley & Sons, New York, N. Y.
- Lahee, F. H. (1961) Field Geology, 6th Edition, McGraw-Hill Book Co., New York, N. Y.
- LaMonica, G. B. (1968) Organization of Topics and Literature References in the Earth Sciences for Machine Storage and Retrieval, Office of Naval Research, Technical Report No. 7, Contract Nonr-1228(36) Northwestern University.
- Landsberg, H. E. and Jacobs, W. C. (1951) Applied climatology, Compendium of Meteorology, American Meteorological Society, Boston, Mass., : 976-992.
- Langbein, W. B. (1947) Topographic Characteristics of Drainage Basins, U. S. Geological Survey, Water Supply Paper 968-C, Washington, D. C.
- Langer, A. M. and Kerr, P. F. (1966) Mohave playa crusts; physical properties and mineral content, Journal of Sedimentary Petrology, 36 (No. 2): 377-396.

Bibliography

- Lassaline, D. M. and Harrison, W. L. (1965) The Prediction of Soil Strength Parameters in Remote or Inaccessible Areas by Means of Soil Analogs, U. S. Army Tank Automotive Center Technical Report No. 8816 (LL102), Warren, Mich. AD465409
- Lee, N. W. E. (1964) Roadway plans from a total air photo technique without ground control, Photogrammetric Engineering, 30 (No. 2): 251-258.
- Leestma, R. A. (1967) A Methodology for Military Geographic Analysis, U. S. Army Engineer Topographic Laboratories, Technical Report No. 36-TR, Ft. Belvoir, Va. AD660350.
- Legget, R. F. (1962) Geology and Engineering, 2nd Edition, McGraw-Hill Book Co., New York, N. Y.
- Liang, T. (1964) Tropical Soils; Characteristics and Air Photo Interpretation, Air Force Cambridge Research Laboratories, AFCRL-64-937, Final Rpt, Contract AF19(628)-291, Cornell University.
- Liang, T. and Belcher, D. J. (1958) Landslides and Engineering Practice, Highway Research Board, Special Report No. 29, Chapter No. 5, Airphoto Interpretation, Washington, D. C.
- Liston, R. A. et al. (1966) Off-the-Road Mobility Research, U. S. Army Tank Automotive Center, Technical Report No. 9560, Research Report No. 6, Land Locomotion Laboratory, Warren, Mich. AD651726.
- Liu, T. K. and Thornburn, T. H. (1965) Engineering Index Properties of Some Surficial Soils in Illinois, University of Illinois Engineering Experiment Station, Bulletin No. 473, Urbana, Ill.
- Lobeck, A. K. (1924) Block Diagrams, John Wiley & Sons, New York, N. Y.
- Lobeck, A. K. (1939) Geomorphology; An Introduction to the Study of Landscapes, McGraw-Hill Book Co., New York, N. Y.
- Lovering, T. S. (1943) Minerals in World Affairs, Prentice-Hall, Inc., New York, N. Y.
- Lustig, L. K. (1967) Inventory of Research on Geomorphology and Surface Hydrology of Desert Environments, U. S. Army Natick Laboratories, Chapter IV, Contract DA49-092-ARO-71, University of Arizona.
- Malley, R. J. (1967) Forward airfield construction in Vietnam, The Military Engineer, 59 (No. 391): 318-322.
- Maxwell, J. C. (1962) Test of Quantitative Terrain Description Systems at Ft. Leonard Wood, Missouri, U. S. Army Engineer Waterways Experiment Station, Contract DA22-079-Eng-303, Univ. of Missouri, School of Mines.
- Maxwell, J. C. (1968) Continental drift and a dynamic earth, American Scientist, 56 (No. 1): 35-51.
- Meinzer, O. E. (1923) The Occurrence of Ground Water in the United States, U. S. Geological Survey Water Supply Paper No. 489, Washington, D. C.
- Meinzer, O. E. (1942) Hydrology, McGraw-Hill Book Co., New York, N. Y.
- Melton, F. A. (1950) The geomorphology and photogeological study of the flat lands, Photogrammetric Engineering, 16: 722-744.
- Melton, F. A. (1959) Aerial photographs and structural geomorphology, Journal of Geology, 67 (No. 4): 351-370.

Bibliography

- Melton, M. A. (1957) An Analysis of the Relations Among Elements of Climate; Surface Properties, and Geomorphology, Office of Naval Research, Technical Report No. 11, Contract N6 ONR 271-30, Columbia University.
- Melton, M. A. (1958) Use of punched cards to speed statistical analysis of geomorphic data, Geol. Soc. of Am. Bull., 69: 355-358.
- Merriam, D. F. (1967) Computer Applications in the Earth Sciences; Colloquium on Classification Procedures, Office of Naval Research, Contract Nonr-1228(36), Kansas Geological Survey AD655445.
- Meyer, M. P. (1966) Comparison of Engineering Properties of Selected Temperate and Tropical Surface Soils, U. S. Army Engineer Waterways Experiment Station, Technical Report No. 3-732, Vicksburg, Miss.
- Meyer, M. P. (1967) Trafficability Classification of Thailand Soils, U. S. Army Engineer Waterways Experiment Station, Technical Report No. 3-753, Vicksburg, Miss.
- Miller, C. L. and LaFlamme, R. A. (1958) The digital terrain model; theory and application, Photogrammetric Engineering, 24 (No. 3): 433-442.
- Miller, R. L. and Kahn, J. S. (1962) Statistical Analysis in the Geological Sciences, John Wiley & Sons, New York, N. Y.
- Miller, V. C. (1961) Photogeology, McGraw-Hill Book Co., New York, N. Y.
- Mintzer, O. W., Yoder, E. J., and Shepard, J. R. (1951) Application of Airphoto Pattern Analysis to Soil Trafficability Studies, Book One, U. S. Army Engineer Waterways Experiment Station, Contract DA-22-079-Eng-59, Purdue University
- Mitchell, W. A. (1940) Outlines of the World's Military History, 4th Edition, Military Science Publishing Co., Harrisburg, Pa.
- Moog, R. D. (1959) Minimum Airfield Concept, Douglas Aircraft Co., Engineering Report No. LB-30049, Santa Monica, California.
- Muller, S. W. (1945) Permafrost or Permanently Frozen Ground and Related Engineering Problems, U. S. Army Office of Chief, Engineers, Special Report, Strategic Engineering Study No. 62.
- Muller, S. W. (1947) Permafrost and Permanently Frozen Ground and Related Engineering Problems, J. W. Edwards Inc., Ann Arbor, Mich.
- McGill University (1955-1958) Reports of the Physical Environment of Canada, Project RAND, Research Memorandum Series 1997-2362, Contract AF49(638)-700, Rand Corp.
- McLellan, H. J. (1965) Elements of Physical Oceanography, Pergamon Press, New York, N. Y.
- National Academy of Sciences (1964) Solid-Earth Geophysics; Survey and Outlook, Panel on Solid-Earth Problems, Division of Earth Sciences, Publication No. 1231, Washington, D. C.
- National Academy of Sciences (1966) Rock Mechanics Research, Publication No. 1466, Washington, D. C.
- Neal, J. T. and Motts, W. S. (1967) Recent geomorphic changes in playas of western United States, The Journal of Geology, 75 (No. 5): 511-525.
- Neal, J. T. (1968) Playa Surface Morphology; Miscellaneous Investigations, Air Force Cambridge Research Laboratories, AFCRL-68-0133, Environmental Research Paper No. 283, Bedford, Mass.

Bibliography

- Neal, J. T., Langer, A. M., and Kerr, P. F. (1968) Giant dessication polygons of great basin playas, Geol. Soc. of Am. Bull., 79 (No. 1): 69-90.
- Needleman, S. M., Klick, D. W., and Molineux, C. E. (1961) Evaluation of an Arctic Ice-Free Land Site and Results of C-130 Aircraft Test Landing, Polaris Promontory, North Greenland, 1958-1959, Air Force Cambridge Research Laboratories, AFCRL-61-252, Air Force Survey in Geophysics No. 132, Bedford, Mass.
- Newton, W. S. and Makrides, C. G. (1954) Effect of Climate and Environment on Ground Support Equipment, Wright Air Development Center, Wright-Patterson AFB, Ohio, Corvey Engineering Co.
- Parvis, M. (1950) Drainage pattern significance in airphoto identification of soils and bedrocks, Soil Exploration and Mapping, Highway Research Board, Bulletin No. 28, Washington, D. C.
- Pearl, R. M. (1951) Guide to Geologic Literature, McGraw-Hill Book Co., New York, N. Y.
- Peltier, L. C. (1955) Landform analysis in operational research, Geol. Soc. Am. Bull., 66: 1716-1717.
- Peltier, L. C. (1959) Area sampling for terrain analysis, Geol. Soc. Am. Bull., 70: 1809.
- Peltier, L. C. and Percy, G. E. (1966) Military Geography, D. Van Nostrand Co., Inc., New York, N. Y.
- Pierson, W. J. and Neumann, G. (1965) Oceanography, Prentice-Hall, N. J.
- Pirsson, L. V. and Knopf, A. (1947) Rocks and Rock Minerals, 3rd Edition, John Wiley & Sons, New York, N. Y.
- Pomeroy, J. A. and Cline, M. G. (1953) The accuracy of soil maps prepared by various methods that use aerial photographic interpretation, Photogrammetric Engineering, 19 (No. 5): 809-817.
- Porter, O. J. Co. (Porter and O'Brien, Egrs) (1961) Surface Site Investigation; Second Deployment Area, WS-133A Operational Facilities, Ellsworth AFB, South Dakota, Volume III, Flight B, Air Force Ballistic Missile Division, Contract AF04(647)-709, Los Angeles, Calif. (Official Government Use Only).
- Portland Cement Assoc. (1950) Soil Primer, Chicago, Ill.
- Post, J. L. (1967) Chemical Stabilization of Playa Soils, Air Force Weapons Laboratory, Technical Report AFWL-TR-67-107, Contract AF29(601)-6002, University of New Mexico.
- Pressman, A. E. (1963) Comparison of aerial photographic terrain analysis with investigation in arctic Canada, Photogrammetric Engineering, 29 (No. 2): 245-252.
- Price, P. H. (1946) Geologists place in the service, Am. Assoc. Petroleum Geol. Bull., 30: 1115-1122.
- Price, P. H. and Woodward, H. P. (1942) Geology and war, Am. Assoc. Petroleum Geol. Bull., 26: 1832-1838.
- Pryor, W. T. (1967) Engineering acceptance of interpretation and measurements, Photogrammetric Engineering, 33 (No. 2): 221-228.

Bibliography

- Purdue Univ. (1951) Application of Airphoto Pattern Analysis to Soil Trafficability Studies, U. S. Army Engineer Waterways Experiment Station, Books I-III, Contract DA-22-079-Eng-59, Lafayette, Ind.
- Putnam, W. C. (1947) Aerial progress in geology, Photogrammetric Engineering, 13: 557-564.
- Raasch, G. O. (1961) First International Symposium on Arctic Geology, Geology of the Arctic, I, II, University of Toronto Press, Toronto, Canada.
- Raisz, E. (1948) General Cartography, McGraw-Hill Book Co., New York, N. Y.
- Rapp, R. R. and Huschke, R. E. (1964) Weather Information; Its Uses, Actual and Potential, The RAND Corporation, Santa Monica, Calif.
- Ray, R. G. (1958) Scale and instrument relationship in photogeologic study, Photogrammetric Engineering, 24 (No. 4): 577-586.
- Ray, R. G. (1960) Aerial Photographs in Geologic Interpretation and Mapping, U. S. Geol. Survey Prof. Paper No. 373, Washington, D. C.
- Ray, R. G. and Fischer, W. A. (1957) Geology from the air, Science, 125 (No. 3277): 725-735.
- Ray, R. G. and Fischer, W. A. (1960) Quantitative photography; a geologic research tool, Photogrammetric Engineering, 26: 143-150.
- Research Studies Institute (1955) Glossary of Arctic and Subarctic Terms, Arctic, Desert, Tropic Information Center, Air University, Maxwell AFB, Alabama.
- Rice, I. M. (1967) Flood prediction in Korea, The Military Engineer, 59 (No. 388): 92-93.
- Rich, J. L. (1916) A graphical method of determining the average inclination of a land surface from a contour, Illinois Academy of Science Transactions, 9: 195-199.
- Riecker, R. E. (1968) NSF Advanced Science Seminar in Rock Mechanics, Boston College, 26 June-28 July 1967, Volumes I and II, Published by Air Force Cambridge Research Laboratories, Bedford, Mass.
- Riecker, R. E. (1966) Bibliography of Experimental Deformation, Part II, 2nd Edition, Air Force Cambridge Research Laboratories, Special Report No. 35(II), Bedford, Mass.
- Riecker, R. E., Cook, H. L., and Pendleton, D. L. (1965) Bibliography of Experimental Rock Deformation, Part I, 2nd Edition, Air Force Cambridge Research Laboratories, Special Report No. 35, Bedford, Mass.
- Robinson, G. W. (1959) Soils; Their Origin, Constitution, and Classification, 3rd Edition, John Wiley & Sons, New York, N. Y.
- Robison, W. C. and Dodd, A. V. (1955) Analogs of Yuma Climate in South Central Asia, U. S. Army Engineer Waterways Experiment Station, Environmental Analogs Project 8-97-10-004, Army Natick Laboratories, Natick, Mass. AD200768.
- Rooney, G. W. and Levings, W. S. (1947) Advances in the use of air survey by mining geologists, Photogrammetric Engineering, 13: 570-584.
- Rosenberg, P. (1958) Earth satellite photogrammetry, Photogrammetric Engineering, 24 (No. 3): 353-360.

Bibliography

- Rosenfeld, A. (1962) Automatic recognition of basic terrain types from aerial photographs, Photogrammetric Engineering, 28 (No. 1): 115-132.
- Rosenfeld, G. H. (1964) Final Report of American Society of Photogrammetry to Commision V, special applications, international society of photogrammetry for the period 1960-1963, Photogrammetric Engineering, 30 (No. 5): 735-745.
- Rowley, D. (1955) Arctic Research, The Arctic Institute of North America, Special Publication No. 2, Washington, D. C.
- Sager, R. C. (1951) Aerial analysis of permanently frozen ground, Photogrammetric Engineering, 17 (No. 4): 551-571.
- Sager, R. C. (1953) Index to aerial and ground photographic illustration of geological topographic features throughout the world, Photogrammetric Engineering, 19 (No. 3): 472-473.
- Sater, J. E. (1963) The Arctic Basin, The Arctic Institute of North America, Tidewater Publishing Corp., Centreville, Md.
- Saucier, R. T. and Broughton, J. D. (1962) A Technique for Mapping Terrain Microgeometry, U. S. Army Engineer Waterways Experiment Station, Technical Report No. 3-612, Vicksburg, Miss.
- Scheidegger, A. E. (1960) Mathematical methods in geology, American Journal of Science, 258: 218-221.
- Scheidegger, A. E. (1961) Theoretical Geomorphology, Prentice-Hall, N. J. and Springer-Verlag, Berlin, Germany.
- Scheidegger, A. E. and Langbein, W. B. (1966) Probability Concepts in Geomorphology, U. S. Geol. Survey Prof. Paper 500-C, Washington, D. C.
- Schmid, W. E. (1966) The Determination of Soil Properties in Situ by an Impact Penetrometer, Air Force Cambridge Research Laboratories, AFCRL-66-43, Scientific Report No. 1, Soil Engineering Series No. 3, Contract AF19(628)-2427, Princeton Univ.
- Schultz, J. R. and Cleaves, A. B. (1955) Geology in Engineering, John Wiley & Sons, New York, N. Y.
- Sharpe, C. F. S. (1938) Landslide and Related Phenomena; A Study of Mass-Movement of Soil and Rock, Columbia Univ. Press, New York.
- Shepard, F. P. (1963) Submarine Geology, 2nd Edition, Harper & Row, New York, N. Y.
- Shepard, J. R., Johnstone, J. G., Lindsey, A. A., Miles, R. D., and Frost, R. F. (1955) Terrain Study of the Yuma Test Station Area, Arizona, U. S. Army Engineer Waterways Experiment Station, Contract DA-22-079-Eng-134, Engineering Experiment Station, Purdue Univ. AD626500
- Schneider, W. J. (1968) Color photographs for water resources studies, Photogrammetric Engineering, 34 (No. 3): 257-262.
- Skehan, J. W. and Arabasz, W. J. (1965) Photogeology of the Sahara and Kalahari Deserts from TIROS, Air Force Cambridge Research Laboratories, AFCRL-65-229, Scientific Report No. 1, Contract AF19(628)-3990, Boston College.
- Smith, H. T. U. (1942) Aerial photographs in geomorphic studies, Photogrammetric Engineering, 8 (No. 2): 129-155.

Bibliography

- Smith, H. T. U. (1943) Aerial Photographs and Their Applications, Appleton-Century Co., New York, N. Y.
- Smith, H. T. U. (1949) Physical effects of pleistocene climatic changes in non-glaciated areas: eolian phenomena, frost action, and stream terracing, Geol. Soc. of Am. Bull., 60: 1485-1516.
- Smith, H. T. U. (1953) Present status of photo interpretation in earth science, Photogrammetric Engineering, 15 (No. 1): 137-143.
- Smith, H. T. U. (1963) Eolian Geomorphology, Wind Direction, and Climatic Change in North Africa, Air Force Cambridge Research Laboratories, AFCRL-63-443, Final Report, Contract AF19(628)-298, Univ. of Mass.
- Smith, U. C. (1953) Identification and Qualitative Chemical Analysis of Minerals, 2nd Edition, Van Nostrand Co., New York, N. Y.
- Snyder, C. T. (1957) Use of geology in planning the Normandy invasion, Geol. Soc. of Am. Bull., 68 (No. 11): 1565.
- Soil Survey Staff (1951) Soil Survey Manual, 2nd Edition, U. S. Dept. of Agriculture, Handbook No. 18, Washington, D. C.
- Starnes, W. L. (1957) Cam Ranh army airfield, The Military Engineer, 59 (No. 391): 358-359.
- Stoertz, G. E. (1961) Techniques for Determination of Terrain Analogs, U. S. Army Engineer Waterways Experiment Station, Project 8-97-10-004, Military Evaluation of Geographic Areas, U. S. Geological Survey.
- Stoertz, G. E. and Needleman, S. M. (1957) Report on Operation Groundhog, North Greenland, 1957; Investigation of Ice-Free Sites for Aircraft Landings in Northern and Eastern Greenland and Results of Test Landings of C-124 Aircraft at Bronlunds Fjord, North Greenland, Air Force Cambridge Research Center, Final Report, Contract 57-24, U. S. Geological Survey.
- Stone, K. H. (1961) World air photo coverage, 1960, Photogrammetric Engineering, 17 (No. 2): 214-227.
- Stone, R. O. and Dugunji, J. (1962) Mapping Classification and Quantitative Expression of Microrelief Features, U. S. Army Engineer Waterways Experiment Station, Interim Report, Contract DA-22-079-Eng-261, Univ. of So. Calif.
- Strahler, A. N. (1952) Hypsometric (area-altitude) analysis of erosional topography, Geol. Soc. of Am. Bull., 63: 1117-1142.
- Strahler, A. N. (1952) Dynamic base of geomorphology, Geol. Soc. of Am. Bull., 63: 923-938.
- Strahler, A. N. (1956) Quantitative slope analysis, Geol. Soc. of Am. Bull., 67: 571-596.
- Strahler, A. N. (1958) Dimensional analysis applied to fluvially eroded landforms, Geol. Soc. of Am. Bull., 69: 279-300.
- Strahler, A. N. (1960) Physical Geography, John Wiley & Sons, New York, N. Y.
- Strahler, A. N. and Koons, D. (1960) Objective and Quantitative Field Methods of Terrain Analysis, Office of Naval Research, Final Report, Contract Nonr 266-50, Columbia Univ.
- Summerson, C. H. (1954) A philosophy for photo interpreters, Photogrammetric Engineering, 20 (No. 3): 396-397.

Bibliography

- Sutton, G. H. (1962) Geophysical techniques for studying the earth's interior, Proceedings of the Inst. Radio Engineers, 50 (No. 11): 2184-2191.
- Switzer, P. C., Mohr, C. M., and Heitman, R. E. (1964) Statistical Analysis of Ocean Terrain and Contour Plotting Procedures; Report on Project TRIDENT, A. D. Little Co., Inc., Cambridge, Mass.
- Szabo, B. et al. (1966) Project GRAVITY HARVEST, Interim Report, Air Force Cambridge Research Laboratories, Bedford, Mass.
- Tator, B. A. (1958) The aerial photograph and applied geomorphology, Photogrammetric Engineering, 24 (No. 4): 549-561.
- Terzaghi, K. (1952) Permafrost (Reprint from Journal of Boston Society of Civil Engineers, 39: 1-50) Harvard University, Soil Mechanics Series No. 37, Cambridge, Mass.
- Thompson, D. G. (1929) The Mohave Desert Region, California, U. S. Geological Survey Water Supply Paper 578, Washington, D. C.
- Thompson, G. A. et al (1967) Geophysical Study of Basin Range Structure, Dixie Valley, Nevada, Air Force Cambridge Research Laboratories, AFCRL-66-848, Final Report, Contract AF19(628)-3867, Stanford Univ.
- Thompson, L. G. D., Hawkins, C. S., and Perry, R. M. (1962) A USAF Air Base Gravity Network, Air Force Cambridge Research Laboratories, AFCRL-62-113, Bedford, Mass.
- Thornburn, T. H. (1963) Surface Deposits of Illinois; A Guide for Soil Engineers, University of Illinois Engineering Experiment Station, Circular No. 80, Urbana, Illinois.
- Thornburn, T. H. and Liu, T. K. (1966) Soil Strip Maps, University of Illinois Civil Engineering Studies, Soil Mechanics Series No. 11, Urbana, Illinois.
- Thornthwaite, C. W. (1948) An approach toward a rational classification of climate, The Geographical Review, 38 (No. 1): 55-94, American Geographical Society.
- Thorp, J. and Smith, G. D. (1949) Higher categories of soil classification order, suborder, and great soil groups, Soil Science, 67: 117-126.
- Tolman, C. F. (1937) Ground water, McGraw-Hill Book Co., New York, N. Y.
- Trask, P. D. (1950) Applied Sedimentation, John Wiley & Sons, New York, N. Y.
- Trefethen, J. M. (1949) Geology for Engineers, Van Nostrand Co., Inc., New York, N. Y.
- Trewartha, G. T. (1954) An Introduction to Climate, McGraw-Hill Book Co., New York, N. Y.
- Troup, E. W. J. (1968) The plateau soils of South Vietnam, The Military Engineer, 60 (No. 394): 117-120.
- Truesdell, P. E. (1950) Naval interest in photogeology, Photogrammetric Engineering, 16 (No. 3): 431-433.
- Truesdell, P. E. (1959) Study of Vegetation and Terrain Conditions from Aerial Photography, U. S. Naval Photographic Interpretation Center, Report No. PIC 207759-U, Washington, D. C. AD217107
- Twenhofel, W. H. (1950) Principles of Sedimentation, 2nd Edition, McGraw-Hill Book Co., New York, N. Y.

Bibliography

- Tyrrell, G. W. (1929) The Principles of Petrology, 2nd Edition, E. P. Dutton and Co., New York, N. Y.
- University of Denver (1967) A Methodological Study of the Physical Environment, Project Duty, Volumes I-III, ARPA Order No. 415, Denver Colo. AD821097, AD821098, AD821099.
- U. S. Army Ballistic Research Laboratories (1965) A Study of the Accuracy of Mask Angle and Visibility Angle in Representing Terrain Effects in Analytical Effectiveness Models, Contract DA-11-022-BRD-4262, Peat Marwick, Caywood, Schiller and Co. AD815469
- U. S. Army Chief of Engineers (1957) Applications of Hydrology on Military Planning and Operations, Military Hydrology Bulletin No. 1, Washington, D. C.
- U. S. Army Chief of Engineers (1957) Glossary of Natural Terrain Features, Engineer Guide No. 13, Washington, D. C.
- U. S. Army Engineer Waterways Experiment Station (1945) The California Bearing Ratio Test as Applied to the Design of Flexible Pavement for Airports, Technical Memorandum No. 213-1, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1947) Trafficability of Soils, Pilot Tests; Self-Propelled Vehicles, Technical Memorandum No. 3-240, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1948) Trafficability of Soils; Laboratory Tests to Determine Effects of Moisture Content and Density Variations, Technical Memorandum No. 3-240, Supplement No. 1, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1948) Trafficability of Soils; Trafficability Studies, Fort Churchill, Summer 1947, Technical Memorandum No. 3-240, Supplement No. 2, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1948) Trafficability of Soils; Development of Testing Instruments, Technical Memorandum No. 3-240, Supplement No. 3, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1949) Trafficability of Soils; Test on Self-Propelled Vehicles, Yuma, Arizona, 1947, Technical Memorandum No. 3-240, Supplement No. 4, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1949) Trafficability of Soils; Analysis of Existing Data, Technical Memorandum No. 3-240, Supplement No. 5, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1949) Trafficability of Soils; Tests on Self-Propelled Vehicles, 1947-1948, Technical Memorandum No. 3-240, Supplement No. 6, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1950) Trafficability of Soils; Tests on Towed Vehicles, 1947-1948, Technical Memorandum No. 3-240, Supplement No. 7, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1951) Trafficability of Soils; Slope Studies, Technical Memorandum No. 3-240, Supplement No. 8, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1951) Trafficability of Soils; Vehicle Classification, Technical Memorandum No. 3-240, Supplement No. 9, Vicksburg, Miss.

Bibliography

- U. S. Army Engineer Waterways Experiment Station (1951) Forecasting Trafficability of Soils; Meteorological and Soil Data, Vicksburg, Miss., 1948-1949, Technical Memorandum No. 3-331, Report No. 1, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1952) Development of Tentative CBR Curves for Airplane Wheels on Unsurfaced Soils, Miscellaneous Paper No. 4-16, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1952) Forecasting Trafficability of Soils; Meteorological and Soil Data, Vicksburg, Miss., 1949-1951, Technical Memorandum No. 3-331, Report No. 2, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1954) Forecasting Trafficability of Soils; The Development of Methods for Predicting Soil-Moisture Content, Technical Memorandum No. 3-331, Report No. 3, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1954) Trafficability of Soils; Soils with Self-Propelled Vehicles, 1951-1953, Technical Memorandum No. 3-240, Supplement No. 12, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1955) Construction Index, Miscellaneous Paper No. 4-100, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1955) Trafficability of Soils; Pilot Study, Tests on Coarse-Grained Soils, Technical Memorandum No. 3-240, Supplement No. 13, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1956) Trafficability of Soils; A Summary of Trafficability Studies Through 1955, Technical Memorandum No. 3-240, Supplement No. 14, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1956) Review of Materials and Methods for Dustproofing and Waterproofing Soils, Miscellaneous Paper No. 3-176, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1957) Forecasting Trafficability of Soils; Information for Predicting Moisture in the Surface Foot of Various Soils, Technical Memorandum No. 3-331, Report No. 4, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1959) Trafficability of Soils; Tests on Coarse-Grained Soils with Self-Propelled and Towed Vehicles, 1956 and 1957, Technical Memorandum No. 3-240, Supplement No. 15, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1959) Forecasting Trafficability of Soils; Development and Testing of Some Average Relations for Predicting Soil Moisture, Technical Memorandum No. 3-331, Report No. 5, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1959) Trafficability Predictions in Tropical Soils; Panama Canal Zone, Miscellaneous Paper No. 4-355, Report No. 1, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1960) List of Publications (Supplements for 1963, 1965), Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1960) Trafficability Predictions in Tropical Soils, Puerto Rico, Miscellaneous Paper No. 4-355, Report No. 2, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1961) Some Factors Affecting Moisture-Content-Density-Cone Index Relations, Technical Report No. 4-457, Vicksburg, Miss.

Bibliography

- U. S. Army Engineer Waterways Experiment Station (1961) Plan of Test; Tropical Soil Studies, Vicksburg, Miss. (Report not numbered)
- U. S. Army Engineer Waterways Experiment Station (1962) Classification of Landscape Geometry for Military Purposes, Technical Report No. 3-521, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1962) Operation Swamp Fox I, Terrain and Soil Trafficability Observations, Technical Report No. 3-609, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1962) A Technique for Mapping Terrain Microgeometry, Technical Report No. 3-612, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1963) A Study of Microrelief: Its Mapping, Classification, and Quantification by Means of a Fourier Analysis, Technical Report No. 3-82, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1963) Military Evaluation of Geographic Areas; Reports on Activities Through April 1963, Technical Report No. 3-610, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1963) Analog of Yuma Terrain in the Southwest United States Desert, Technical Report No. 3-630, Volume I, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1963) Trafficability of Soils; Tests on Coarse-Grained Soils with Self-Propelled and Towed Vehicles, 1958-1961, Technical Memorandum No. 3-240, Supplement No. 17, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1964) Forecasting Trafficability of Soils; A Pilot Study of Soils Subjected to Freezing and Thawing, Technical Memorandum No. 3-331, Report No. 7, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1964) The Description and Classification of Hydrologic Characteristics for Military Purposes, Technical Report No. 3-23, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1964) Strength-Moisture-Density Relations of Fine-Grained Soils in Vehicle Mobility Research, Technical Report No. 3-639, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1965) Environmental Data Collection Manual, Surface Microgeometry, Volume 5, Instruction Report No. 6, Vicksburg, Miss.
- U. S. Army Engineer Waterways Experiment Station (1965) Vicksburg Mobility Exercise; A Vehicle Analysis for Remote Area Operation, Miscellaneous Paper No. 4-702, Vicksburg, Miss. AD613366
- U. S. Army Engineer Waterways Experiment Station (1967) Forecasting Trafficability of Soils; Variability of Physical Properties of Loess Soils, Warren County, Miss., Technical Memorandum No. 3-331, Report No. 8, Vicksburg, Miss. AD824443
- U. S. Army Engineer Waterways Experiment Station (1967) Report of Conference on Soil Trafficability Prediction, 29-30 Nov 1966, Vicksburg, Miss.
- U. S. Army Engineer Coastal Engineering Research Center (1964) Land Against the Sea, Miscellaneous Paper No. 4-64, Washington, D. C.

Bibliography

- U. S. Bureau of Plant, Industry, Soils, and Agricultural Engineering (1951), Soil Survey Manual, U. S. Dept. of Agriculture Handbook No. 18, U. S. Govt. Printing Office, Wash. D. C.
- U. S. Bureau of Reclamation, (1963) Earth Manual, 1st Edition, Revised, U. S. Govt. Printing Office, Wash. D. C.
- U. S. Dept. of Agriculture (1935) Soils of the United States; Atlas of American Agriculture, Part III., Washington, D. C.
- U. S. Dept. of Agriculture (1941) Climate and Man, The Yearbook of Agriculture, 1941, Washington, D. C.
- U. S. Dept. of Agriculture (1960) Soil Classification; A Comprehensive System, 7th Approximation, Soil Survey Staff, Washington, D. C.
- U. S. Dept. of Defense (1962) Unified Soil Classification System: Roads, Airfields, Embankments, and Foundations, MIL-STD-619A, U. S. Govt. Printing Office, Washington, D. C.
- U. S. Navy Bureau of Yards and Docks (1955) Arctic Engineering, Technical Publication ND TP-PW-11, Washington, D. C.
- U. S. Navy Office of Chief Naval Operations (1956) Canadian North, Report No. OPNAV PO 3-4, Technical Assistant to Chief of Naval Operations for Polar Projects (OP-03A3), Washington, D. C.
- U. S. Navy Office of Chief Naval Operations (1956) Dynamic North, Books I, II, Technical Assistant to Chief of Naval Operations for Polar Projects, (OP-03A3), Washington, D. C.
- Vadnais, R. R. (1965) Quantitative Terrain Factors as Related to Soil Parent Materials and Their Engineering Classification, University of Illinois Civil Engineering Studies Soil Mechanics Series No. 10, Urbana, Illinois.
- Vadnais, R. R. Jr., (1966) Site Selection in the Binh Dinh and Hue Areas, South Vietnam, Air Force Weapons Laboratory, Kirtland AFB, New Mexico.
- Vadnais, R. R. Jr., and Triandafilidis, G. E. (1967) Soil Stabilization of Low-Strength Austere Landing Strips, Technical Report No. AFWL-TR-66-155, AF Weapons Laboratory, Kirtland AFB, New Mexico AD811447
- Vishner, S. S. (1941) Climate and geomorphology; some comparisons between regions, Journal of Geomorphology, 5: 54-64.
- Vishner, S. S. (1945) Climatic maps of geologic interest, Geol. Soc. Am. Bull., 56: 713-736.
- Von Engeln, O. D. (1948) Geomorphology, The MacMillan Co., New York, N. Y.
- Wanless, H. R. and others, (1951) Outstanding Aerial Photographs in North America, Am. Geol. Inst., Report No. 5, National Research Council, Washington, D. C.
- Warntz, W. and Woldenberg, M. (1967) Concepts and Application -- Spatial Order, Harvard University Paper in Theoretical Geography, ONR Contract No. 00014-66---121, Washington, D. C. AD 653464
- Washburn, A. C. (1956) Classification of patterned ground and review of suggested origins, Geol. Soc. Am. Bull., 67: 823-866.
- Webster, R. W. (1965) Minor Statistical Studies on Terrain Evaluation, Military Engineering Experimental Establishment, Report No. 877, Christchurch, Hampshire, England AD809-689

Bibliography

- Westbrook, J. H. (1961) A Method of Predicting the Frequency Distribution of Windchill, U. S. Army QM Research and Engineering Command, Technical Report EP-143, Natick, Massachusetts.
- Whitmore, F. C. Jr. (1955) Manpower for military photo interpretation of terrain, Photogrammetric Engineering, 21 (No. 5): 717-719.
- Whitmore, F. C. (1960) Terrain intelligence and current military concepts, Am. Journal of Science, 258-A: 375-387.
- Wilson, R. B. Jr. (1965) A Study of Geodetic Techniques, Air Force Cambridge Research Laboratories 65-102, Final Report, Contract AF19(604)-8852, Barkeley and Dexter Laboratories, Inc.
- Winterkorn, H. F. (1960) The Scientific Foundations of Soil Engineering, Princeton University Press, New Jersey.
- Winterkorn, J. F. (1966) Shear Resistance and Equation of State for Noncohesive Granular Macromeritic Systems, Air Force Cambridge Research Laboratories, AFCRL 67-0048, Scientific Report No. 3, Contract No. AF19(628)-2414, Princeton University, New Jersey.
- Wolfanger, L. A. (1941) Land Form Types: A Method of Qualitative and Graphic Analysis and Classification, Michigan State College Agricultural Experiment Station, Technical Bull. 175, East Lansing, Michigan.
- Woloshin, A. J. (1968) Evaluation and Comparison of Terrain Classification Methods, U. S. Army Engineer Topographic Laboratories, Final Rpt., Contract No. DAAK OL-67-C-0487, Geonautics, Inc., Falls Church, Va.
- Womack, L. M. (1965) Traffic Tests to Determine the Benefits of Vegetation in Increasing Traffic Coverages, U. S. Army Engineer Waterways Experiment Station, Miscellaneous Paper No. 4-769, Vicksburg, Miss.
- Womack, L. M. and Hanes, F. P. (1965) Telemetry of Soil Moisture and Weather Variables, U. S. Army Engineer Waterways Experiment Station, Miscellaneous Paper No. 5-711, Vicksburg, Miss.
- Wood, W. F. (1956) Increasing the value of small scale maps for landform study by the use of statistical inference, Annals American Assoc. of Geographers, 26 (No. 2): 282-283.
- Wood, W. F. and Snell, J. B. (1959) Predictive Methods in Topographic Analysis I: Relief, Slope, and Dissection on Inch to Mile Maps in the United States, U. S. Army Quartermaster Research and Engineering Command, Technical Report No. EP-112, Washington, D. C.
- Wood, W. F. and Snell, J. B. (1959) Predictive Methods in Topographic Analysis II, Estimating Relief From World Aeronautical Charts, U. S. Army Quartermaster Research and Engineering Command, Technical Report No. EP-114, Washington, D. C.
- Woodruff, J. F. and Evenden, L. J. (1962) Geomorphic measurements from aerial photos, Professional Geographers, 14 (No. 3): 23-26.

Bibliography

2. REMOTE SENSING PUBLICATIONS

2.1 General

Blinn, E. E. (Ed.) (1967) Remote Sensing of the Geological Environment AFRL.

Buckmeier, F. J. et al, Airborne Remote Sensing Techniques for Site Selection, Technical Rpt. AFWL-TR-68-115, Air Force Weapons Laboratory, December, 1969.

Colwell, R. N. (1968) Remote Sensing of natural resources, Scientific American, p. 54-69.

National Academy of Sciences (1966) Spacecraft in Geographic Research, Publication 1353, National Resource Council.

Parker, D. C. (1968) Developments in remote sensing applicable to airborne engineering surveys of soils and rocks, Materials Research and Standards, 8 (No. 2): 22-30.

Parker, D. C. and Wolff, M. F. (1965) Remote Sensing, International Science and Technology, p. 20-31, 73, 75.

University of Michigan, (1963) Remote Sensing of Environment, Report 4864-6-F Final Report, Contract Nonr. 1224(44).

Woods Hole Oceanographic Institution (1965) Oceanography from Space WHOI Ref. No. 65-10.

2.2 Aerial Photography

Anson, A. (1966) Comparative Photointerpretation from Panchromatic, Color and Ektachrome IR Photography, Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, Technical Note 66-3.

Anson, A. (1968) The use of color and aerial photography in the reconnaissance of soils and rocks, Materials Research and Standards, 8 (No. 2): 8-16.

Davis, C. K. and Neal, J. T. (1963) Descriptions and airphoto characteristics of desert landforms, Photogrammetric Engineering, 29 (No. 4): 621-631.

Cornell Aeronautical Laboratory (1966) Project AMPIRT, ARPA Multiband Photographic and Infrared Reconnaissance Test, CAL No. VE-1931-D-5.

Ludlum, R. and Van Lopik, J. R. (1966) A Remote Sensing Survey of Areas in Central Coastal Louisiana, Texas Instruments Inc., Report NR 387-039/3-22-66.

Merifield, P. M. (1964) Geologic Information from Space Photography, American Society of Photogrammetry.

Mintzer, O. W. (1968) A Comparative Study of Photography for Soils and Terrain Data, Technical Rpt. 38-TR, U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Va.

Smith, J. T. Jr. (1963) Color a new dimension in photogrammetry, Photogrammetric Engineering, 29 (No. 6): 999-1013.

Bibliography

2.3 Multispectral Photography

- Brown, G. D. Jr. (1967) Multispectral Photographic Studies of a Red Bed Facies, Minas Basin, Nova Scotia, AFCRL 67-0603.
- Colwell, R. N. (1961) Some practical applications of multiband spectral reconnaissance, American Scientist, 49: 9-36.
- Cronin, J. F. (1967) Terrestrial Multispectral Photography AFCRL 67-0076.
- Itek Corporation (1966) Airborne Spectral Reconnaissance System - VELA Cloud Gap Program
- Mallila, W. A. (1967) Multispectral Techniques for Contrast Enhancement and Discrimination, Report 8725-9-S/J, Institute of Science and Technology, The University of Michigan.
- Robinson, C. J. and Skibitzke, H. E. (1967) An Airborne Multispectral Television System, U. S. Geological Survey Professional Paper 575-D.

2.4 Polarized Light Photography

- Cantreel, J. L. (1964) Infrared geology, Photogrammetric Engineering 30 (No. 6): 916-922.
- Chan, H. (1967) Investigations of the Polarization of Light Reflected by Natural Surfaces, Department of Meteorology, University of California, AFCRL 67-0089.
- Clark, J. (1964) Workshop on Techniques for Infrared Survey of Sea Ice Temperatures, Preliminary Report, Sandy Hook Marine Laboratory.
- Fischer, W. A. (1964) Infrared surveys of Hawaiian volcanoes, Science 146 (No. 6): 733-742.
- Hallock, H. B. and Grusauskas, J. (1966) The Polarimetric Signature of Water and Some Factors Affecting Potential Applications, Grumman Aircraft Engineering Corporation Advanced Systems Report.
- Kern, C. D. (1965) Evaluation of Infrared Emission of Clouds and Ground as Measured by Weather Satellites, AFCRL 65-840.
- Lorenz, D. (1963) Measurements of the Earth's Surface Temperature from Aircraft, Research Translation ETG-63-34 AFCRL
- McLerran, J. H. (1967) Infrared thermal sensing, Photogrammetric Engineering 33 (No. 5): 507-512.
- McLennan, J. H. (1968) Infrared sensing of soils and rocks, Materials Research and Standards 8 (No. 2): 17-21.
- Menon, V. K. and Ragotskie, R. A. (1967) Remote Sensing by Infrared and Microwave Radiometry, Department of Meteorology, The University of Wisconsin, Technical Report No. 31.
- Mundie, L. G. (1967) Comparison of the 3 to 5 and 8 to 13 Micron Bands for Terrain Reconnaissance and Optimization of Other Parameter Values, The Rand Corporation.
- Murcray, D. G. (1967) Infrared Radiance of Selected Terrain Features as Viewed from High Altitude, University of Denver, AFCRL 67-0448.

Bibliography

Moxham, R. M. and Wallace, R. E. (1967) Use of Infrared Imagery in Study of the San Andreas Fault System, California, U. S. Geological Survey Professional Paper 575-D p. 147-156.

Williams, R. S. and Ory, T. (1967) Infrared imagery mosaics for geological investigations, Photogrammetric Engineering 33 (No. 512): 1377-1380.

2.5 Ultraviolet Sensing Techniques

Air Force Avionics Laboratory, (1965) Ultraviolet Photographic Research, Technical Documentary Report AL-TDR 64-231

Cronin, J. F. et al (1968) Ultraviolet Radiation and the Terrestrial Surface, Special Report No. 83 AFCRL 68-0572

Mangold, V. L. (1966) Narrow-Band Ultraviolet Filter Photography, Air Force Flight Dynamics Laboratory, Technical Report AFFDL-TR-66-140.

Olson, D. and Cantrell, J. L. (1965) Comparison of airborne conventional photography and scanned ultraviolet imagery, Photogrammetric Engineering, 32 (No. 2).

2.6 Photometry and Spectrometry

Army Engineer Research and Development Laboratories (1963) Reflectance Curves of Soils, Rocks, Vegetation and Pavement, Research Report 1746-RR

Band, H. E. and Block, L. C. (1965) Spectral Reflectance and Albedo Measurements of the Earth from High Altitudes, AFCRL-65-674

Cosgriff, R. L. (1960) Terrain scattering properties for sensor system design, Terrain Handbook 29 (No. 3) Engineering Experiment Station, Ohio State University

Gerbes, W. W. and Naumann, S. J. (1967) Radar Return from Target Hidden by Ground Clutter AFCRL 67-0668

Hackman, R. J. (1967) Geologic Evaluation of Radar Imagery in Southern Utah, U. S. Geological Survey Professional Paper 575-D p. 135-142

Rinker, J. N. and Mock, S. J. (1967) Radar Ice Thickness Profiles, Northwest Greenland, Army Cold Regions Research and Engineering Laboratory

Romanova, M. N. (1964) Air Survey of Sand Deposits by Spectral Luminance, Translations Consultants Bureau, N. Y.

Wilburn, D. K. (1965) Spectra Notebook, Volume I: Material, Target and Background Data, Army Tank Automotive Center, Technical Report 8863

2.7 Imagery Analysis Techniques

Brody, R. H. and Ermlich, J. R. (1966) Fourier analysis of aerial photographs, Proceedings Fourth Symposium on Remote Sensing of Environment, p. 375-392 University of Michigan

Cutrona, L. J. (1960) Optical data processing and filtering systems, IRE Transactions of the Professional Group on Information Theory, IT-6 (No. 3).

Champagne, E. B. (1967) A Qualitative and Quantitative Study of Holographic Imaging, Air Force Avionics Laboratory, Technical Report AFAL-TR-67-107

Bibliography

- Dalke, G. W. (1966) Automatic Processing of Multi Spectral Images, Center for Research, Inc., The University of Kansas, CRES Report 61-16
- Everiden, G. I. (1967) Digital Recording and Processing of Airborne Geophysical Data, U. S. Geological Survey Professional Paper 575-D p. 79-84
- Hawkins, J. K. and Munsey, C. J. (1963) Automatic photo reading, Photogrammetric Engineering 29 (No. 4): 632-640
- Heinz-Lohse, K. (1965) Multiband Photographic Extraction Techniques, Aeronautical Division, Final Report, Contract DA-44-009-AMC-1613(X)
- Latham, J. P. and Witmer, R. E. (1967) Comparative waveform analysis of multi-sensor imagery, Photogrammetric Engineering 33 (No. 7): 779-786
- Lowe, D. S. and Braithwaite, J. G. N. (1966) A spectrum matching technique for enhancing image contrast, Applied Optics, 5,6
- McClure, G. W. and Dute, J. C. (1963) Probability Characteristics of Sensor Output Data, Institute of Science and Technology, The University of Michigan, Report 2900-329-R
- Mumbower, L. and Richards, T. W. (1962) Image information processing for photo-interpretation operations, Photogrammetric Engineering 28 (No. 4): 569-578
- Ory, T. R. (1965) Line scanning reconnaissance systems in land utilization and terrain studies, Proceedings Third Symposium on Remote Sensing of Environment, p. 393-398 The University of Michigan
- Rall, L. R. (Ed.) (1966) Geographic data processing, Photogrammetric Engineering 36 (No. 6): 978-986
- Rosenfield, A. (1962) Automatic recognition of basic terrain types from aerial photographs, Photogrammetric Engineering 28 (No. 1): 115-132
- Shepard, J. R. (1964) A concept of change detection, Photogrammetric Engineering 30 (No. 4): 648-651
- Steiner, D. and Haefner, H. (1965) Tone distortion for automated interpretation, Photogrammetric Engineering 31 (No. 2): 269-280
- Witmer, R. E. (1967) Waveform Analysis of Geographic Patterns Recorded on Visible and Infrared Imagery, Department of Geography, Florida Atlantic University, Technical Report No. 4 Contract Nonr. 476 1(00)

2.8 Passive Microwave Radiometry

- Catoe, C. (1967) Preliminary Results from Aircraft Flight Tests of an Electrically Scanning Microwave Radiometer, NASA Goddard Space Flight Center, Report X-622-67-352
- Hyatt, H. A. (1965) Airborne Measurement of Microwave Emission from the Earth's Surface and Atmosphere, Space Sciences Department, Douglas Missile and Space Systems, Douglas Paper No. 3684
- Katz, Y. H. (Ed.) (1963) The Application of Passive Microwave Technology to Satellite Meteorology: A Symposium, The Rand Corp. Memorandum RM-3401-NASA
- Edgerton, A. T. (1968) Passive Microwave Measurements of Snow, Soils, and Snow-Ice Water Systems, Space General Corp., Technical Report SGC-829-R-4

Bibliography

- Kennedy, J. M. (1968) A microwave radiometric study of buried karst topography, Geological Society of America Bulletin, 79, p. 735-742
- Moore, R. P. (1964) Microwave Radiometric Contrasts of Metal Targets Against a Terrain Background, Research Department, Naval Ordnance Laboratory Corona, NAVWEPS Report 8198
- Porter, R. A. (1966) Microwave Radiometric Measurements of Sea Water, Concrete and Asphalt, Raytheon Company, Technical Report
- Wager, E. (1965) The Radiative Properties of Some Terrestrial and Man-Made Materials at Microwave Frequencies, Raytheon Company, Report FR65-39

2.9 Airborne Profile Recorders

- Quinlan, D. L. (1961) Comparison of Pulse and F. M. Radar Altimeters Based on Terrain Return Theory, Engineering Experiment Station, The University of New Mexico, Technical Report EE-56
- Rempel, R. C. and Parker, A. K. (1965) An information note on an airborne laser terrain profiler for micro-relief studies, Proceedings, Third Symposium on Remote Sensing of Environment, University of Michigan
- Waite, A. H. and Schmidt, S. J. (1962) Gross errors in height indication from pulse radar altimeters operating over thick ice or snow, Proceedings IRE 50

2.10 Gamma-Ray Sensing

- Moxham, R. M. (1965) Gamma-ray spectrometer studies of hydrothermally altered rocks, Economic Geology 60 (No. 4)
- Rogers, J. J. and Adams, J. A. (1963) Quantitative detection and interpretation of terrestrial gamma-ray spectra, Proceedings, Second Symposium on Remote Sensing of Environment, p. 329-342, The University of Michigan
- Vaughn, W. W. (1959) Scintillation Counters for Geologic Use, Geological Survey Bulletin 1052-F

2.11 Airborne Magnetometer

- Boyd, D. (1967) The Contribution of Airborne Magnetic Surveys to Geological Mapping, Canadian Centennial Conference on Mining and Groundwater Geophysics
- Cook, J. C. and Carts, S. L. (1962) Magnetic effects and properties of typical topsoils, Journal of Geophysics Research 67
- Maple, E. (1966) Aerial Magnetic Detection in Counter Insurgency Warfare, Preliminary Technical Report, AFCRL-66-58
- Ward, S. H. (1966) AFMAG-Applications and limitations, Geophysics 31 (No. 3)
- The Oil and Gas Journal (1963) Biggest magnetometer survey spans 144,000 sq. miles

2.12 Gravity Surveys

- Hammer, S. (1963) Rock densities and vertical gradient of gravity in the earth's crust, Journal of Geophysics Research 68

Bibliography

Romberg, F. E. (1961) The Detection of Subsurface Voids by Gravimetry, Texas Instruments Inc., Final Report AFCRL-1014 Contract AF 19(604)-8348

Woollard, G. P. (1962) The Relation of Gravity Anomalies to Surface Elevation, Crustal Structure and Geology, The University of Wisconsin, Research Report Ser. 62-9

2.13 Seismic Exploration Methods

Thompson, G. A. (1967) Geophysical Study of Basin-Range Structure, Dixie Valley Region, Nevada, Geophysics Department, Stanford University AFCRL-66-848

2.14 Electrical Resistivity Measurements

Hall, G. R. (1967) Geophysical instruments for civil engineering, The Military Engineer 59

Tuman, V. S. (1963) Thermo-telluric currents generated by an underground explosion and other geological phenomena, Geophysics 28 (No. 5)

Vozoff, K. (1963) Results and limitations of magnetotelluric surveys in simple geologic situations, Geophysics 28 (No. 5)

2.15 Droppable Sensors

Aeronutronic Division, Philco (1966) Research, Development and Preliminary Design for the Lunar Penetrometer System Applicable to the Apollo Program, Publication No. U-3556

Beswick, A. G. (1964) Instrumentation for Investigating the Physical Properties of the Lunar Surface, Instrument Society of America, N. Y.

Knight, S. J. (1967) The aerial cone penetrometer, The Military Engineer (no. 390): p. 240-

Schmid, W. E. (1966) The Determination of Soil Properties in Situ by an Impact Penetrometer, Princeton University, AFCRL 66-43

Thorman, H. C. (1963) Review of Techniques for Measuring Rock and Soil Strength Properties at the Surface of the Moon, Jet Propulsion Laboratory, California Institute of Technology, Technical Report 32-374

2.16 Airborne Sensing Limitations

Colwell, R. N. (1963) Basic matter and energy relationships involved in remote reconnaissance, Photogrammetric Engineering 29 (No. 5): 761-799

Dutton, J. A. (1959) Space and Time Response of Airborne Sensors for the Measurement of Ground Parameters, Department of Meteorology, The University of Wisconsin, Technical Report No. 1

Hackman, R. J. (1967) Time, Shadows, Terrain and Photointerpretation, p. 155-160, U. S. Geological Survey, Professional Paper 575-B

Itek Laboratories (1962) Photographic and Photogrammetric Methods of Terrain Analysis for Determination of Aircraft Landing Sites, Final Report AFCRL-62-644

Bibliography

- Leonardo, E. S. (1964) Capabilities and limitations of remote sensors, Photogrammetric Engineering 30 (No. 6): 1005-1010
- Mestwerdt, H. R. (1961) The Influence of Supersonic Airflow on Aerial Photography, Aeronautical Systems Division, ASD Technical Note 61-35
- Silverman, S. M. and Taylor, J. B. (1966) Some Aspects of Night Visibility Useful for Air Force Operations, AFCRL 66-862
- Williams, R. S. and Fenn, R. W. (1967) Degradation of Imagery from Optical Mechanical Scanners: Moisture Condensation on Optics, AFCRL 67-0398

2.17 Data Gathering Vehicles

- Bird, J. B. and Morrison, A. (1964) Space photography and its geographical applications, Geographical Review 54 (No. 4)
- Lowman, P. D. Jr (1964) A Review of Photography of the Earth from Sounding Rockets and Satellites, Goddard Space Flight Center, NASA-TN-D-1868
- Lowman, P. D. Jr (1967) Geologic Applications of Orbital Photography, Goddard Space Flight Center, Technical Memorandum X-55724
- Wilson, R. C. (1967) Space photography for forestry, Photogrammetric Engineering 33 (No. 5): 483-490

3. SELECTED MILITARY PUBLICATIONS

3.1 Field Manuals

FM 5-10	Routes of Communications
FM 5-15	Field Fortifications
FM 5-20	Camouflage
FM 5-34	Engineer Field Data
FM 5-36	Route Reconnaissance and Classification
FM 21-10	Military Sanitation
FM 21-26	Advanced Map and Aerial Photographic Reading
FM 30-20	Military Intelligence, Military Maps
FM 30-21	Aerial Photography, Military Applications
FM 31-70	Basic Arctic Manual
FM 31-71	Operations in the Arctic
FM 70-10	Mountain Operations
FM 72-20	Jungle Warfare
FM 101-10	Staff Officers Field Manual
AFM 1-2	USAF Basic Doctrine
AFM 1-4	Air Doctrine, Air Defense Operations

Bibliography

AFM 1-0	Air Doctrine, Air Operations in Conjunction With Amphibious Operations
AFM 1-9	Air Doctrine, Theater Airlift Operations
AFM 55-6	Tactical Air Reconnaissance
AFM 64-5	Search and Rescue Survival
AFM 85-4	Maintenance and Construction Methods for Buildings and Structures
AFM 85-6	Land Management and Grounds Maintenance
AFM 85-8	Maintenance of Pavements
AFM 85-13	Maintenance and Operation of Water Plants and Systems
AFM 86-1	Landing Zone Criteria for C-130 Aircraft
AFM 86-3	Planning and Design of Theater of Operations Air Bases
AFM 86-5	Ice Airfields
AFM 86-8	Airfields and Airspace Criteria
AFM 88-5	Soils, Site Preparation, Grading and Drainage, Surface Drainage Facilities for Airfields
AFM 88-6	Airfield Pavement Design
AFM 88-10	Water Supply
AFM 88-14	Visual Air Navigation Facilities
AFM 88-16	Navigational Aids
AFM 88-19	Arctic and Subarctic Construction
AFM 88-20	New Construction
AFM 88-24	Airfield Pavement
AFM 88-27	Planning, Design and Construction of Radioactive Fallout Protection
AFM 95-6	Cartographic Aerial Photography
AFM 200-30	Regional Photointerpretation Manual on Antarctica
AFM 200-50	Photographic Interpretation Handbook
AFM 400-5	Logistical and Operational Planning Manual, USAF

3.2 Air Force Systems Command Manuals

AFSCM 80-1	HIAD	Handbook of Instructions for Aircraft Design
AFSCM 80-6	IIAGED	Handbook of Instructions for Aerospace Ground Equipment Design
AFSCM 80-8	IIMD	Handbook of Instructions for Missile Design, (Missile and Space Technical Facilities)

Bibliography

AFSCM 80-9	HLASD I	Handbook of Instructions for Aerospace Systems Design (General Design Criteria)
AFSCM 80-9	HLASD V	Handbook of Instructions for Aerospace Systems Design (Environmental Engineering)
AFSCM 80-14		Design Criteria Handbooks

3.3 Air Force Regulations

AFR 0-2	Numerical Index of Standard Air Force Publications
AFR 0-6	Subject Index of Air Force Publications
AFR 80-2	Documents Used in the Management of Air Force R & D
AFR 80-14	Testing/Evaluation of Systems, Subsystems, and Equipment
AFR 85-5	Operation and Maintenance of Installation Facilities
AFR 88-15	Engineering Manuals and Guide Specifications for Military Construction
AFR 91-23	Maintenance and Improvement of Grounds

3.4 Air Force Specification Bulletins

106	General Environmental Criteria for Guided Missile Weapons Systems
115	Environmental Criteria for Ground Support Equipment

3.5 Technical Manuals

TM 3-414	Trafficability of Snow
TM 5-230	Topographic Drafting
TM 5-231	Mapping Functions of the Corps of Engineers
TM 5-233	Construction Surveying
TM 5-234	Topographic Surveying
TM 5-235	Special Surveys
TM 5-236	Surveying Tables and Graphs
TM 5-240	Aerial Photography
TM 5-246	Interpretation of Aerial Photographs
TM 5-248	Foreign Maps
TM 5-250	Roads and Airfields
TM 5-252	Use of Road and Airfield Construction Equipment
TM 5-255	Aviation Engineers Manual
TM 5-280	Construction in the Theater of Operations

Bibliography

TM 5-295	Military Water Supply and Purification
TM 5-296	Ground Water Supply for Military Operations
TM 5-297	Well - Drilling
TM 5-302	Construction in the Theater of Operations
TM 5-310	Military Protective Construction
TM 5-330	Planning, Site Selection and Design of Roads, Airfields, and Heliports in the Theater of Operations
TM 5-335	Drainage Structures, Subgrades, and Base Courses
TM 5-349	Arctic Construction
TM 5-350	Military Pipeline Systems
TM 5-366	Planning and Design for Rapid Airfield Construction in the Theater of Operations
TM 5-560	Arctic Construction
TM 5-624	Roads, Runways, and Miscellaneous Pavements, Repairs, and Utilities
TM 5-630	Grounds, Maintenance, Dust and Erosion Control, Repairs and Utilities
TM 5-742	Concrete and Masonry
TM 30-245	Photographic Interpretation Handbook
TM 30-246	Tactical Interpretation of Air - Photos

3.6 Technical Bulletins

TB 5-255-3	Construction of Runways, Roads, and Buildings on Permanently Frozen Ground
TB 5-550-1	Soils Trafficability

Glossary of Terms in Common Usage*

Acceleration of Gravity - The acceleration of a body falling freely in a vacuum due to the gravitational attraction of the earth. The International Committee of Weights and Measures has adopted as a standard or accepted value of $980.665 \text{ cm./sec}^2$ or 32.174 ft/sec^2 , but its true value varies with latitude, altitude, and the nature of the underlying rocks.

Active Layer - Annually thawed layer; layer of ground above the permafrost which thaws in the summer and freezes in the winter.

Adobe - An impure, calcereous clay widely used in the United States for making sun-dried bricks.

Age - Any great period of time in the history of the earth or the material universe marked by special phases of physical conditions or organic development; formal geologic time unit corresponding to a stage; informal geologic time unit corresponding to any stratigraphic unit.

Aggradation - The process of building up a surface by deposition; the growth of a permafrost area.

Aggregated - To bring together; to collect or unite into a mass; composed of a mixture of substances, separable by mechanical means; the mineral material such as sand, gravel, shells, slag, or broken stone, or combination thereof, with which cement or bituminous material is mixed to form a mortar or concrete.

Airborne Scintillation Counter - Any scintillation counter especially designed to measure the ambient radioactivity from an aircraft in flight.

Albedo - The percentage of the incoming radiation that is reflected by a natural surface such as the ground, ice, snow, or water.

*American Geological Institute (1960)

Alkali Flat - A level lakelike plain formed in low depressions where accumulated water evaporates depositing fine sediment and dissolved minerals which form a hard surface if mechanical sediments prevail or a crumbly powdered surface if efflorescent salts are abundant.

Alluvium - A general term for all detrital deposits resulting from the operations of modern rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.

Angle of Repose - The maximum slope or angle at which a material such as soil or loose rock remains stable. When exceeded, mass movement by slipping as well as by water erosion may be expected.

Angstrom Unit - A unit of length of 10^{-8} cm., commonly used in crystallography.

Archipelago - Any sea or broad sheet of water interspersed with many islands or with a group of islands; also a group of islands.

Arid Climate - A climate in which the rainfall is insufficient to support vegetation.

Arroyo - The channel of an ephemeral or intermittent stream, usually with vertical banks of unconsolidated material 2 ft or more high.

Artésian Water - Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

Atmosphere - The gaseous envelope surrounding the earth; the atmosphere is odorless, colorless, tasteless, very mobile, flowing readily under even a slight pressure gradient; elastic, compressible, capable of unlimited expansion, a poor conductor of heat, but able to transmit vibrations with considerable velocity.

Atoll - A ringlike "coral" island or islands encircling or nearly encircling a lagoon. An atoll reef is a ring-shaped, coral reef, often carrying low sand islands, enclosing a body of water.

Avalanche - A large mass of snow or ice, sometimes accompanied by other material, moving rapidly down a mountain slope.

Backshore - Upper shore zone beyond the reach of ordinary waves and tides; one or more nearly horizontal surfaces called berms formed landward from the beach crest; may slope inland.

Badlands - A region nearly devoid of vegetation where erosion, instead of carving hills and valleys of the ordinary type, has cut the land into an intricate maze of narrow ravines and sharp crests and pinnacles. Travel across such a region is almost impossible; extremely rough topography formed in an advanced stage of gullying in poorly consolidated sediments and characterized by sharp-edge ridges separated by narrow and steep gullies.

Bajada - A nearly flat surface of a continuous apron consisting of confluent alluvial fans that make up the general slope in a basin; a series of confluent alluvial fans along the base of a mountain range.

Bar - A mass of sand, gravel or alluvium deposited on the bed of a stream, sea, or lake or at the mouth of a stream forming an obstruction to water navigation.

Barchan - A dune having crescentic ground plan, with the convex side facing the wind; the profile is assymetric, with the gentler slope on the convex side, and the steeper slope on the concave or leeward side; the barchan type is most characteristic of the inland desert regions.

Base Level - The level below which a land surface cannot be reduced by running water. Sea level is considered the principal base level. Principal streams serve as local or temporary base levels for their tributaries.

Basin - A region in which the strata or layers of rock dip in all directions towards a central point such as an inverted dome; a river basin is the total area drained by the river and its tributaries; a lake basin is the basin filled by water of the lake; any hollow or trough in the earth's crust whether filled by water or not.

Beach Berm - Nearly horizontal bench or narrow terrace formed by wave action in unconsolidated material on the backshore of a beach with surface rising behind it and sloping off in front.

Bedrock - The solid rock beneath the loose material, or soil and subsoil, with which most of the land surface of the earth is covered. It is sometimes several hundred feet beneath the surface, but it usually is found at a much smaller depth; in places, especially on steep slopes, it has no soil cover at all.

Bench Mark - In surveying, a mark, usually cut in stone as a relatively permanent material object, natural or artificial, bearing a marked point whose elevation above or below an adopted datum (such as sea level) is known.

Block Diagram - Three-dimensional perspective representation of geologic or topographic features showing a surface area and generally two vertical cross sections.

Bluff - Any high headland or bank presenting a precipitous front; it is usually applied to the slopes bordering a river; these bluffs often formed by the action of the river in cutting into the valley sides.

Bog - An area of soft, wet, spongy ground, consisting chiefly of decayed or decaying moss and other vegetable matter. It often forms in shallow, stagnant lakes or ponds, and is largely produced by sphagnum moss; the latter spreads out from the shores, floating on the surface, and gives a deposit of vegetable matter or peat on the bottom. A swamp or tract of wet land, covered in many cases with peat.

Bolson - A basin; a depression or valley having no outlet; a wide valley drained by a stream flowing through canyons at each end.

Caldera - A large basin-shaped volcanic depression, more or less circular or cirquelike in form, the diameter of which is many times greater than that of the included volcanic vent or vents, no matter what the steepness of the walls or form of the floor. Three major types: explosion, collapse, erosion.

Caliche - Secondary calcareous material occurring in a layer or layers at or near the surface. May be a soft or hard horizon of lime accumulation in the soil, but more commonly the term refers to a cemented layer a few inches to many feet in thickness containing impurities of clay, sand, or gravel. Most caliche deposits appear to form by a variety of processes whereby soil moisture evaporates or deposits its content of calcium carbonate.

Canyon - A gorge, relatively narrow but of considerable size, bounded by steep slopes.

Cave - A hollow space developed in a portion of the earth's crust. A sea-cave may be produced by the action of the waves and also by boulders and pebbles being thrown against a cliff by the sea. It may also be formed by the contraction and expansion of the air in a rock fissure as the waves advance and retreat. Inland caves are often formed in a limestone region where water containing carbon dioxide dissolves out underground channels and enlarges them in places to form caves, usually with a stream flowing through them.

Chain - A mountain system consisting of a collection of more or less parallel ranges, and possibly including plateaus, provided that the general longitudinal arrangement is maintained.

Chemical Weathering - The weathering of rock by chemical processes such as oxidation, carbonation, hydration, and solution.

Climatology - The science that treats of the various climates of the earth and their influence on the natural environment.

Coastal Plain - A plain that borders the sea coast and extends from the sea to the nearest elevated land. It is sometimes formed through deundation by the sea, the beach being later raised by earth movement to form a plain, frequently known as a Raised Beach, or by deposition of solid matter at their mouths by rivers.

Compaction - The increase in density of a soil mass by rolling, tamping, vibrating, or other methods; expressed as pounds of wet soil or dry soil per cubic foot.

Coniferous Forest - A forest of evergreen coniferous or cone-bearing trees carrying needle-shaped leaves. From such forests is obtained the valuable softwood timber of commerce.

Continental Drift - The supposed horizontal displacement of portions of the original continent that comprised the entire land mass of the world to form the present-day continents. It is described as Wegener's Hypothesis.

Continental Shelf - The terrace-like submerged surface bordering the continents, sloping gently and extending as far as 600 miles out under the sea.

Coral Reef - A chain of rocks lying at or near the surface of the sea and built up principally from immense numbers of skeletal marine creatures; both on and behind the reef, fragments of shells, coral, and coral sand are piled up by the wind and wave action, and new land is thus formed. Three more or less distinct kinds of coral reef are recognized: fringing reefs, barrier reefs, and atolls.

Crater - A steep-sided pit or basin, usually at the summit of a volcano, and formed when the top of the volcano was removed by explosion or collapse.

Crevasse - A deep, vertical crack in a glacier. Transverse crevasses develop across a glacier wherever there is a marked steepening of the slope of its floor. Longitudinal crevasses, roughly parallel to the direction of flowage, are formed whenever ice is obliged to spread out. Marginal crevasses point upstream from the sides of the glacier.

Deciduous Forest - A forest consisting of trees that lose their leaves at some season of the year. In the case of the monsoon forests, such as those of India and Burma, the trees shed their leaves during the hot season in order to protect themselves against excessive loss of moisture by evaporation. From the deciduous forests is obtained much of the valuable hardwood timber of commerce; the monsoon forests yield such extremely hard wood as teak, oak, elm, and beech from the cool intermediate forests.

Degradation - A process that tends to wear down the land surface; it is usually applied to a river and it involves the deepening of its valley by the river.

Delta - An alluvial deposit formed at the mouth of a flowing stream emptying into the relatively quiet water of a lake, sea, or ocean.

Dendritic Drainage - A tree-like arrangement of a main stream and successively smaller tributaries joining it at acute angles.

Deposition - The laying down in a new location of material that has been carried from another place.

Desert - An almost barren track of land in which the precipitation is so scanty or spasmodic that it will not adequately support vegetation.

Diastrophism - Deformation of the earth's crust by folding, bending, warping, or faulting.

Dome - A curved stratum of rock in which the slope is in all its directions away from a central point.

Drumlin - An elongated, half-egg-shaped hill made up of material deposited beneath glacial ice; it occurs in a previously glaciated region, the long axis lying parallel to the direction of flow of the ice, with the thick, steep end to the north.

Dune - An accumulation, as a hill or ridge, of windblown sand common from erosion in deserts. The sand particles are carried along by the wind and piled into a heap that gradually increases in size until it becomes a small hill; the dune is often commenced where an obstacle of some kind impedes the free movement of the wind. The sand is then heaped against the obstacle until it is covered. By the action of the wind, the shape and size of the dune are always changing.

Dust - Solid matter consisting of minute particles, smaller than sand particles, and occurring everywhere in the atmosphere; it is often carried immense distances by the wind, and is constantly being deposited on the earth's surface. The sources of dust are various: in and near to industrial areas, the smoke from factory and domestic chimneys charges the atmosphere with particles of carbon and other substances; in the deserts dust is raised from the ground by the wind while volcanic dust enters the air during an eruption.

Earth - The fifth in size of the eight major planets in the solar system, and the third in nearest distance from the sun. The solid outer crust of the earth, known as the lithosphere, is partially covered (72%) by an extensive area of water, known as the hydrosphere, and around the earth is a gaseous envelope known as the atmosphere. Although the earth is often regarded as being a sphere, it is actually an oblate spheroid, being slightly flattened at the poles; the polar distance is about 27 miles shorter than the equatorial diameter, that being 7,926 miles in length.

Earthquake - A movement or tremor of the earth's crust that originates naturally and below the surface, it sometimes causes a permanent change of level at the surface, but often the damage done by the shaking provides the only lasting visible effect. It may be produced by a volcanic explosion; earthquakes are common in most volcanic areas and often precede or accompany eruptions.

Ecology - The science that treats of organisms in relation to their environment; it is frequently subdivided into human ecology, plant ecology, animal ecology, and bio-ecology. Bio-ecology deals with the inter-relationships between animal life and plant life. Ecology lies on the frontiers of many areas including geography.

Equatorial Forest - (Tropical Rain Forest) The hot, wet, evergreen forest of the equatorial region, where rainfall is very heavy and where there is no dry season; it extends in parts into the typical monsoon areas. Because of the extreme heat and moisture, the growth is dense and luxuriant.

Erosion - The wearing away of the land surface by various natural agencies, the most important being those consisting of water — the sea, rivers, and rain. Ice, in the form of glaciers, frost, and melting snow also assists in the process of erosion.

Esker - A long narrow sinuous ridge composed chiefly of irregularly stratified sand and gravel. It was once the bed of a stream flowing beneath or in the ice of a glacier, and was left behind when the ice melted.

Estuary - A broad, shallow indentation of a coastline where the sea advances far up a river valley, inundating lowlands and permitting tidal currents to back up the river for some distance upstream.

Exfoliation - A weathering process that consists in the peeling off of thin layers of rock from the surface. In hot deserts it is caused by the heating of the rocks by day and their cooling by night, leading to alternate expansion and contraction. The corners of rock masses especially are broken off, and the surfaces assume a rounded form. The process is often assisted by others, such as the chemical weathering of the outer layers. The term "onion weathering" is sometimes used for exfoliation.

Fault - A fracture of the earth's crust along which movement has taken place.

Fauna - The animal life of a region or of a geological period, corresponding to the term "flora" for plant life.

Firn - Old snow that has lasted through at least one summer; the flakes have changed to grains of spherical shape that may or may not be bonded together. Firn may later become glacial ice.

Fjord - A long, narrow, deep, and steep-sided indentation of the sea along a mountainous coast, covering a sunken valley that was formed by glacial erosion.

Flood Plain - A broad expanse of land in a stream valley that was built up by the deposition of alluvium or sediment carried down by the river during the overflow of water.

Flora - The plant life of a region or of a geological period.

Frost Action - The weathering process caused by repeated cycles of freezing and thawing.

Geodesy - The science of the measurement of the size and shape of the earth and the surveying of large portions of the earth's surface.

Geography - The subject that describes the earth's surface - its physical features, climates, products, peoples, and their distribution.

Geoid - A term used to signify the shape of the earth, an oblate spheroid with certain variations.

Geology - The science of the composition, structure, and history of the earth. It includes the study of the materials of which the earth is made, the forces that act upon these materials and the resulting structures, the distribution of the rocks of the earth's crust, and the history, not only of the earth itself, but also of the plants and animals that inhabited it throughout the different ages.

Geomorphology - The study of the physical features of the earth, the arrangement and form of the earth's crust, and of the relationship between these physical features and the underlying geological structures.

Geophysics - The study of the physical processes relating to the structure of the earth, including not only the lithosphere but also the hydrosphere and the atmosphere. It signifies the physics of the earth linking the sciences of physics and geology.

Glacier - An accumulation of ice that has become so large that sufficient pressure is created to cause movement along the outer margins of the mass.

Gorge - A valley that is more than usually deep and narrow, with steep walls; there is no sharp distinction between a gorge and a canyon. The sides of a small gorge are sometimes nearly vertical.

Grasslands - Those regions of the world where the natural vegetation consists of grass; the rainfall is too light to permit forest growth, but is less scanty and irregular than that of the deserts; the grasslands are thus normally situated between the forest belts and the arid regions.

Gravel - A deposit of rounded stones, usually mixed with finer material such as sand or clay, formed by the action of moving water — by a river or a lake, or by the sea.

Ground Water - Water that has seeped below the earth's surface and occupies porous spaces in the underlying materials.

Ground Water Table - The top of the saturated zone in which ground water has completely filled the openings between individual soil and rock particles. Most of the ground water occurs within a few hundred feet of the earth's surface.

Gulch - A narrow deep ravine with steep sides formed by a torrent.

Gully - A long, narrow channel worn out by the action of the water, particularly in a hillside; it is smaller than a ravine or a valley. The term is often used of a channel produced in the erosion of soil; such a gully normally carries water only during or immediately after rain or the melting of snow.

Hardpan - A hardened or cemented layer of soil, impervious to drainage, lying below the surface.

Hot Spring - A stream of hot water issuing from the ground, often after being heated by buried lava, and commonly occurring in a volcanic region when eruptions have ceased.

Humus - Semidecayed plant and animal matter in soil.

Hydrologic Cycle - The giant circulatory system in which water passes through several stages: from water vapor to precipitation to surface water, and again to water vapor by means of evaporation and transpiration.

Hydrology - The study of water, especially in relation to its occurrence in streams, lakes, wells and as snow and including its discovery, uses, control, and conservation; the science that relates to the water of the earth.

Ice Age - A geological period in which ice sheets and glaciers covered large areas of the continents, reaching the sea in places and lowering the temperature of the oceans.

Ice Field - A uniform, unbroken ice-floe of great extent; a continuous sheet of ice formed when lumps of ice join up.

Ice Floe - An extensive mass of floating ice, detached from the main polar ice, whose limits of dimension are normally within sight.

Ice Sheet (Ice-Cap) - A vast mass of ice and snow that covers large land areas in the polar regions; its surface is almost flat.

Impermeable Rocks - Rocks that, being nearly non-porous, do not allow water to soak into them. This rock may be pervious owing to joints and fissures.

Impervious Rocks - Rocks that do not allow water to pass through them freely; they may be porous.

Insolation - The heat or radiant energy received from the sun by the earth and other planets.

Isostasy - The state of equilibrium existing between the highlands and the lowlands of the earth, due to the fact that the former are made of lighter rock materials than the latter.

Joint - A crack in a mass of rock that has been formed along a plane of weakness.

Kame - A mound of stratified gravel and sand that was formed by the deposition of the sediment from a stream as it ran from beneath a glacier.

Karst Region - A limestone region in which most or all of the drainage is by underground channels, the surface being dry and barren. It is characterized by sink holes and uneven topography caused by the unequal dissolution of porous underlying limestone rock.

Lacustrine - Relating to a lake or lake materials.

Landslide - The downward movement of a large mass of earth or rocks from a mountain or cliff. It is often caused by rainwater soaking into the soil and material on a steep slope; their weight is much increased, and they become more mobile. It may be caused by an earthquake or on the seacoast by the undermining action of the sea.

Lava - Molten rock that flows from fractures in the earth's outer crust out upon the earth's surface.

Leaching - The process by which water percolating downward in the soil, or moving across the surface of the soil, chemically removes soluble minerals from one place and deposits them elsewhere.

Local Relief - Amount of relief within an area in contrast to absolute altitudes above sea level.

Loess - An accumulation of fine sand transported and deposited by the wind.

Magma - Molten material that moves through the rocks of the earth's outer shell and hardens before it reaches the atmosphere.

Mantle Rock - The unconsolidated weathered material that has accumulated on the surface of the earth.

Marl - A mixture of clay and calcium carbonate, although the term is loosely applied to a wide variety of rocks and soils. Some of the marls are marine deposits while others are of fresh-water origin.

Mechanical Weathering - The weathering of rock by physical forces without chemical change.

Mesa - A flat, table-like mass, that slopes steeply on all sides. The harder top layers of rock have resisted denudation, and, being practically horizontal, have maintained a uniform surface parallel to the stratification.

Metamorphic Rock - Any rock affected by action of pressure, heat, and water, resulting in a more compact and highly crystalline condition.

Meteorology - The science that investigates the weather, in particular the physical processes that occur in the atmosphere, and the connected processes of the lithosphere and hydrosphere.

Mineral - A natural inorganic substance with fairly definite chemical composition and with distinctive physical characteristics such as crystal form, hardness, color, luster, and type of fracture.

Moraine - An irregularly shaped hill, or ridges and depressions formed by glacial deposition.

Mountain - A land mass reaching comparatively high altitude and having most of its surface in slope and of greater altitude than its surroundings.

Muskeg - A swamp or bog in an undrained or poorly drained area of alluvium or glacial till, or, more especially, in a rocky basin filled with water-saturated muck, decayed vegetal matter, and sphagnum moss incapable of sustaining much weight. The surface is commonly hummocky.

Oceanography - The study of the oceans, including the nature of the water, its movements, its temperature, its depth, the ocean bed, and the flora and fauna.

Outcrop - The portion of a rock stratum that projects above the earth's surface and is thus exposed to view.

Outwash Plain - A level area formed by deposits of minerals carried beyond the ice front of a melting glacier by running water.

Pack-Ice - Large blocks of ice, of greater extent and depth than ice-floes, that were formed on the surface of the sea when the ice-field was broken up by winds and waves, and have drifted from their original position. They are termed "close pack" if the blocks are mainly in contact, "open pack" if they are not. Most of the pack ice gradually melts and disappears in warm weather.

Pedalfer - One of the two types into which soils are sometimes classified; it is roughly equivalent to "soil of a humid region", and is rich in iron and clay. The pedalferes are divided into podzolic and lateritic soils.

Pedology - The science of the study of soils.

Peneplain - A rolling area that has experienced a long period of erosion during which mountains were generally worn down to form relatively flat terrain.

Permafrost - A thickness of soil, superficial deposit, or bedrock of variable depths beneath the surface of the earth in which below-freezing temperature has existed continuously for a long time. The term also used is perennially frozen ground. Permafrost results solely from below-freezing temperature, irrespective of the texture, degree of compaction, water content or lithologic character of the frozen materials involved.

Petrology - The study of the composition, structure, and history of the rocks forming the lithosphere or earth's crust and their mineral structure.

Physiography - The study of the physical features of the earth, their causes and their relation to one another.

Plain - An area of low relief.

Plasticity - The property of a material that enables it to undergo permanent deformation without appreciable volume change or elastic rebound, and without rupture.

Plateau - An area of relatively level land having a higher elevation than a plain and occasionally interrupted by deep valleys and areas of steep slope.

Playa - A dry-lake bed; a track of land that is temporarily filled with water and becomes a shallow muddy lake, but dries up again in hot weather.

Pleistocene - The latest epoch in the geological time scale that includes all of post-pliocene time. It is sometimes called the Ice Age.

Podzol - A type of soil that is characteristic of regions having a sub-polar climate and in a coniferous forest.

Precipitation - Water in solid or liquid form falling from the atmosphere to the earth as a result of the excessive cooling of large amounts of air.

Profile - (Soil) A section through the soil showing the different horizons, or layers, usually designated by the letters A, B, or C, that extend downwards from the surface to the parent material.

Radiation - The process by which a body emits radiant energy in the form of heat. It causes a loss of heat as cooling. Radiant energy is constantly emitted in all directions by the sun, some of this reaching the earth and converted into heat. The earth is constantly losing heat into space by radiation.

Raised Beach - A beach that has been raised by earth movement to form a narrow coastal plain; it is often bounded by inland cliffs.

Recessional Moraine - A deposit of glacial drift laid down during the retreat of a glacier.

Reef - A ridge of rocks, lying near the surface of the sea, that may be visible at low tide but is usually covered by the water.

Rift Valley - A valley lying between two relatively parallel faults.

River Terrace - A platform of land formed beside a river flowing across a plain.

Rock - One of the solid materials of which the earth's crust is mainly composed, being made of an aggregate of minerals. The many different kinds of rocks in the earth's crust are divided into three major classes: igneous, sedimentary, and metamorphic.

Salt Lake - A lake, situated usually in an arid region, in which the evaporation exceeds the amount of water entering through precipitation and inflow, so that the water becomes extremely salty.

Sand - A mass of minute particles of mineral debris that is finer than gravel but coarser than silt. It is also not as fine as dust and is not normally lifted by the winds far above the earth's surface. Its movement is controlled by obstacles in its path and it is often heaped up in mounds called dunes.

Savanna - The tropical region that borders the equatorial forest in each hemisphere and lies between the latter and the hot deserts; the natural vegetation is mainly grass with scattered trees, for there are distinct wet and dry seasons, and the lack of rainfall during the latter prevents the growth of forests except in particularly moist places.

Scarp - A relatively steep, straight slope of any height.

Scrub - A dense mass of low-growing evergreen plants, about 4 to 6 feet high, with occasional taller trees. It is usually found in regions that have insufficient rainfall or poor soil for forest growth.

Seismic Focus - The place below the earth's surface where an earthquake originates and from which the vibrations spread in all directions; it is usually several miles beneath the surface.

Seismology - The science of the study of earthquakes.

Silt - A deposit that is laid down in a river or lake, and is finer than sand but coarser than clay.

Sink Hole - A depression in the earth's surface where water has seeped down and dissolved underlying rocks or collapsed the roofs of caves.

Soil - Unconsolidated material on the earth's surface.

Soil Horizon - A distinctive layer of soil parallel to the earth's surface and having particular chemical and physical properties.

Soil Series - A group of soils having similar profiles except for the texture of the surface soil, and developed from a particular type of parent material.

Soil Structure - The arrangement of soil particles within the soil mass.

Soil Type - A term used in the classification of soils. It is the principal unit used in soil mapping as well as other soil studies.

Steppe - Short grass-type vegetation found on the humid margins of the desert regions.

Stratum - A more or less distinct layer of rock, occurring as one of a series of strata in the earth's crust. Rock strata vary in thickness from a fraction of an inch to several feet, and normally are horizontal.

Striation - A groove made by a glacier indicating the direction of the glacial movement.

Subsoil - The layer of rock particles lying below the true soil; it has less organic matter than the latter. It is less fertile than the true soil, but is penetrated to some depth by the roots of trees and plants.

Swamp - A tract of low-lying land that is saturated with moisture and usually overgrown with vegetation; it differs from a marsh in that it is not ordinarily covered with water, and from a bog in that the latter consists largely of decaying vegetation.

Talus - An accumulated heap of rock fragments derived from and lying at the base of a cliff or very steep mountain slope. The fragments may be large or small and the aggregate heap usually has a form determined by gravity and angle of rest of the material involved.

Tectonic Force - A force originating within the earth's interior, resulting from the expansion, contraction, or the transfer of molten matter, involving both the deformation of the earth's crust and the movement of molten material from one place to another.

Terminal Moraine - A deposit of glacial drift marking the farthest advance of a glacier.

Topography - A detailed description or representation of the features, both natural and artificial, of an area, that are shown on topographic maps.

Trellis Drainage - The pattern formed when major streams are arranged in relatively straight parallel lines with tributaries joining them at right angles.

Tsunami - A huge sea wave occasionally experienced along the coasts of Japan and other regions in the Pacific Ocean, caused by an earthquake taking place on the ocean bed; the wave rises to progressively greater heights as it approaches the coastline, and on a single occasion has been known to cause the deaths by drowning of thousands of people.

Tundra - A broad area of grasses, bushes, mosses, and stunted trees lying between subarctic forests and polar seas.

Valley - A long narrow depression in the earth's surface with a regular downward slope.

Volcanic Ash - Fine particles of lava that have been ejected from a volcano in eruption. The particles are coarser than those of volcanic dust.

Volcanism - The transfer of igneous or molten matter that is frequently accompanied, preceded, or followed by earth movement.

Water Table - The surface of the ground water or the surface below which the pores of a rock are saturated with water. This surface is uneven and it is also variable.

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Appendix A

Terrain Programs in Department of Defense

I. AIR FORCE

Investigations by the Air Force Cambridge Research Laboratories (OAR) in the use of natural terrain for military operations began with studies of seismic propagation through sea ice in 1950. This led to long-term glaciological studies of ice shelves and their suitability as landing strips for aircraft (Assur, 1956; USAF AFM 86-5 Ice Airfields, 1958). Engineering studies of sea ice were culminated in Operation ICE WAY in 1961, which verified the capability of sea ice to support flight operations of the heaviest of Air Force aircraft.

A 5-year program of photogeologic identification of terrain in all environments, field investigations, site evaluations, development of techniques, and proof tests of ice-free natural land areas in Greenland was completed in 1960. This program provided detailed scientific descriptions of a number of natural soil surfaces in arctic areas that could support flight operations.

Based on these proven techniques for assessing terrain and selecting airstrip sites for use in their natural unimproved or semi-prepared condition, similar studies of dry lake bed (playa) landforms were undertaken in 1961. These involved considerations of location, bearing strength, surface roughness, seasonal conditions, site monitoring for degree of useability, site stability, and morphology.

Concurrent studies of natural terrain concerned the quantification of terrain parameters, research in the remote sensing of terrain by airborne methods, and evaluation of analogous areas. Geophysical measurements were made of typical geologic regions involving seismic, magnetic, gravimetric, and electrical resistivity measurements of surface and sub-surface structures.

Research pertaining to the landforms of global humid and tropical regions included photogeologic interpretation and analogous area studies. Field and airborne investigations of natural geothermal sources throughout the world were undertaken, primarily in Iceland and Italy.

The playa and remote sensing programs were extended to the arid regions of the world. These areas are in the Middle East, Near East, South America, and Australia.

Other agencies participating in Air Force programs have been the Army Engineers, Army Natick Laboratories, Naval Civil Engineering Laboratories, Naval Oceanographic Office, and U. S. Geological Survey. Universities and commercial organizations provided much laboratory and field assistance.

The Air Force Weapons Laboratory (AFSC) began their terrain and civil engineering research studies in 1960 to: study the effects of weapons on different soil and rock structures, develop the technology of base facilities, select sites on varied types of terrain to support facilities, and develop soil-stabilization techniques. The agency conducts studies in the evaluation of engineering properties of terrain by geophysical and remote sensing methods. Site selection studies were expanded in 1964 to include the location of suitable natural landing strips in support of operations for all types of aircraft in the Air Force inventory.

The Air Force Flight Dynamics Laboratory has been designing aircraft landing gears suitable for operating on natural or stabilized terrain and on asphalt, cement, or concrete runways. The parameters incorporated into the designs are surface roughness, bearing strength, dimensions of runways, and flight zones, wheel loading, tire size, and other related factors for all AF aircraft.

The Air Force Flight Test Center (AFSC) conducts performance tests of all aircraft on varied types of runways to determine operational characteristics and criteria for maximum capabilities and limitations. Modifications to the prototype models are made dependent upon the test results.

The Hq USAF, Directorate of Civil Engineering (AFOCE) has been responsible for the administration of the civil engineering forces and the assignment of specific operational problems for resolution to the field commands. These problems pertaining to terrain include soil stabilization, selection of sites for permanent or expedient airstrips for contingency operations, and repair or emergency construction of facilities.

The Air Force Civil Engineer Construction Operations Group (CECOG), established in 1966, is the field extension of the Hq USAF Directorate of Civil Engineering (AFOCE) as an operating subordinate unit to AFOCE. CECOG is responsible for the field organization, training, deployment, use, and logistical support of the special engineering forces to meet the requirements of the Air Force global mission. One of their major functions is the use of site selection teams for rapidly locating contingency airfields and other facilities on natural terrain to meet the expanding operational needs of the strategic, tactical, defense, and limited war forces.

2. ARMY

Corps of Engineer studies of terrain properties and vehicle mobility were initiated in the early 1930's at the Ohio River Division Laboratories and at the Waterways Experiment Station at Vicksburg, Miss. Soil trafficability studies were expanded by the Ordnance Department in 1942 and concentrated at the Waterways Experiment Station in 1945. Corollary efforts were in soil stabilization, vehicle trafficability, and aircraft landing mat research, development, and evaluation.

The Snow, Ice, and Permafrost Research Establishment was organized in 1949 to investigate the properties of polar terrain and problems of construction in an extremely cold environment. This group was combined in 1961 with the Arctic Construction and Frost Effects Laboratory (established in 1953) to form the Cold Regions Research and Engineering Laboratory (CRREL), redesignated as Terrestrial Science Center (TSC) in 1968. The Transportation Corps similarly studied operations in a polar environment, conducting vehicle and light aircraft (fixed wing and helicopter) trafficability programs since 1950.

Other Army agencies conducting theoretical and experimental investigations of terrain properties by ground and airborne methods are the Engineer Research and Development Laboratories (renamed Army Mobility Equipment Research and Development Center in 1964) and the Geodesy Intelligence and Mapping Research and Development Agency (renamed Engineer Topographic Laboratories in 1967). The Land Locomotion Laboratory at the Army Tank-Automotive Command (renamed as a Center) develops the criteria for the design of ground vehicles and conducts terrain-vehicle interaction studies for cross-country mobility. The Army Natick Laboratories was established in 1953 to develop methods for protecting military personnel and equipment in all global and regional environments. The USANL also has been responsible for climatological studies of terrain, the development

of criteria for analogous area methods, and efficient logistical use of supplies and equipment in support of military operations. Most of the efforts of the Army agencies are under the jurisdiction of the Hq U. S. Army Research Office, Corps of Engineers, and the Army Materiel Command.

3. NAVY

Terrain studies by the Navy began when the U. S. Navy Amphibious and Training Base established a beach trafficability unit in 1945 to investigate the use of beaches in operations. In 1950, the Navy delegated the responsibility of beach trafficability in DOD to the Army Engineer Waterways Experiment Station.

The Office of Naval Research performed studies of global terrain and its classification since 1950. It also initiated the long-term study of remote sensing of the environment, including terrain properties, that is mainly devoted to terrain quantification and earth science applications.

The Naval Civil Engineering Research and Evaluation Laboratory was organized in 1950 as a research unit of the Construction Battalion Corps under the Bureau of Yards and Docks. It has been concerned with installations, construction, ship-to-shore transportation, equipment, materials, and methods that are related to the engineering properties of terrain. The organization was later redesignated as Naval Civil Engineering Laboratory.

The Naval Ordnance Laboratory conducts studies of water and ice properties related to underwater ordnance and weapons. The Navy Electronics Laboratory has performed considerable work on ice properties and devised extensive instrumentation for surface and subsurface operations in a polar environment. The Naval Oceanographic Office is engaged in intensive investigations of ice surfaces, coastal shelves, reefs, barriers, marine science, sea water parameters, and submarine terrain in addition to major oceanographic studies.

Appendix B

Classification of Terrain Data

I. INTRODUCTION

The majority of terrain studies and classifications are usually qualitative or a description of the genetic origin of various landform features. A quantitative approach defines terrain parameters by a series of numerical values that offer the advantage of achieving accuracy in mapping. This approach also permits the computerization of data on all terrain parameters for an efficient determination of the effects of either an individual factor or a group of selected factors on a particular activity (see Figure 31 in report).

A semi-quantitative system combining the genetic approach with the digitization of the terrain factor values avoids over complexity yet provides more objectivity than the qualitative method in characterizing the terrain for its military significance. The terrain factor subunits of any geographic region can be identified by a series of designated digits or matrixes. Additional digits indicating any preferred range of values can be added to a matrix grouping for supplementary definition as necessary.

2. TERRAIN AND SOIL CLASSIFICATION SYSTEMS

2.1 Terrain Classification

Most terrain classification systems are qualitative and, therefore, not designed to evaluate terrain for a specific use. These qualitative systems merely describe in prose all the elements of the terrain environment, necessitating ground surveying for planning tactical operations.

2.1.1 PHYSICAL GEOGRAPHIC SYSTEM

In military geography, the regions of the world are described by the predominant physical elements of land-surface forms, as shown in Figure B-1. The major descriptive units are plains, plateaus, hills, and mountains.

2.1.2 GEOMORPHIC SYSTEM

This approach provides a genetic method for interpreting the geological structure and changing climatic processes and weathering action resulting in differential erosion of varying resistant lithology and geomorphic evolution of the landscape. The major units of classification are mountains, terraces, beaches, mesas, glacial features, etc., as listed in Table B-1.

2.1.3 REGIONAL PHYSIOGRAPHIC TERRAIN ENVIRONMENT

This method combines the physical geographic and geomorphic systems, subdividing large regions into smaller areas and predominant landform units. The terrain is classified by a synthesis of data on the geology and its processes, rocks, and stratigraphic formations, soils, vegetation, and the climate. The concept is largely intuitive, statistical, and indirect, but it can result in reliable data when employed by skilled scientifically trained analysts (Curtis, 1966).

Figure B-2 shows the extent of glaciation over a large portion of the world (Flint, 1961, p. 53), and Figures B-3 through B-8 illustrate the distribution of the other key terrain elements.

2.2 Classification of Rocks

Rock classifications are shown in Table B-2, Table B-3, and Table B-4. Generalized rock properties are listed in Table B-5.

2.2.1 CLASSIFICATION OF IGNEOUS ROCKS

In Table B-3, igneous rocks of similar chemical composition or mineral content are listed in the vertical columns; those of similar textures are listed in the horizontal columns. Classification of each variety is dependent on both texture and chemical composition.

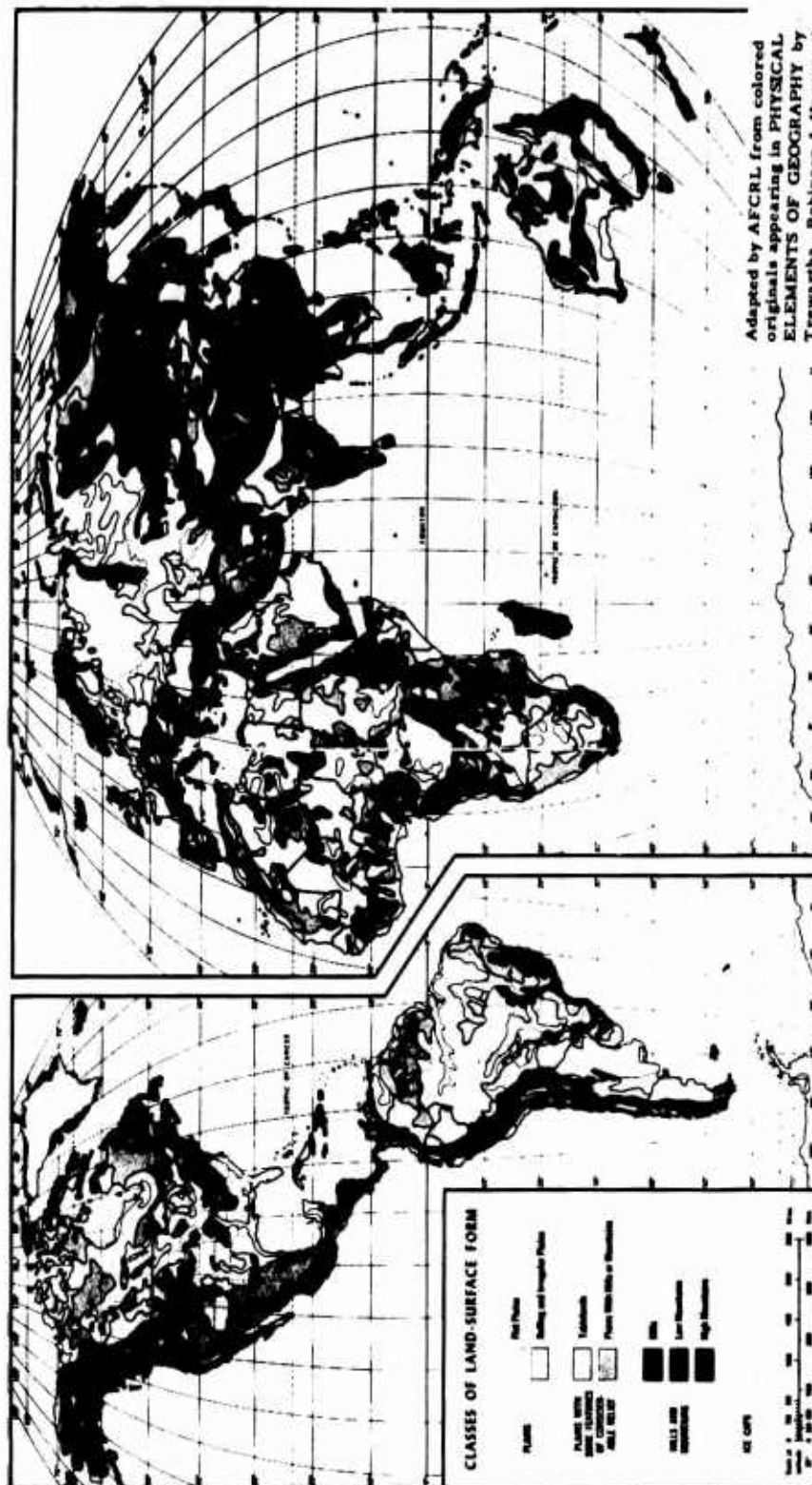


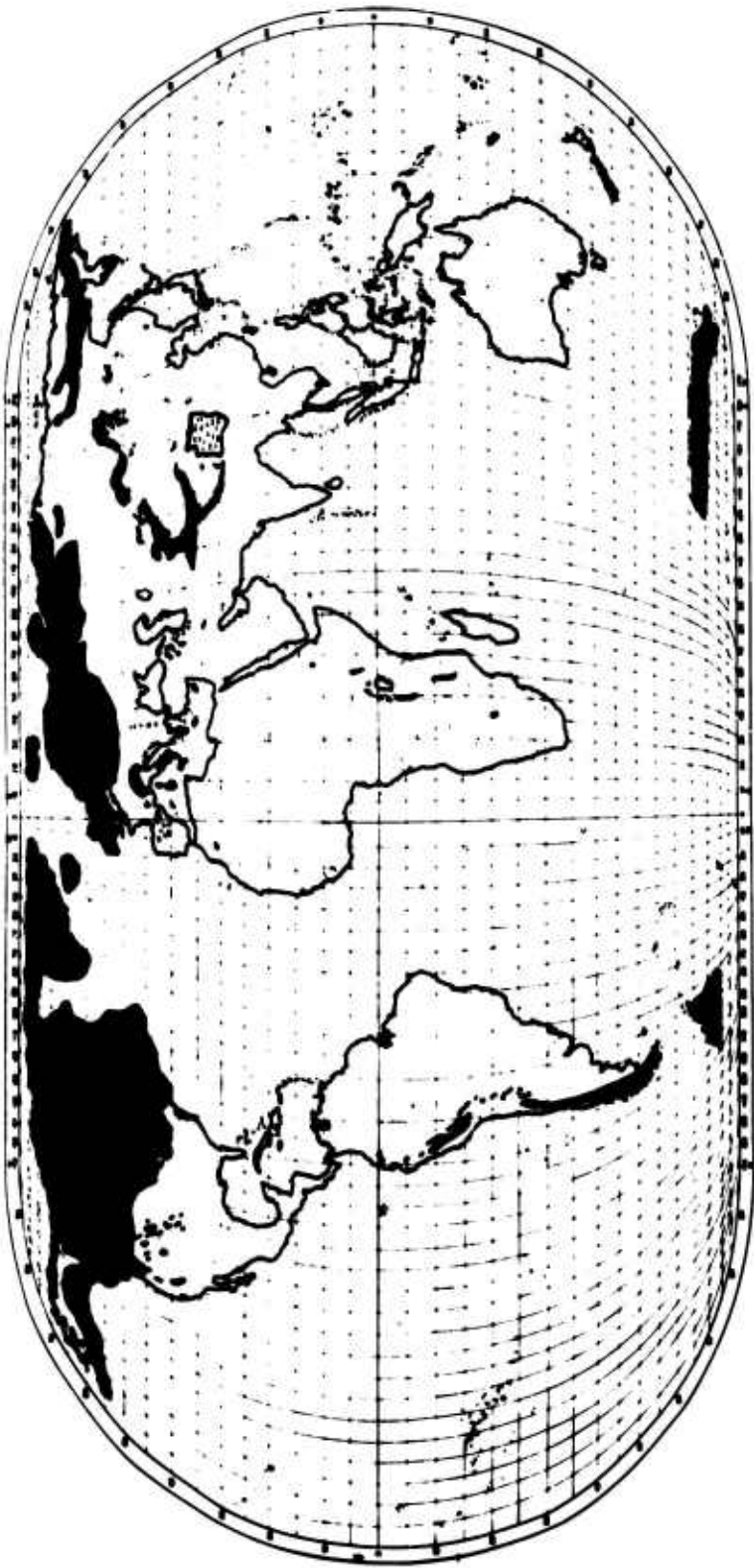
Figure B-1. Land Surface Forms (World Distribution)

Table B-1. Summary of Landform Types, Material, and Use

<u>Landform</u>	<u>Materials</u>	<u>Use</u>
<u>Waterlaid</u>		
Flood Plains	Fine-grained and well-stratified interbedded fine silts, sand, and gravel.	Highway, airfield construction; large structures require pilings.
Filled Valleys	Coarse sands and gravels to fine silts and clays	Highways, airfield construction; drainage structure required.
Continental Alluvial Plains	Thin silt cover underlain by stratified semi-consolidated materials of all textures	Highways, airfield, and building construction; drainage for dam sites required to prevent leakage.
Alluvial Fans and Related Forms		Highways, airfield, and building construction; drainage structure required; water supply.
Talus Cones	Rock fragments	
Alluvial Cones	Medium size rock fragments	
Alluvial Fans	Silt, clays, sand, gravel	
Delta Fan	Silt, clays, sand, gravel	
	Unconsolidated sands and small gravel with pockets of silt and clay	
Deltas	Silt, clays, sand, and gravel in stratified, cross-bedded, thick deposits of unconsolidated deposits	Source of construction materials.
Dry Lakebeds (Playas)	Unconsolidated fine sands, clays, silts, and salts	Roads, airfields, and buildings; foundation support for structures required.
Beach Ridges	Sand and gravel	Road, railroad lines; source of construction material.
Coastal Plains	Interbedded clays, silts, and sands in unconsolidated deposits	Road, railroad lines on undissected areas; landslide conditions; drainage controls required.
Tidal Flats	Silt, clay, and sand	Roads require stabilization; source of construction materials.
Marsh and Swamp	Peat, muck, silt	Temporary roads must be stabilized.

Table B-1. Summary of Landform Types, Material, and Use (Cont'd)

<u>Landform</u>	<u>Materials</u>	<u>Use</u>
<u>Glacial</u>		
Eskers	Sand, gravel, and sand	Roads, railroad lines; source of construction material.
Kames	Fine sand, silt, and gravel	Source of construction material.
Outwash Plains	Stratified sand and gravel	Source of construction material and foundations with stabilization.
Terraces	Sand, gravel, clays, silt	Foundations for structures require stabilization; source of construction materials.
Lakebeds		Foundations for structures require stabilization; drainage controls needed.
Delta Deposits	Coarse sand and gravel	
Near-Shore Deposits	Coarse silt and sand	
Deep-Water Deposits	Silts and clays	
Till Plains	Silt, clay, gravel	Foundation for structures require stabilization; drainage controls needed.
Moraines	Silt, clay, sand, boulders	Source of construction material; drainage controls needed; foundation for structures require stabilization.
Drumlins	Sand, clay, and gravel	Source of construction material.
<u>Windlaid</u>		
Sand Dunes	Sand	Source of sand for construction; foundation for structures requires stabilization.
Loess	Silt	Foundation for structures requires stabilization.



GLACIATED AREAS OF THE WORLD

■ AREAS OF FORMER GLACIATION ■ AREAS OF PRESENT GLACIATION

Figure B-2. Glaciated Areas (World Distribution)

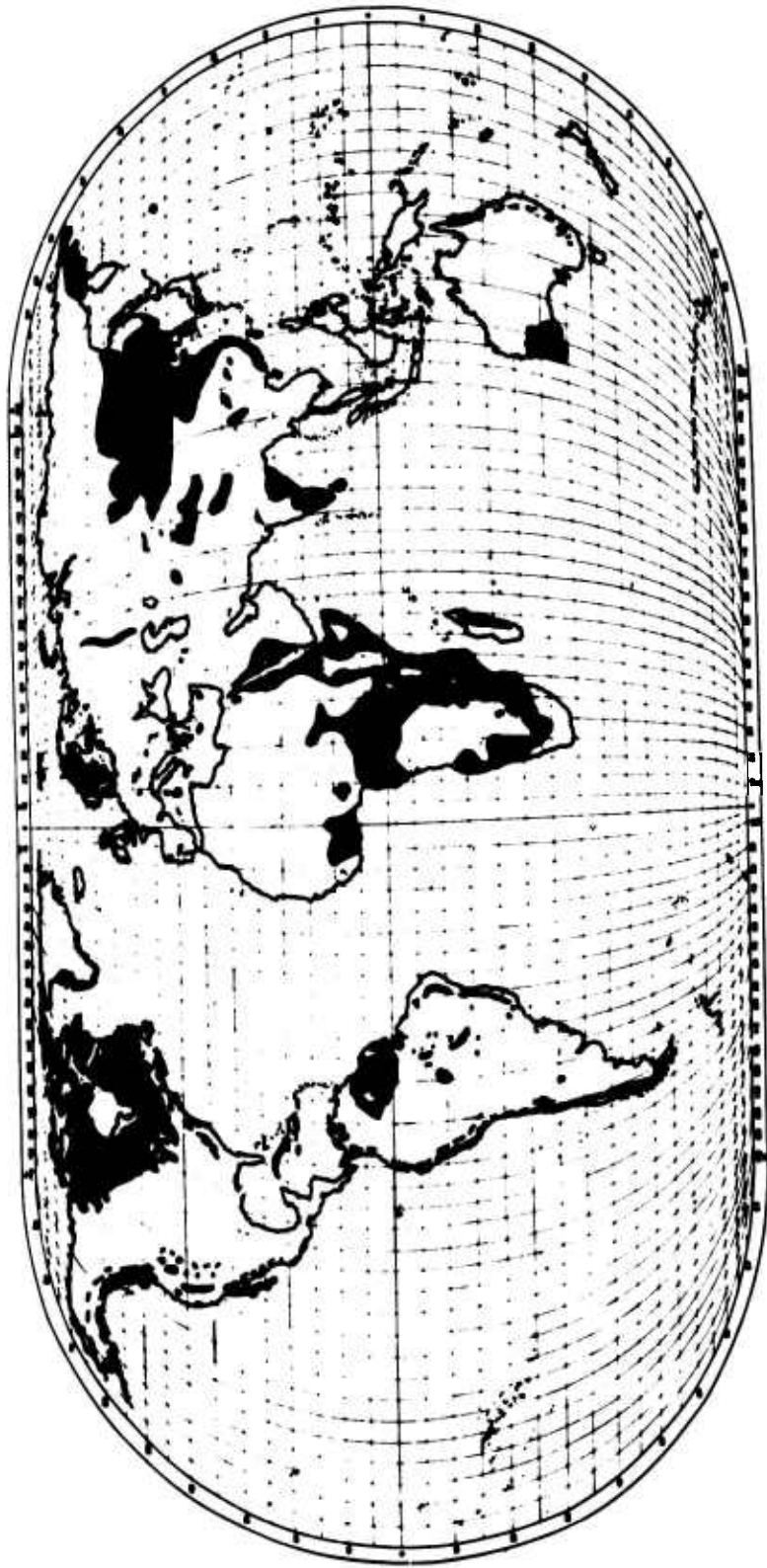


Figure B-3a. Igneous Rocks (Intrusive) (World Distribution)

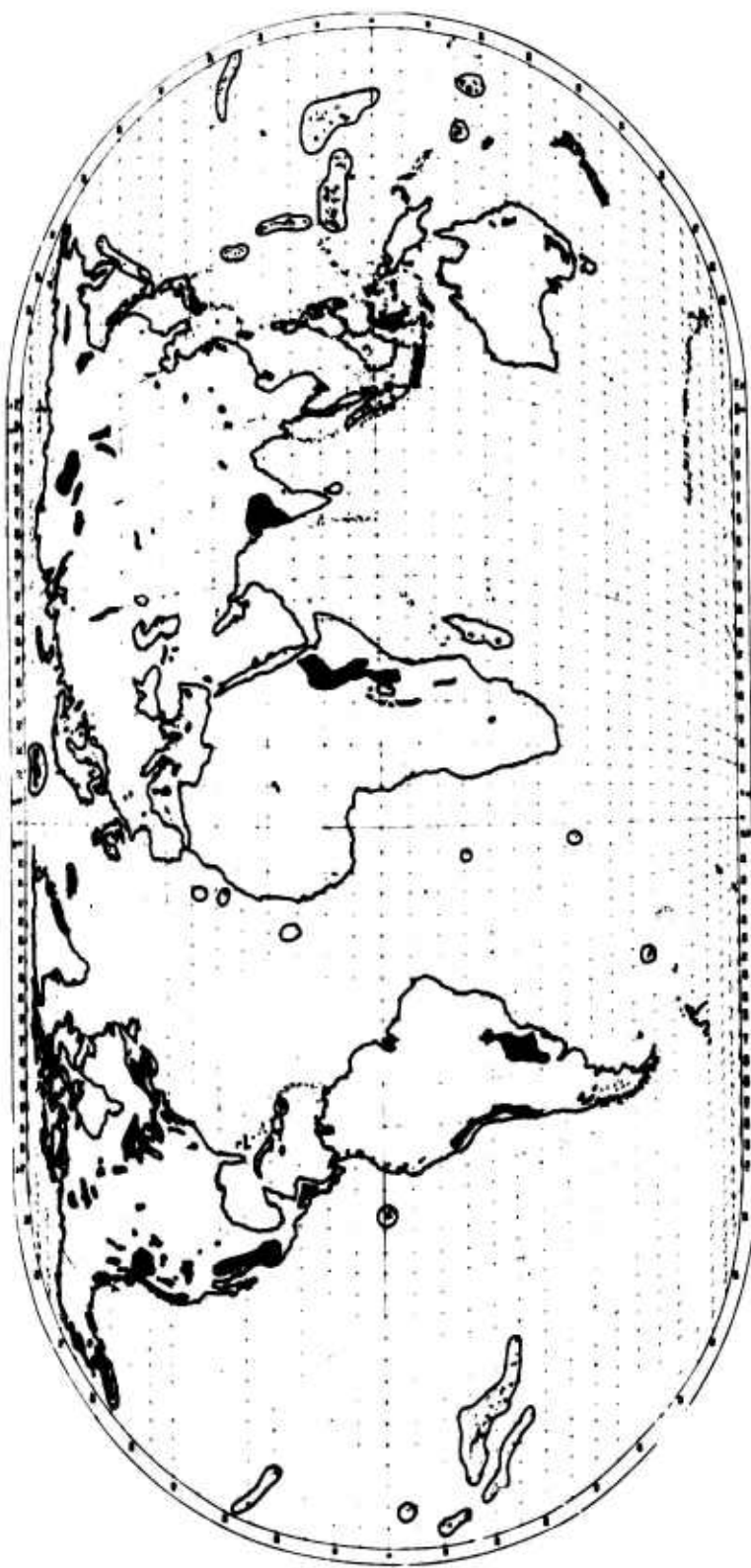


Figure B-3b. Igneous Rocks (Extrusive) (World Distribution)



Figure B-4. Sedimentary Rocks (World Distribution)



Figure B-5. Metamorphic Rocks (World Distribution)

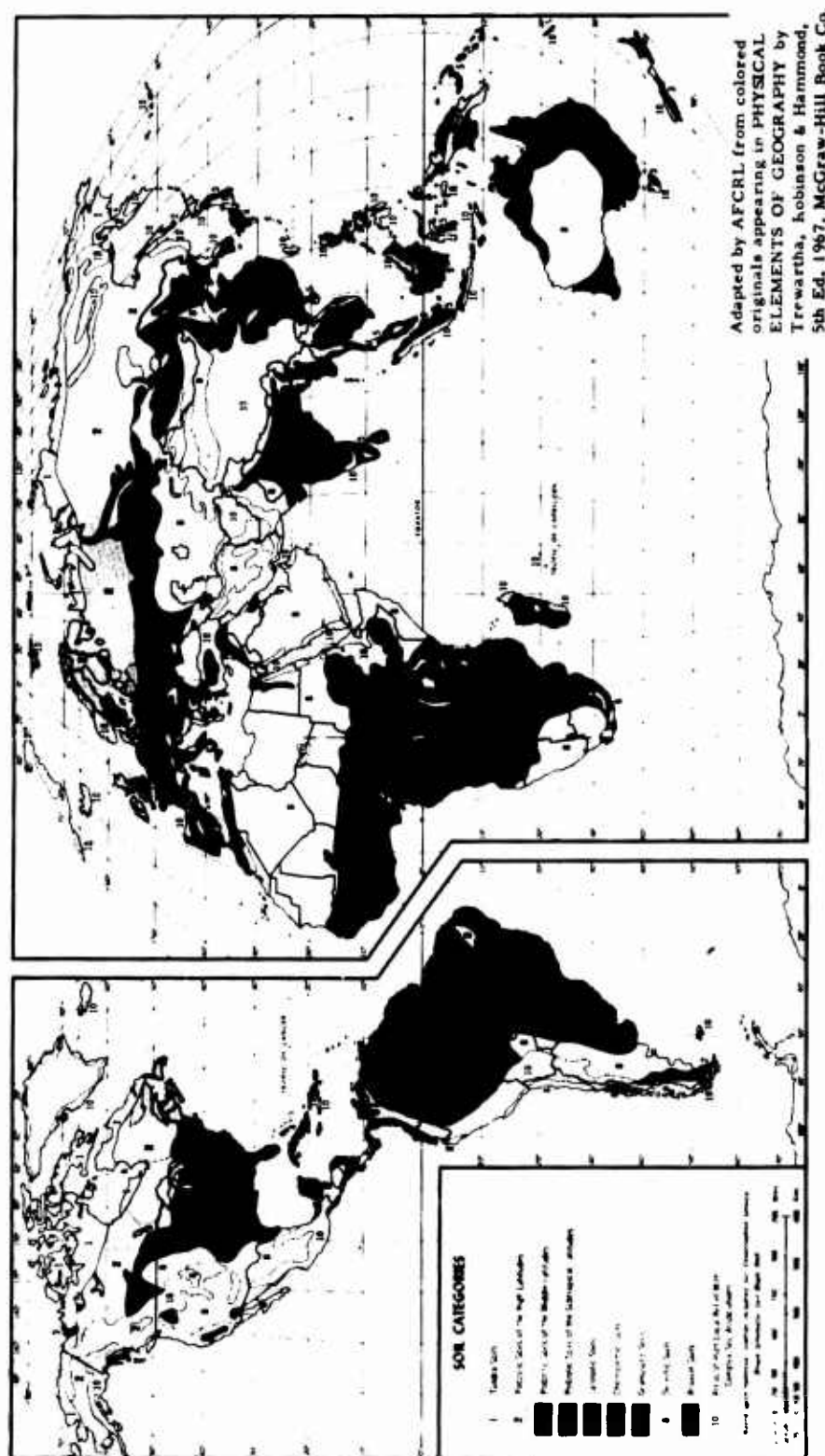


Figure B-6. Soil (World Distribution)

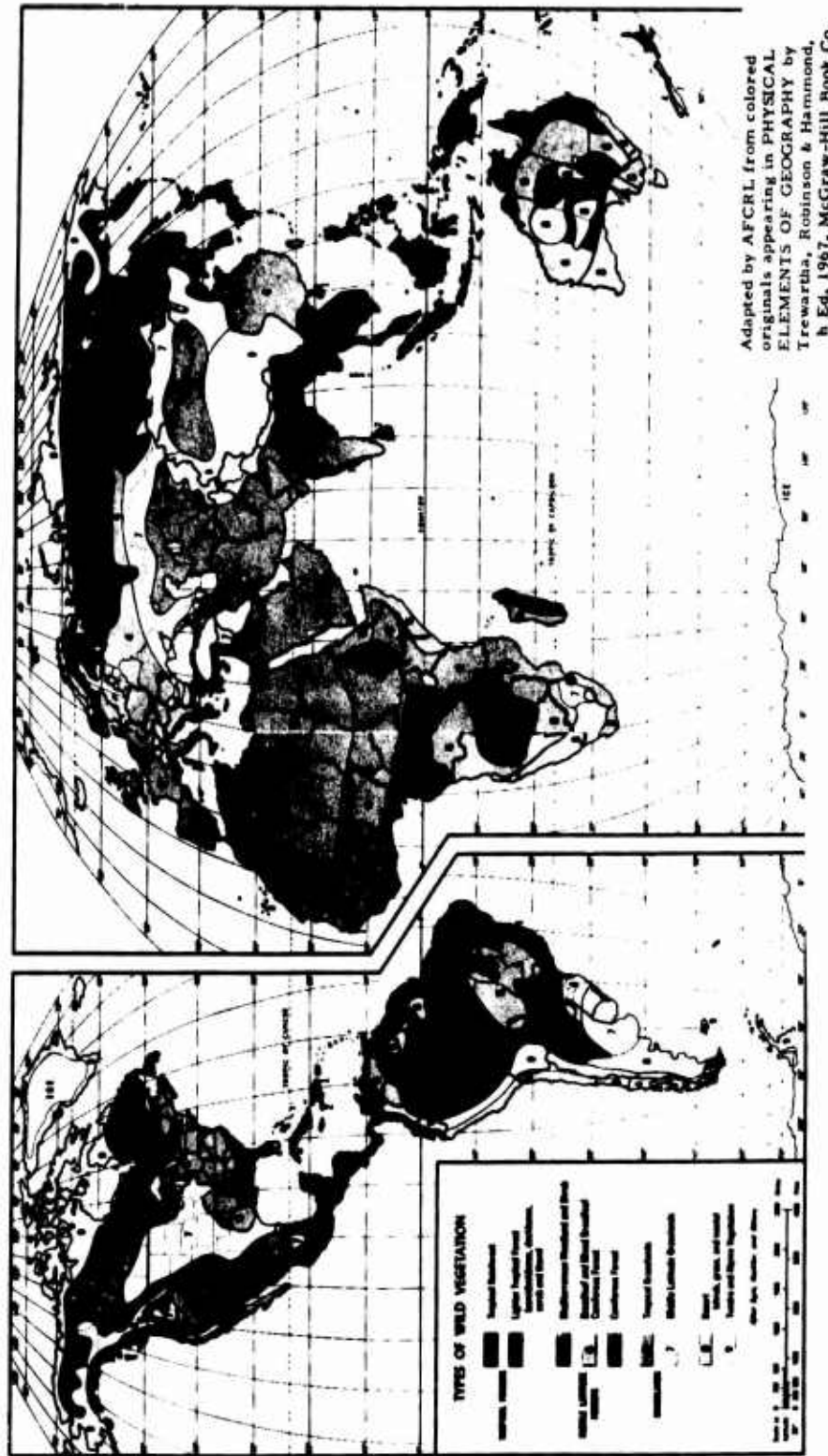


Figure B-7. Vegetation (World Distribution)



Figure B-8. Climate (World Distribution)

Table B-2. Igneous Rocks

Composition			
Texture	Acidic Rocks (more than 50 percent silica)		Basic Rocks (less than 50 percent silica)
	Light-colored minerals, chiefly feldspar, pre- dominate		Dark-colored minerals predominate
	Abundant quartz	Little or no quartz	Abundant amphibole pyroxene, and plagio- clase feldspar
Coarse-grained (mineral crystals easily visible to naked eye).	Granite	Diorite	Gabbro
Fine-grained (mineral crystals generally in- visible to naked eye).	Rhyolite	Andesite*	Basalt*
Glassy	Obsidian, pitch- stone, pumice		

* Sometimes called traprock.

2.2.2 CLASSIFICATION OF SEDIMENTARY ROCKS

Sedimentary rocks (Table B-3) are classified as clastic, pyroclastic, chemical, or organic, based upon the mode of origin of the sediment from which they are derived. The clastic rocks commonly show separate grains. The chemical precipitates and evaporates, on the other hand, either have interlocking crystals or are in earthy masses. The organically formed rocks commonly contain easily recognized animal and plant remains, such as shells, bones, stems, or leaves.

2.2.3 CLASSIFICATION OF COMMON METAMORPHIC ROCKS

Metamorphic rocks (Table B-4), on the basis of their primary structure, are readily divided into two descriptive groups: the foliates and non-foliate. The foliated metamorphic rocks display a pronounced primary structure, as they have a banded appearance from the differential pressures to which they have been subjected. The nonfoliated or massive metamorphic rocks exhibit no primary structural features. These structural differences are used as the basis for the simplified classification of the common metamorphic rocks.

Table B-3. Sedimentary Rocks

Type	Sediment	Rock
Clastic or fragmental	Coarse (gravel) Medium (sand) Fines (silt and clay)	Conglomerate Sandstone Siltstone and shale
Pyroclastic	Coarse (cinder) Fine (ash)	Agglomerate Tuff
Chemical precipitates and evaporites	Calcium carbonate (CaCO_3) Calcium magnesium carbonate ($\text{Ca}(\text{Mg, Fe}) (\text{CO}_3)$) Silicon dioxide (SiO_2) Calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) (CaSO_4) Sodium Chloride (NaCl)	Limestone Dolomite Chert Gypsum anhydrite
Organic	Calcium carbonate (animal remains) Carbon (plant remains)	Rock salt Coquina, some coral rock, and chalk Coal

Table B-4. Metamorphic Rocks

FOLIATED		
Texture	Rock	Characteristics
Coarse-grained	Gneiss	Streaked or banded; imperfectly foliated
Medium-grained	Schist	Well-foliated; splits easily; generally rich in mica
Fine-grained	Slate	Splits readily into smooth sheets
NONFOLIATED AND MASSIVE		
Mineral Content	Rock	Characteristics
Chiefly quartz	Quartzite	Hard and brittle
Chiefly calcite (or dolomite)	Marble	
Chiefly hydrous magnesium silicate	Some types of serpentine	Fairly soft; green

Table B-5. Generalized Rock Properties

Rock Type	RATINGS OF WORKING CHARACTERISTICS																								
	Abrasive-ness					Excavational Requirements					Permeability					Stability in Steep-walled Cuts					Roof Strength in Tunnels				
	A	B	C	D	E	a	b	c	d	e	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1. IGNEOUS																									
2. Intrusive																									
3. Extrusive																									
3a. Solidified																									
3b. Cemented																									
4. METAMORPHIC																									
5. SEDIMENTARY																									
6. Sandstone																									
7. Limestone																									
8. Shale																									
9. Evaporites																									
Rock Type	SUITABILITY FOR																								
	Compacted Subgrade					Dimension Stone					Road Metal					Bituminous Aggregate					Concrete Aggregate				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1. IGNEOUS																									
2. Intrusive																									
3. Extrusive																									
3a. Solidified																									
3b. Cemented																									
4. METAMORPHIC																									
5. SEDIMENTARY																									
6. Sandstone																									
7. Limestone																									
8. Shale																									
9. Evaporites																									

Modified from von Balow (Ref. 22)

Abrasive-ness (as it affects excavation tools and equipment):

- A. Extreme
- B. Severe
- C. Moderate
- D. Slight
- E. Nominal or none

Tools and procedures required to excavate rock:

- a. Spade and shovel
- b. Pick and shovel
- c. Pick, crowbar, and wedge
- d. Repeated drilling and blasting
- e. Almost continuous drilling and blasting

All other properties:

- 1. Excellent
- 2. Good
- 3. Adequate or fair
- 4. Poor or usable only in emergencies
- 5. Inadequate, unsuitable or absent

2.3 Soil Classification

Most soil classification systems are based on grain size analysis, with arbitrary limits of grain sizes set for different soil groups. These major soil categories are gravels and sands (coarse-grained soils), silts and clays (fine-grained), and organics. The percentage of each particular type (gravel, sand, silt, or clay) in a composite soil determines the classification of the soil. Some classification systems describe the identified soil constituents, and others determine the engineering properties of a soil.

Of the eight or more methods developed for classifying soils, three systems — Unified Soil Classification System, Agricultural Soil Classification System, and Geologic Soil Classification System — are the most commonly used.

2.3.1 UNIFIED SOIL CLASSIFICATION SYSTEM

This system, known as the USCS, classifies the physical properties of soil for engineering purposes (see Tables B-6, B-7, and Figure B-8). It lists eight groups of coarse-grained soils, six groups of fine-grained soils, and one group of organic soils.

Identification and classification are based upon grain size, mechanical analysis, plastic limit tests, and other physical properties.

2.3.2 AGRICULTURAL SOIL CLASSIFICATION SYSTEM

This system, known as USDA, classifies surface soils for agricultural purposes (Figure B-9). Based on physical properties and specific percentages of gravel, sand, silt, and clay in a composite soil, the potential agricultural productivity of a soil can be determined. The soil properties also reflect the influence of geologic processes, age, climate, vegetation, and topographic features. Figure 2 in the report lists the gradation limits of soil for use with Figure B-9.

2.3.3 GEOLOGIC SOIL CLASSIFICATION SYSTEM

This system is based upon the geologic origin of soils. The major divisions of residual and transported soils by landform features are glacial, fluvial (stream-laid), eolian (wind blown), lacustrine (water), littoral (shore), and volcanic.

The Wentworth Scale is used to classify a soil or rock by grain size gradation from boulders to fine-grained soils, as listed in Figure 2 in the report (Leet and Judson, 1965, p. 98).

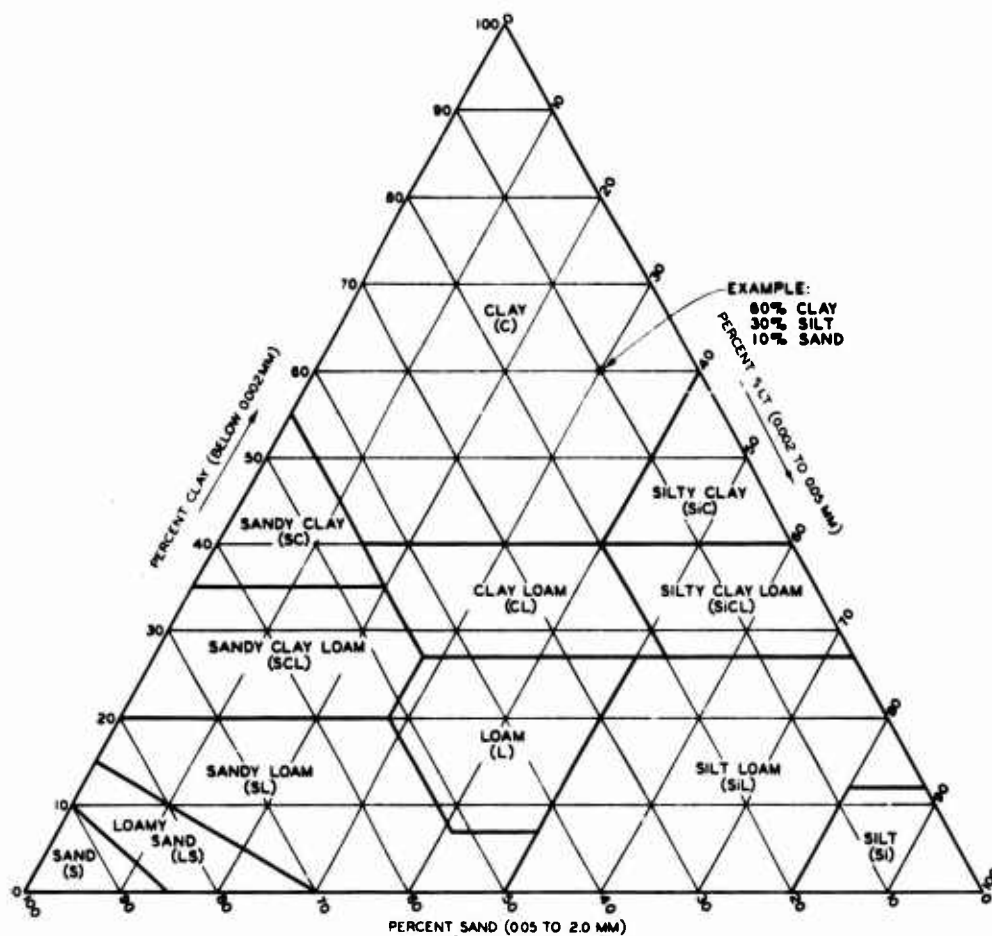


Figure B-9. USDA Soil Textural Classification

2.3.4 CORRELATION OF SOIL CLASSIFICATION SYSTEMS

With certain limitations, laboratory analysis of soil samples has shown that a general correlation exists between the USCS and USDA soil types (U. S. Army C.E.WES, TM 3-240, 16th Supplement). Of 1176 samples classified, many categories of the USDA Agricultural Soil Classification System can be correlated with the soil groups of the Unified Soil Classification System. The correlations range from 41 to 100 percent, the average being about 60 percent. See Table B-8. The grain size and soil groups of the USDA, USCS, and Wentworth systems are shown in Figure 2 in the report to be in close agreement.

Table B-8. Frequency of USDA Types Occurring as USCS Soil Types

		USCS Soil Type																Total %		n
		Coarse-Grained Soils With Fines						Fine-Grained Soils				Organic Soils								
		GW	GP	GM-W	GM	GM-FC	GC	SW	CL-ML	MH	CL	CH	OL	OH	Pt					
USDA Soil Type	Sand, Sols	S			4	1												100		
		n			21	1												46		
		L				1												100		
		n				1												57		
		CL†				1				4				2	2			100		
		n	1									1		5	4			207		
	CL	CL				11		2			1							100		
		n						1			1							29		
		CL									60							100		
		n																2		
	Clayey, Silty, and Heavy Soils	CL							11			1		3		4		100		
		n			1					1						1		161		
		CL							6	10	3	1		2	2	2		100		
		n							172	47	16	21				10		441		
		CL							1									100		
		n							1									11		
		CL									1		15			1		100		
		n									1		39			1		40		
	Organic Soils	SiCL							1	1	1	1	27			3		100		
		n							1	1	1	1	27			2		34		
		SiCL									24	1						100		
		n							1				1					21		
	Organic Soils	C							3		10	13	1					100		
		n							3		10	13	1					27		
	Organic Soils	Pt															1	100		
		n															1	1		
Total samples																			117	

n = Number of samples.

* = Less than 1%.

† = Prefixed with the term gravelly, silty, or stony for GM or GC soil types.

		Sample Interpretation
SiL	CL	45% of all SiL samples were CL. The sample indicates that a greater number of SiL samples occurred as CL than as any other USCS type. 215 samples were classified as SiL and CL.
	215	

3. BEARING STRENGTH OF TERRAIN AND SOIL.

An index of trafficability for most ground vehicles is the wet season characteristics of soil and generally trafficable vegetation as shown in Table B-9. Most dry soils and certain saturated fine-grained soils have a relatively high resistance to penetration, while many physical properties contribute to the bearing strength of a soil.

The primary determinant of bearing strength is the nature of the surface materials — its density, grain size and shape, moisture content, and vegetation — which are measured in standard engineering terms of the California Bearing Ratio applied to soil and rock strength. Moisture affects the strength of some soils severely (Figure B-10).

The distribution of soil-strength regions in the world (Figure B-11) show five qualitative divisions for trafficability conditions based on an interpretation and evaluation of Figures B-1, B-5, B-6, B-7, B-9, and B-10. The divisions are: (1) soft ground most of the time, (2) soft ground and firm ground alternating all year, (3) seasonality of soft and firm ground, (4) season of firm ground and season of alternating firm and soft ground, and (5) firm ground most of the time. About 78 percent of the land area of the world has a firm soil with a Rating Cone Index exceeding 60; 17 percent has a soft soil with a RCI of from 25 to 60; and 5 percent has a very soft soil with a RCI of less than 25.

3.1 California Bearing Ratio (CBR)

The California Bearing Ratio is the most reliable engineering test for measuring the shearing and traction resistance of a soil under controlled conditions of density and moisture (AFM 88-52, AFM 88-51, TM 5-541). Refer to Appendix C of this report for further information.

3.2 Terrain and Soil as Foundation Materials

For guidance in the design of major facilities and structures, an estimation of the maximum allowable loading values, in tons per square foot, is shown in Table B-10 for all types of rocks and soils (Aviation Egr. Force, 1956). These values vary from 1 ton PSF to over 40, but do not apply if the foundation is underlain by a weaker material. Controlled laboratory and field tests of representative samples obtained from the proposed site are always recommended prior to construction (AFM 88-52, p. 286).

Table B-9. Trafficability Characteristics of USCS Soils in Wet Season

Class	Soils	USCS Soil Type	Probable CI Range	Probable RI Range	Probable RCI Range	Slipperiness Effects	Stickiness Effects	Comments
A	Coarse-grained, cohesionless sand and gravels	GW, GP SW, SP	80 to 300	1	80 to 300	Slight to none	None	Will support continuous traffic of military vehicle tracks or with high tires. Moist sand dry sand only fair. Wheeled vehicles with standard tires may be immobilized in dry sands
E	Inorganic clays of high plasticity, fat clays	CH	55 to 165	0.75 to 1.35	65 to 140	Severe to slight	Severe to slight	Usually will support more than 50 passes of military vehicles. Going will be difficult at times
C	Clayey gravels, gravel-sand-clay mixture	GC	85 to 175	0.45 to 0.75	45 to 125	Severe to slight	Moderate to slight	Often will not support 40 to 50 passes of military vehicles, but usually will support unlimited traffic. Going will be difficult in most cases
	Clayey sand, sand-clay mixtures	SC						
	Gravelly clays, sandy clays, inorganic clays of low to medium plasticity, lean clays, silty clays	CL						
D	Silty Gravels, gravel-sand-silt mixtures	GM	85 to 180	0.25 to 0.85	25 to 120	Moderate to slight	Slight	Usually will not support 40 to 50 passes of military vehicles. Often will not permit even a single pass. Going will be difficult in most cases
	Silty sands, sand-silt mixtures	SM						
	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	ML and CL-ML						
	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH						
	Organic silts and organic silty clays of low plasticity	OL						
	Organic clays of medium to high plasticity, organic silts	OH						
E	Peats and mucks	Pt	10 to 100	0.25 to 0.65	10 to 85	Slight to none	Moderate to slight	Often will not permit even a single pass. Going will be difficult to impossible

Note: Taken from Trafficability of Soils, A Summary of Trafficability Studies Through 1955, TM No. 3-240, 14th Supplement, December 1956

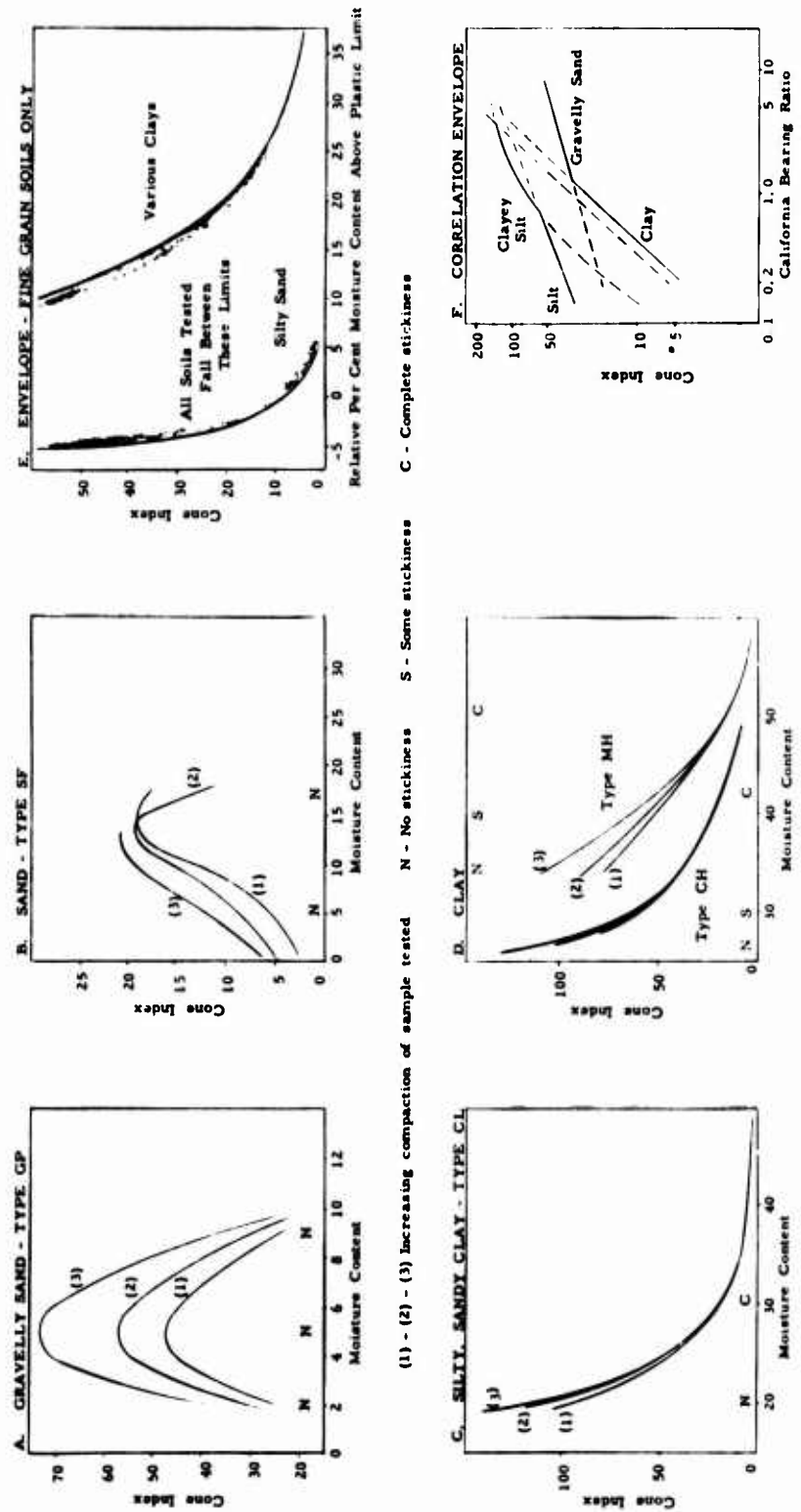


Figure B-10. Variation of Soil Strengths With Moisture Content and Correlation of Cone Index With California Bearing Ratio

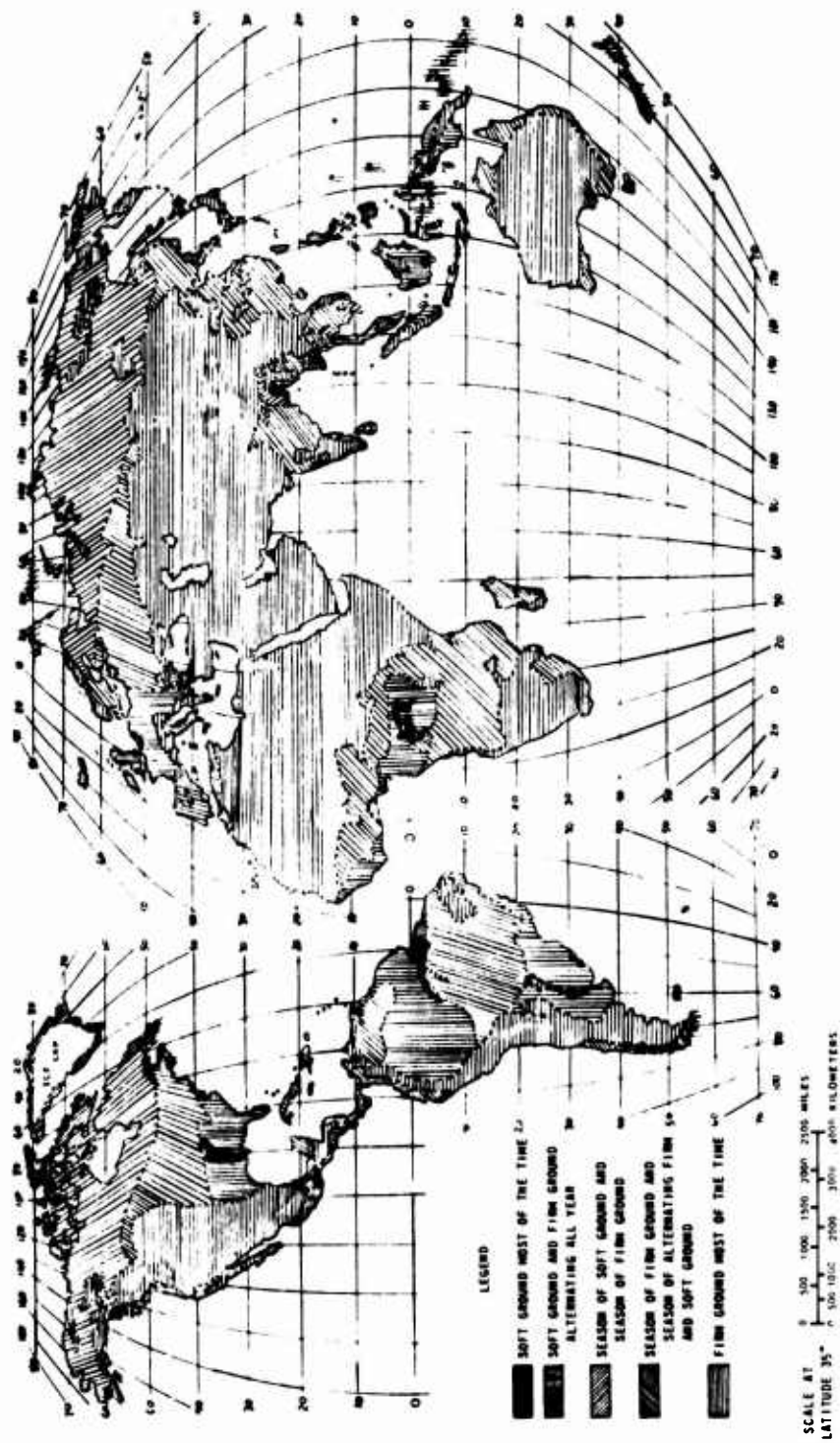


Figure B-11. Soil Strength Regions (World Distribution)

Table B-10. Allowable Pressures for the Design of Shallow Foundations

	Maximum allowable pressure, tons per square foot
Hard, sound rock	40+
Soft rock	8-10
Hardpan overlying rock	10-12
Compact gravel and boulder-gravel deposits; very compact sandy gravel	10
Loose gravel and sandy gravel; compact sand and gravelly sand; very compact inorganic sand-silt soils	5-6
Hard, dry, consolidated clay	5
Loose coarse to medium sand; medium compact fine sand	4
Compact sand-clay soils	3
Loose fine sand; medium compact inorganic sand-silt soils	2
Firm or stiff clay	1.5-2
Loose saturated sand-clay soils; medium soft clay	1

Note. Values are not applicable if foundation soil is underlain by a weaker soil. Use of the tabular values for the design of shallow foundations of major structures is not recommended unless their use is justified by experience or additional investigation.

Appendix C

Data Acquisition and Representative Applied Processing

1. INTRODUCTION

Terrain data acquired by either the contact, non-contact, or indirect method can be digitized conveniently to characterize the factor groups and their subclasses. This permits their amenability to computer system programming (processing, storage, retrieval, analysis, and presentation phases). In data processing terms, the application (that is, the specifications of proposed use of the terrain being evaluated) and the terrain factors (designators) constitute the input; the result of their interaction is the evaluation model; and the measure of predicted performance under a given set of environmental conditions is the output. The description of the tests, nomenclature of equipment, and computer models of specific cases are beyond the scope of this report. The computer approach is applicable to a broad spectrum of military uses.

2. CONTACT METHOD

The field measurement of all terrain factors and their subclasses is done with standard testing and sampling equipment and by procedures that are described in detail in the literature. Some new equipment used is described in Section 5 below.

With the contact method, each critical value of the specified terrain factor and its subclass at the surface and subsurface is measured and mapped precisely for total data quantification. Such data can be used directly for computerized storage or applied to the model of the required use. The data also can serve as ground controls and clues to the non-contact imagery.

3. NON-CONTACT METHOD

Remote sensing of the terrain environment yields largely qualitative but some semi-quantitative information. Figure 10 in the report indicates the type of sensors used and the extensive instrumentation necessary for acquiring and interpreting the data. These sensors are aerial photography in the ultraviolet, visible, and infrared; radar; radio waves; and instrumentation in air-drop devices. The references on remote sensing are numerous; the reader is referred to a selected list in the bibliography under a special heading, Remote Sensing Publications.

4. INDIRECT METHOD

The indirect method of terrain-data acquisition is often employed to estimate the critical terrain factor class values. Highly trained individuals can infer, evaluate, and predict terrain characteristics and expected performance of a military activity through analysis of data acquired by this method.

This method utilizes standard photographic and photogrammetric devices, data obtained from the contact and non-contact methods, library source data, and the skills of regional, scientific, and technical specialists.

5. DEVICES FOR MEASURING BEARING STRENGTH OF TERRAIN PROFILE

The terrain factor subclass affecting the trafficability and load-bearing capacity of a soil is its shear strength. Although vegetation and its root structure, interbedded rock and gravel, and other terrain properties influence its strength, the measured shearing resistance of a soil mainly indicates its degree of ability to support military air and ground operations, such as aircraft and vehicular trafficability.

5.1 Cone Penetrometers

Several types of penetrometers have been developed to measure the soil shearing and traction resistance for the trafficability evaluation of unsurfaced areas (TM 3-240, Supp. 1; USA WES Landing Strip Evaluation, 1952). In Figure C-1, penetrometer measurements of fine-grained soils, in units of cone index, are conservatively correlated with CBR criteria of specific calibrated soil types.

Vehicle and aircraft trafficability and other requirements for composite or single-soil load-bearing strengths are based upon direct CBR or CBR-equivalent values (Figure C-2). Further refinement of CBR-equivalent correlations of penetrometer index values for different soils will narrow the deviation from directly measured CBR data (Molineux, 1955; USA WES Misc. Paper 4-101).

Variation of soil strength with moisture content and correlations of cone index of selected classified soil types with CBR-equivalents are illustrated in Figures B-10 and C-1. The cone index shown in the curves refers to the Army Engineer proving ring penetrometer criteria, unless otherwise designated as the tension spring model.

5.1.1 SHEAR STRENGTH CONE INDEX

Any air-drop or ground cone penetrometer measures the cone index, and this measurement is correlated with the California Bearing Ratio (CBR) by soil type, as classified by the USCS System, to obtain CBR-equivalent units.

Basically, a penetrometer is a bearing-strength measuring device consisting of a 30-deg circular cone mounted on the end of a steel shaft; the cone normally has a base end area of 0.5 sq in. The force required for the cone to penetrate the ground surface is indicated on a dial or on an engraved scale. Generally, air-drop models are previously calibrated to shear a pin of known cone index. The use and design of the penetrometer (proving ring) and related test equipment, including the manual, linear, coiled-tension-spring model (150- and 300-lb models) are completely described in AFM 88-51, p. 93. The proving ring model has a dial ranging from 0 to 300 (Figure C-3). The value 300 occurs under a force of 150 lb. The spring model is read directly in pounds of force, with a maximum limit of 300 lb (Figure C-4).

Air-drop devices are treated in Chapter III, Remote Sensing.

5.1.2 AUTOMATIC RECORDING CONE PENETROMETER

An automatic recording model based on the original 300-lb spring-load design model was developed by Air Force Cambridge Research Laboratories and is

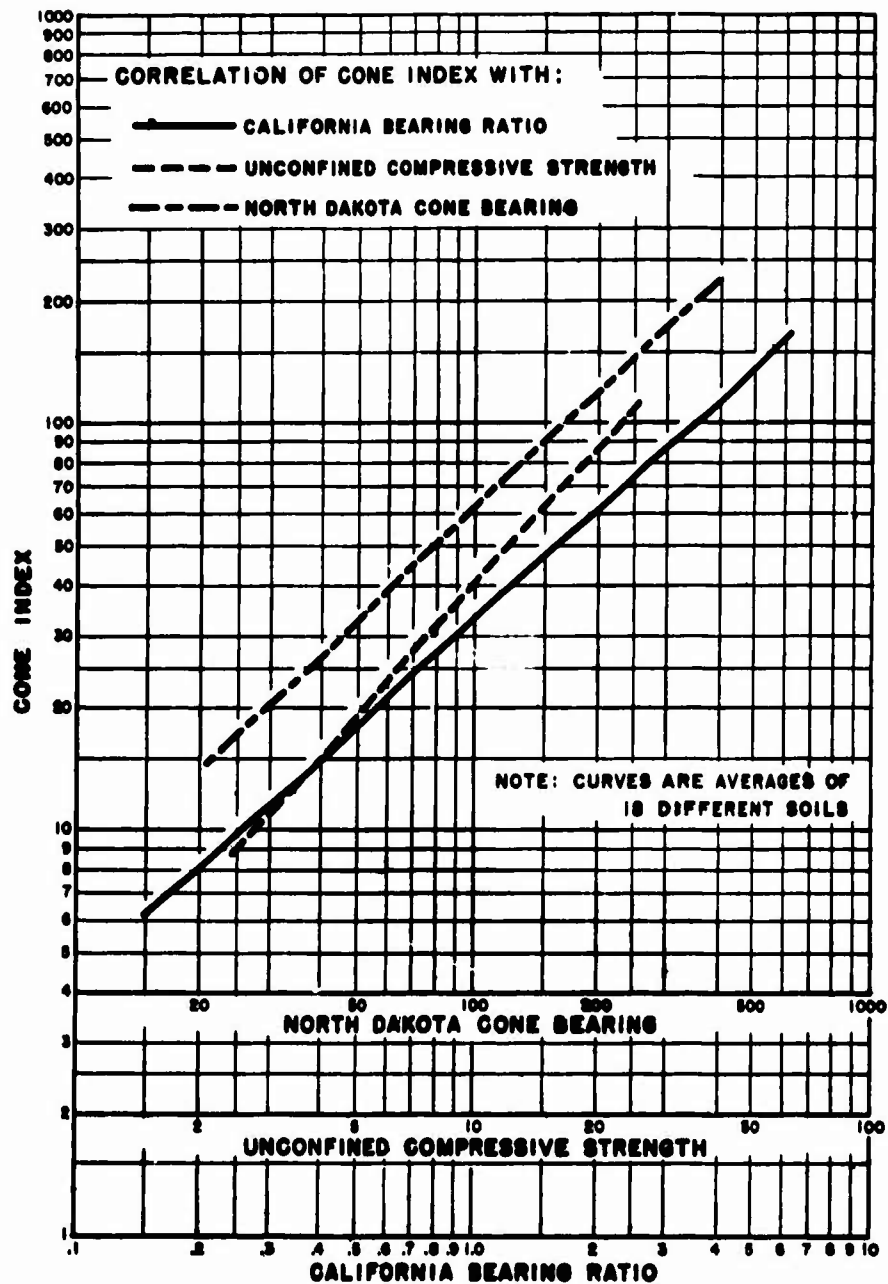


Figure C-1. Relation of Cone Index to California Bearing Ratio, Unconfined Compressive Strength, and North Dakota Cone Bearing Strength

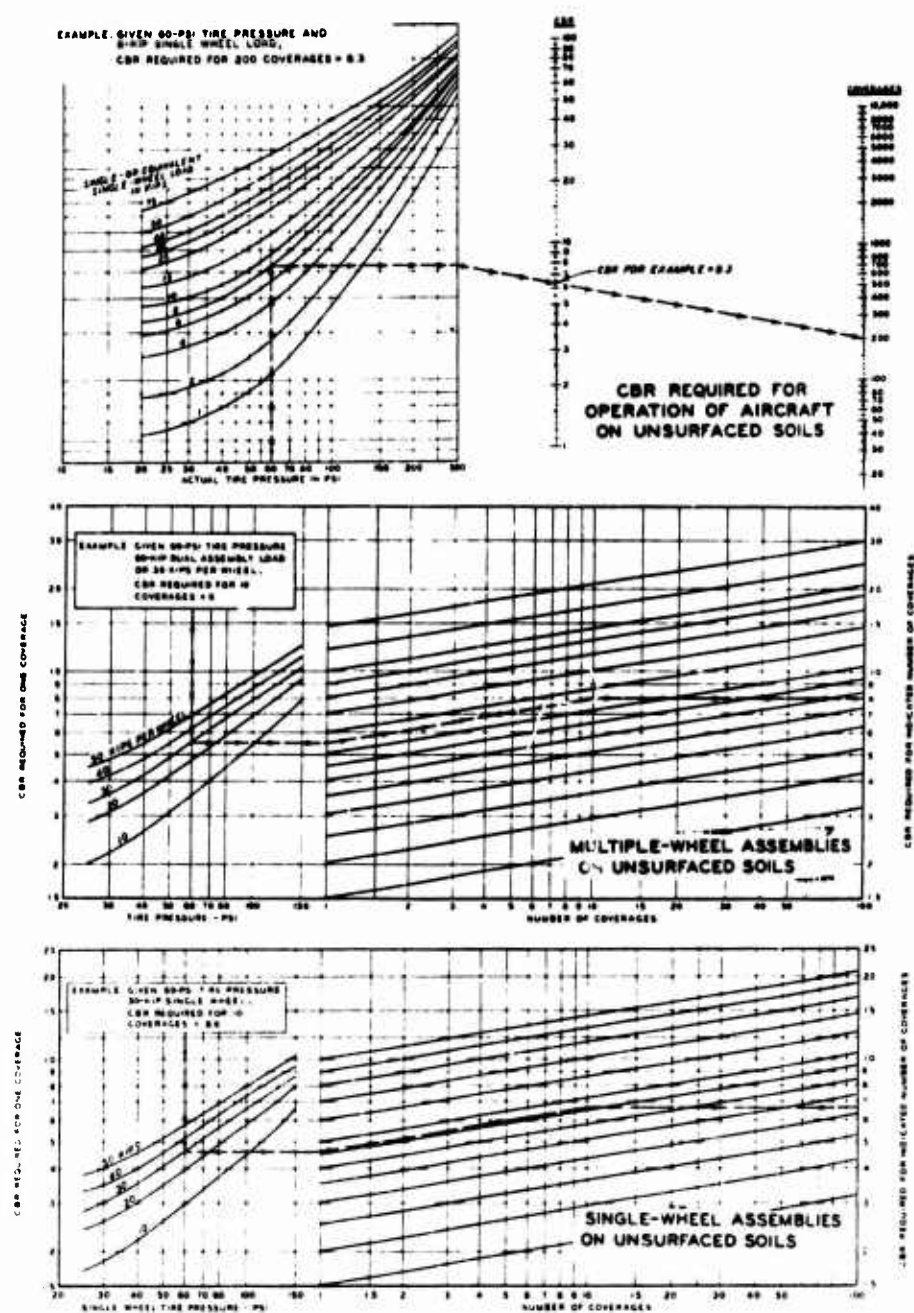


Figure C-2. California Bearing Ratio Required for Operation of Aircraft on Unsurfaced Soils by Wheel Load, Tire Pressure, and Traffic in Coverages

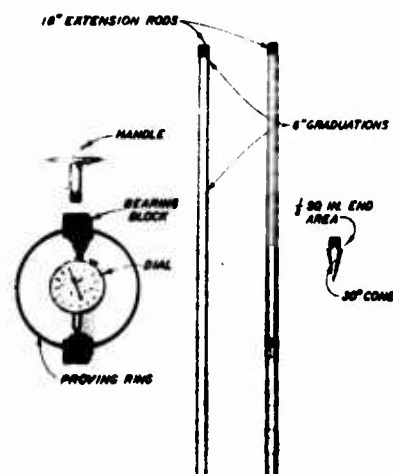


Figure C-3. Proving Ring Manual Cone Penetrometer

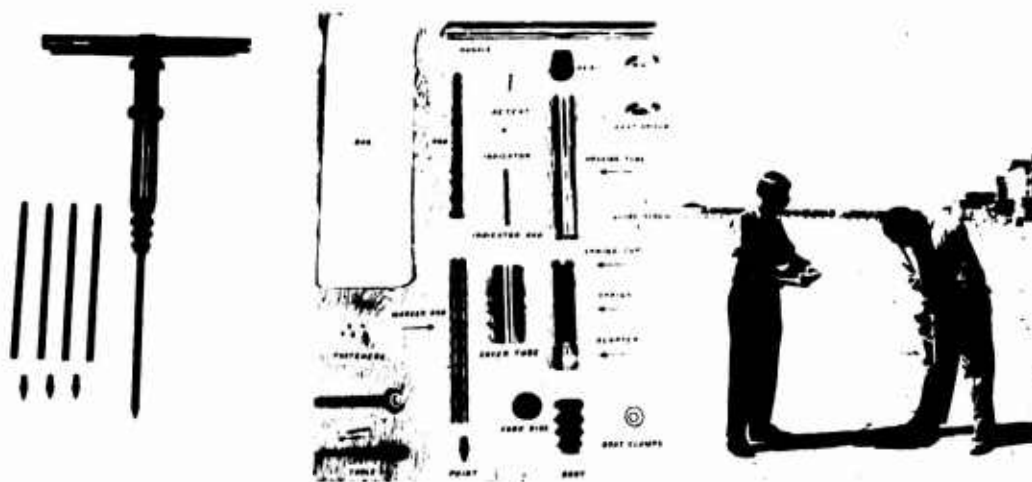


Figure C-4. AFCRL Tension Spring Manual Cone Penetrometer

shown in Figure C-5. It incorporates all the features of the AFCRL manual air-field penetrometer, in addition to having the capability of recording and providing strength-thickness information automatically and immediately. The most important improvement is that the maximum soil load-bearing-strength measurement has been extended to a CBR (equivalent) of over 70. An added feature is that this instrument can be operated in darkness.

This model retains the standard 30-deg cone tip mounted on a 20-in.-long, 7/16-in. shaft. A spring-loaded chain-drive action is proportional to the load applied to the cone. A maximum of 600 lb is designed for the spring load. Dual cranker levers drive the rod-mounted cone into the soil. Data are rapidly obtained as a permanent record. The instrument can be operated by non-professional personnel.

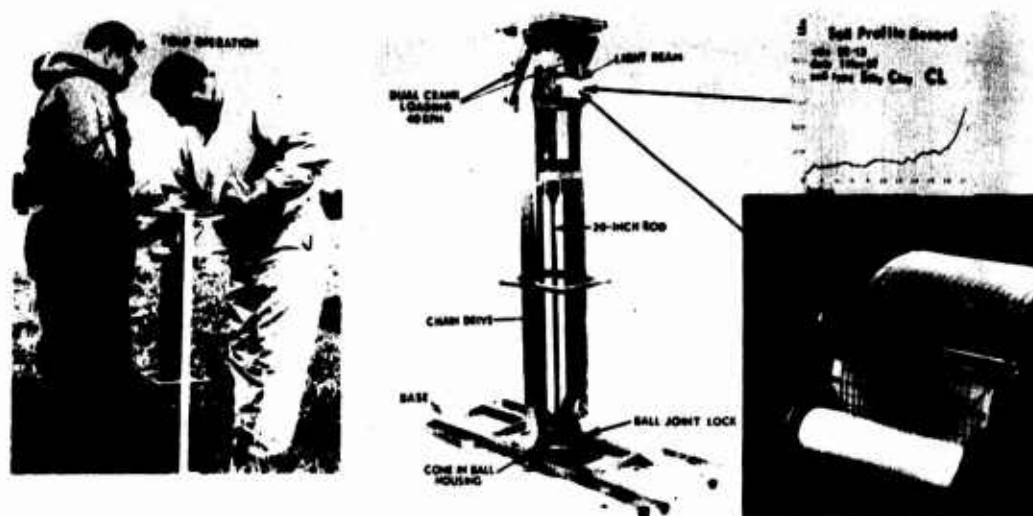


Figure C-5. AFCRL Automatic Recording Cone Penetrometer (600 lb Model)

6. MATRIX DESIGNATOR METHOD

A class value coding system of digitized terrain parameters (matrix groups) can be used to describe an area of interest for military operations. Within each matrix group, the associated parameters are sub-divided into classes to designate the characteristic features in terms of the primary and secondary parameter groups, depending upon the application. Matrix coding can be increased to characterize complex terrain conditions more accurately. The system permits the flexibility for extending parameter limits, modifying categories, and adding new parameters.

6.1 Matrix Composition

Each matrix group is composed of several classes selected to meet the requirements for terrain information. A single terrain factor is divided into a number of matrix class ranges with an assigned class designator in an arrangement of sequential coding (Bredhal and Kiefer, 1957, p. 40).

6.2 Description of Natural Unprepared Landing Surface by Matrix Format

The system for describing landing areas establishes a minimum of five matrix groups, each of which is described by a class-designator code for the selected related factors. These groups and subclasses, as summarized in Tables C-1 to C-7, are suitable for describing any area in a global terrain environment.

Table C-1. Terrain Matrix Classes of Landing Areas

Matrix	Parameter Group	Parameter Subclass	Class Designator Code	Table of Class Designators
Group I (3 Digits)	Landing Area	Length (Ft) Width Slope (Deg) Length Slope (Deg)	1st & 2nd Digits 3rd Digit 4th Digit	Table C-2
Group II (3 Digits) 1st Group Designator Code	Terrain Surface	Primary Undulation ¹ Height	1st Digit	Table C-3
		Primary Undulation Slope	2nd Digit	
		Primary Undulation Spacing	3rd Digit	Table C-4
		Type of Undulation	Subscript Letter	
2nd Group Designator Code		Secondary Undulation Height	1st Digit	
		Secondary Undulation Slope	2nd Digit	
		Secondary Undulation Spacing	3rd Digit	
		Type of Undulation	Subscript Letter	
3rd Group	If warranted for Complete Classification			
Group III (2 Digits) 1st Group Designator Code	Surface Roughness (Obstacle)	Primary Obstacle Height	1st Digit	Table C-5
		Primary Obstacle Spacing	2nd Digit	
		Type of Obstacle	Subscript Letter	
2nd Group Designator Code		Secondary Obstacle Height	1st Digit	
		Secondary Obstacle Spacing	2nd Digit	
		Type of Obstacle	Subscript Letter	
3rd Group Designator Code	If warranted for Complete Classification			
Group IV (4 Digits)	Soil Type and Bearing Strength	Soil Type (USCS) Bearing Strength Dust, Ice, Snow, Water Conditions	1st & 2nd Digit 3rd & 4th Digit Subscript Letter	Table C-6
Group V (3 Digits)	Utilization	Type of Aircraft Trafficability	1st & 2nd Digit 3rd Digit	Table C-7

¹ Negative undulations below horizontal reference plane have minus sign.

Table C-2. Matrix I - The Landing Area

AREA LENGTH (1st and 2nd Digits - Matrix I)		WIDTH SLOPE (3rd Digit - Matrix I)	
Class Designator	Actual Length Available (feet)	Class Designator	Width Slope (Degrees)
00	> 10000	0	0 - 2
01	8000 - 10000	1	2 - 4
02	6500 - 8000	2	4 - 6
03	5000 - 6500	3	6 - 9
04	4000 - 5000	4	9 - 12
05	3000 - 4000	5	12 - 15
06	2500 - 3000	6	15 - 20
07	2000 - 2500	7	20 - 30
08	1500 - 2000	8	30 - 45
09	1000 - 1500	9	> 45
10	900 - 1000	LENGTH SLOPE (4th Digit - Matrix I)	
11	800 - 900	Class Designator	Length Slope (Degrees)
12	700 - 800	0	0 - 2
13	600 - 700	1	2 - 4
14	500 - 600	2	4 - 6
15	400 - 500*	3	6 - 9
16	300 - 400*	4	9 - 12
17	200 - 300*	5	12 - 15
18	100 - 200*	6	15 - 20
19	50 - 100*	7	20 - 30
		8	30 - 45
		9	> 45

Note - The Parameter Categories are read: from and including the shorter length and up to but not including the longer length or greater slope.

* These dimensions may be considered as area diameters unless a width limitation is indicated.

Table C-3. Matrix II - The Surface Configuration

UNDULATION HEIGHT (1st Digit - Matrix II)		UNDULATION SLOPE (2nd Digit - Matrix II)		UNDULATION SPACING (3rd Digit - Matrix II)
Class Designator	Height (Inches or feet as indicated)	Class Designator	Slope (Degrees)	Center-to-Center Distance*
0	< 3"	0	0 - 2	*See Table C-4.
1	3" - 6"	1	2 - 4	
2	6" - 12"	2	4 - 6	
3	12" - 18"	3	6 - 10	
4	18" - 24"	4	10 - 15	
5	2' - 5'	5	15 - 20	
6	5' - 10'	6	20 - 30	
7	10' - 25'	7	30 - 45	
8	25' - 50'	8	45 - 60	
9	50' - 100'	9	60 - 90	

Note - The parameter categories are read: from and including the lesser, and up to, but not including, the greater height or slope.

Descriptive Subscript Legend

- C - Small Stream or Creek
- D - Ditch or Embankment (cultural rather than natural formations)
- E - Erosion Gullies (natural rather than cultural formations)
- H - Holes (irrespective of how formed)
- M - Mounds
- P - Plowed, tilled or cultivated furrows
- R - Roads
- S - Sand Dunes or Sand Ripples
- W - Undulations parallel to width
- L - Undulations parallel to length

Table C-4. Matrix IIA - Center to Center Spacing

(USE IN CONJUNCTION WITH TABLE C-3)									
CENTER-TO-CENTER SPACING AND CLASS DESIGNATORS FOR UNDULATION HEIGHT CATEGORIES									
UNDULATION SPACING FOR HEIGHT CLASS (0) (less than 3 inches height)		UNDULATION SPACING FOR HEIGHT CLASS (1) (3 - 6 inches height)		UNDULATION SPACING FOR HEIGHT CLASS (2) (6 - 12 inches height)		UNDULATION SPACING FOR HEIGHT CLASS (3) (12 - 18 inches height)		UNDULATION SPACING FOR HEIGHT CLASS (4) (18 - 24 inches height)	
Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)
0	> 10	0	> 250	0	> 500	0	> 750	0	> 1000
1	8 - 10	1	100 - 250	1	250 - 500	1	500 - 750	1	750 - 1000
2	6 - 8	2	50 - 100	2	100 - 250	2	250 - 500	2	500 - 750
3	5 - 6	3	25 - 50	3	50 - 100	3	100 - 250	3	250 - 500
4	4 - 5	4	10 - 25	4	25 - 50	4	50 - 100	4	100 - 250
5	3 - 4	5	5 - 10	5	10 - 25	5	25 - 50	5	50 - 100
6	2 - 3	6	3 - 5	6	5 - 10	6	10 - 25	6	25 - 50
7	1 - 2	7	2 - 3	7	2 - 5	7	5 - 10	7	10 - 25
8	0.5 - 1	8	1 - 2	8	1 - 2	8	2 - 5	8	3 - 10
9	< 0.5	9	< 1	9	< 1	9	< 2	9	< 3
UNDULATION SPACING FOR HEIGHT CLASS (5) (2 - 5 feet height)		UNDULATION SPACING FOR HEIGHT CLASS (6) (5 - 10 feet height)		UNDULATION SPACING FOR HEIGHT CLASS (7) (10 - 25 feet height)		UNDULATION SPACING FOR HEIGHT CLASS (8) (25 - 50 feet height)		UNDULATION SPACING FOR HEIGHT CLASS (9) (50 - 100 feet height)	
Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)	Class Designator	C-to-C Distance (feet)
0	> 2500	0	> 2500	0	> 2500	0	> 2500	0	> 2500
1	1000 - 2500	1	1500 - 2500	1	2000 - 2500	1	2000 - 2500	1	2000 - 2500
2	500 - 1000	2	1000 - 1500	2	1500 - 2000	2	1500 - 2000	2	1750 - 2000
3	250 - 500	3	500 - 1000	3	1000 - 1500	3	1250 - 1500	3	1500 - 1750
4	100 - 250	4	250 - 500	4	750 - 1000	4	1000 - 1250	4	1250 - 1500
5	50 - 100	5	100 - 250	5	500 - 750	5	750 - 1000	5	1000 - 1250
6	25 - 50	6	50 - 100	6	250 - 500	6	500 - 750	6	750 - 1000
7	10 - 25	7	25 - 50	7	100 - 250	7	250 - 500	7	500 - 750
8	6 - 10	8	12 - 25	8	50 - 100	8	100 - 250	8	200 - 250
9	< 6	9	< 12	9	< 50	9	< 100	9	< 200

Table C-5. Matrix III - The Surface Roughness (Obstacles)

OBSTACLE HEIGHT (1st Digit - Matrix III)		OBSTACLE SPACING (2nd Digit - Matrix III)	
Class Designator	Height (Inches or Feet as Indicated)	Class Designator	Edge to Edge Distance (Inches or Feet as Indicated)
0	< 3"	0	> 1000'
1	3" - 5"	1	500' - 1000'
2	5" - 7"	2	100' - 500'
3	7" - 9"	3	50' - 100'
4	9" - 12"	4	25' - 50'
5	12" - 18"	5	10' - 25'
6	18" - 36"	6	3' - 10'
7	3' - 6'	7	1' - 3'
8	6' - 10'	8	6" - 12"
9	> 10'	9	< 6" (Very dense)

Note - The Parameter categories are read: From and including the first number, to but not including the second number (heights and spacings).

Descriptive Subscript Legend

- B - Bushes

C - Cultivated Crops

D - Tree Stumps

F - Fence

M - Transient man-made obstructions (Haystacks, etc.)

P - Permanent man-made obstructions (Buildings, Power Lines, etc.)

R - Rocks (Imbedded as opposed to loose)

S - Stones (Loose surface rocks)
- G - Grasses

T - Trees

H - Hedges

Table C-6. Matrix IV - Soil Description and Bearing Capacity

SOIL BEARING CAPACITY (1st and 2nd Digits - Matrix IV)		SOIL CLASSIFICATION (3rd and 4th Digits - Matrix IV)	
Class Designator	California Bearing Ratio	Class Designator	Soil Description and Group Symbol (Unified Soil Classification)
00	> 20	00	(GW) Group - Gravel, Sand Mixtures, Well Graded
01	15 - 20	01	(GP) Group - Gravel, Sand Mixtures, Poorly Graded
02	12 - 15	02	(GM) Group - Silt, Sand, Gravel Mixtures
03	10 - 12	03	(GC) Group - Clayey Gravels
04	9 - 10	04	(SW) Group - Well Graded Sands
05	8 - 9	05	(SP) Group - Poorly Graded Sands
06	6.5 - 8	06	(SM) Group - Silty Sands
07	5.5 - 6.5	07	(SC) Group - Clayey Sands
08	4.5 - 5.5	08	(ML) Group - Inorganic Silts
09	3.5 - 4.5	09	(CL) Group - Inorganic Clays
10	2.0 - 3.5	10	(OL) Group - Organic Silts
11	1.5 - 2.0	11	(MH) Group - Inorganic Elastic Silts
12	1.0 - 1.5	12	(CH) Group - Inorganic Clays, High Plasticity
13	0.5 - 1.0	13	(OH) Group - Organic Clay and Silt, High Plasticity
14	< 0.5	14	(Pt) Group - Peat and Highly Organic Soils

Table C-7. Matrix V - Aircraft Trafficability

Type of Aircraft (1st and 2nd Digits - Matrix V)		Trafficability (3rd Digit - Matrix V)	
Class Designator	Aircraft Series	Class Designator	Category Criteria ¹
00	C-7A	0	Safe with landing mat on surface
01	C-47	1	Safe with stabilized soil
02	C-54	2	Remove obstacles
03	C-118	3	Minor grading
04	C-130	4	Major construction effort
05	C-133	5	Divert drainage
06	C-135	6	Unsafe
07	C-141	7	Hazardous weather
08	B-47	8	Prevailing cross-wind
09	B-52	9	Long periods of ice and snow
10	B-58		
11	F-86		
12	F-89		
13	F-100		
14	F-101		
15	F-102		
16	F-104		
17	F-105		
18	F-106		
19	F-4		
20	F-5		

¹ Subscript: Category Criteria of Operations
 Full (F) 2000 Coverages
 Minimum (M) 700 Coverages
 Emergency (E) 40 Coverages
 Single Cycle (1 Takeoff and 1 Landing) (S)
 Dust

6.2.1 TERRAIN MATRIX DESIGNATOR

The codes of the factors and subclasses by matrix group form the respective matrix group designators. The Simple Terrain Matrix Designator, comprised of the five matrix groups, as illustrated in Figure C-6, indicates the following assumed landing area described in minimum detail as 0311-112-145-0904-035:

<u>Matrix Group I</u>	(Matrix Group Designator: <u>0311</u>)
Length: 500-6500 ft	(1st and 2nd Digits: 03XX)
Width Slope: 0-2 deg	(3rd Digit: XXIX)
Length Slope: 2-4 deg	(4th Digit: XXXI)
<u>Matrix Group II</u>	(Matrix Group Designator: <u>112</u>)
Undulation Height: 3-6 in.	(1st Digit: IXX)
Undulation Slope: 2-4 deg	(2nd Digit: X4X)
Undulation Spacing: 50-100 ft	(3rd Digit: XX2)
<u>Matrix Group III</u>	(Matrix Group Designator: <u>145</u>)
Obstacle Height: 3-5 in.	(1st Digit: IXX)
Obstacle Spacing: 25-50 ft	(2nd Digit: X4X)
Obstacle Type: Loose Stones	(3rd Digit: XXS)
<u>Matrix Group IV</u>	(Matrix Group Designator: <u>0904</u>)
Soil Type: Inorganic Clay, Type Cl.	(1st and 2nd Digits: 09XX)
Soil Strength: CBR 9-10	(3rd and 4th Digits: XX04)
<u>Matrix Group V</u>	(Matrix Group Designator: <u>035</u>)
Type of Aircraft: C-130	(1st and 2nd Digits: 03X)
Trafficability: Operational	(3rd Digit: XX5)

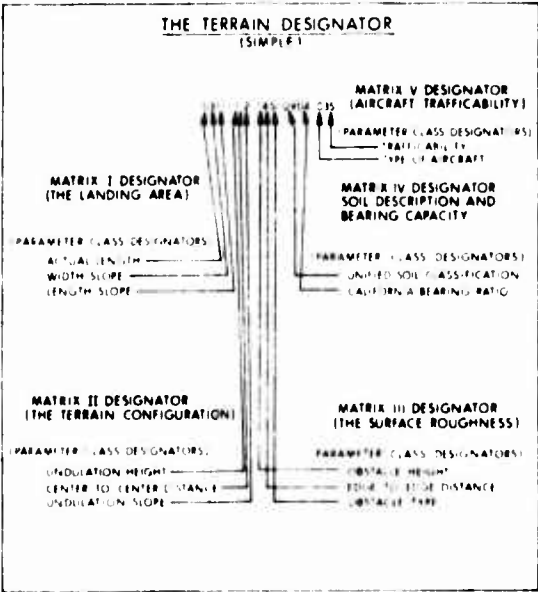


Figure C-6. Simple Terrain Matrix Designator

6.2.1.1 Complex Terrain Matrix Designator

Varying conditions cause the designator to become more complex as additional information is incorporated into the description. Figure C-7 is an example of a more detailed designator that could be applied to the additional data listed below:

$$\begin{array}{r} 0311 \\ \hline 250 \end{array} - \begin{array}{r} 112 \\ 232M \\ \hline -598E \\ 3 \end{array} \quad \begin{array}{r} 14S \\ 06R \\ 47B \end{array} - \begin{array}{r} 0904 \\ \hline 10 \end{array} - \begin{array}{r} 035 \\ \hline 65 \end{array}$$

Matrix Group I

$$\begin{array}{r} \text{Width Limitation} \qquad \qquad \qquad 250 \text{ ft} \qquad \qquad \qquad \frac{1}{250} \end{array}$$

Matrix Group II

$$\begin{array}{l} \text{Tertiary Undulations (Positive and Negative)} \\ \text{Mound (positive)} \\ \quad 6 - 12 \text{ in. high, } 6 - 10 \text{ deg slopes spaced } 100\text{-}250 \text{ ft apart} \\ \text{Erosion Gully (Negative)} \\ \quad 2 - 5 \text{ ft deep, } 60 - 90 \text{ deg slope depressions} \\ \quad \text{Spaced } 6 - 10 \text{ ft apart, and representative width of } 3 \text{ ft} \end{array} \quad \begin{array}{r} 232M \\ \hline -598E \\ 3 \end{array}$$

Matrix Group III

$$\begin{array}{l} \text{Obstacles (Rocks)} \\ \quad \text{Less than } 3 \text{ in. and spaced } 3 - 10 \text{ ft} \\ \text{Obstacles (Vegetative)} \\ \quad \text{Bushes } 9 - 12 \text{ in. and spaced } 1 - 3 \text{ ft} \end{array} \quad \begin{array}{r} 06R \\ \\ 47B \end{array}$$

Matrix Group IV

$$\begin{array}{r} \text{Soil Moisture} \qquad \qquad \qquad \text{Less than } 10 \text{ percent} \qquad \qquad \qquad \frac{1}{10} \end{array}$$

Matrix Group V

$$\begin{array}{l} \text{Period of Operation} \\ \quad \text{Number of months of year} - 6 \\ \quad \text{Subscript for first usable month of operation} - 5 \end{array} \quad \begin{array}{r} 1 \\ \hline 65 \end{array}$$

7. MATRIX DESCRIPTION OF REPRESENTATIVE TERRAIN

Two small areas of terrain in Hart County, Kentucky, were selected as examples for the application of the proposed method of quantifying the trafficability characteristics at each location. The first case example described with the aid of an aerial stereophotographic view by a Simple Terrain Designator (0921 705L 94T 0907 035), depicts conditions suitable for landing a C-130 aircraft or smaller. A secondary Matrix V class designator may be added for equivalent vehicular traffic or other uses (Figure C-8).

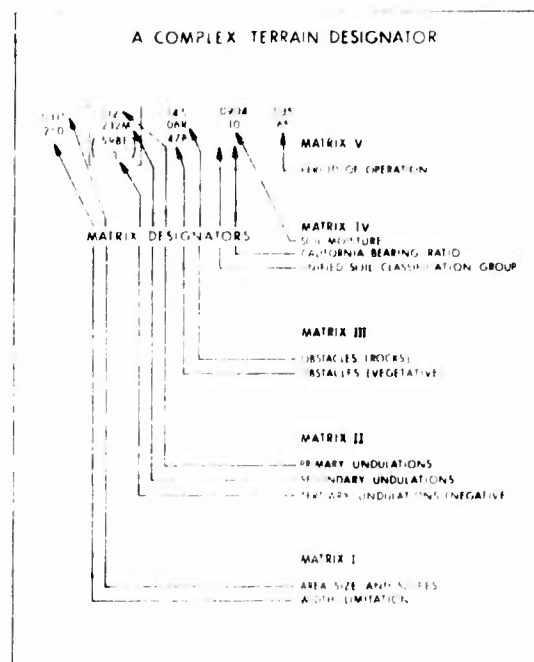
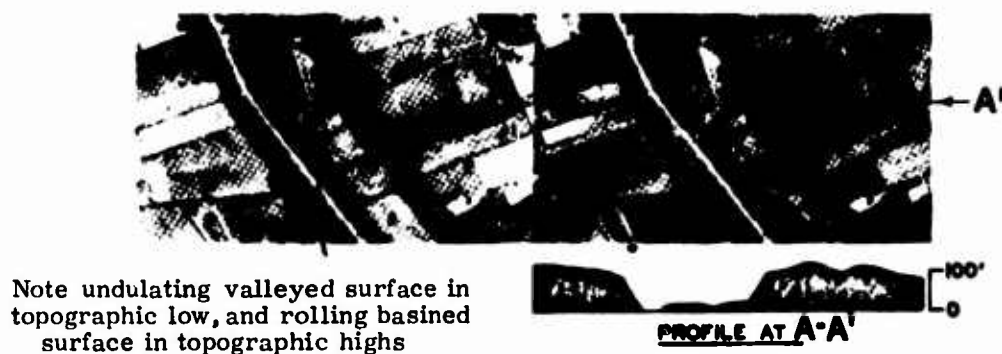


Figure C-7. Complex Terrain Matrix Designer

The second case example, also shown in a similar stereophotographic view, is a Complex Terrain Designator $\frac{0902}{368}$ 717 WC 61T 0906 $\frac{035}{65}$ that describes in more detail the capability of the terrain to support particular categories of aircraft and vehicular traffic (Figure C-9). Topographic cross-section profiles are inserted below each stereopair for ease in visualizing the microrelief along the cross profiles in both areas.

Table C-8 tabulates the many related important trafficability characteristics of Hart County, Kentucky, which includes Areas A and B. They are bearing strength, surface features, vegetation, and hydrology. Climate and weather of the area were classified under the Köppen System; they are: Cfa, which denotes warm temperature climate (C), sufficient precipitation in all months (f), and warmest month mean over 71.6°F or 22°C (a).

The trafficability units of Area A (see Table C-8) are largely 1'a followed by 4' and 2'b in progressively minor occurrence. The units of Area B are 1'a, 1'b, and 2'a in a similar order.



Stereophotography of Valley and Basin Area, Hart County, Kentucky;
Scale 1:20,000, Date: 28 August 1958 (Photo is Courtesy of U. S. Army
Engineer Waterways Experiment Station, TM 3-331, Report 6, Vol. II)

Terrain Designator (Simple) Area A

[0921 705L 94T 0907 035]

Matrix Group I		
(Length) 10/16"	1050'	09
(Width Slope) ⁰	4 - 6 ⁰	2
(Length Slope) ⁰	0 - 2 ⁰	1
(0921)		
Matrix Group II		
(Undulation Height)	20'	7
(Undulation Slope)	0 - 20 ⁰	0
(Center to Center Distance)	624'	5
(Undulations Parallel to Length)		L
(705L)		
Matrix Group III		
(Obstacle Height)	20'	9
(Obstacle Spacing)	25 - 50'	4
Trees	T	
(94T)		
Matrix Group IV		
(Soil Classification)	CL-ML	09
(Bearing Strength)	Rating Cone Index - 120	07
	CBR Equivalent 5.5 - 6.5	
(0907)		
Matrix Group V		
(Type of Aircraft)	C-130	03
(Trafficability)		5
(035)		

Figure C-8. Terrain Matrix Designator, Area A, Hart County, Kentucky



Stereophotography of Undulating Basin, Hart County, Kentucky;
Scale 1:20,000, Date: 28 August 1958 (Photo is Courtesy of U. S. Army
Engineer Waterways Experiment Station, TM 3-331, Report 6, Vol.II)

Terrain Designator (Complex) Area B

$$\left[\left(\frac{0902}{368} \right) 717WC \ 61T \ 0906 \left(\frac{035}{65} \right) \right]$$

Matrix Group I

(Length) 13/16"	1365'	09
(Width Slope)	0 - 2°	0
(Length Slope)	4 - 6	2
Actual Width	368'	
	$\left(\frac{0902}{368} \right)$	

Matrix Group II

(Undulation Height)	20'	7
(Undulation Slope)	2 - 4°	1
(Center to Center Distance)	1/16" - 105'	7
W (Undulations Parallel to Width)	(717WC)	

Matrix Group III

(Obstacle Height)	10'	6
(Obstacle Spacing)	100' - 500'	1
Trees	T	
	(61T)	

Matrix Group IV

(Soil Classification)	CL-ML	09
(Bearing Strength)	Rating Cone Index - 140	06
	CBR Equivalent 6.5 - 8	
	(0906)	

Matrix Group V

(Type of Aircraft)	C-130	03
(Trafficability)		5
Period of Operation	6 Months	
	Commencing in May	
	$\left(\frac{035}{65} \right)$	

Figure C-9. Terrain Matrix Designator, Area B, Hart County, Kentucky

Table C-8. Terrain Trafficability Characteristics of Areas in Hart County, Kentucky

Region 1/ Topo- graphic Highs	Rating Cone Index*		Slopes, % Characteristic Maximum	Surface Characteristics**			Traverse† in miles	"Stepped" Surface	Trees††	Shrubs†	Hydro- graphic Character- istics‡‡
	Topo- graphic Lows	Topo- graphic Highs		Ditches	Cut and Fill Banks	Gullies					
1'a	125	125	<20	a	b	d	0.4	e	D	C	2
1'b	125	125	<20	c	c	d	0.5	c	B	B	2
2'a	120	120	<30	b	b	d	0.3	e	C	C	2
2'b	120	120	<50	c	c	d	0.4	a	B	B	1
3'a	140	45	<30	b	b	b	0.3	d	C	C	2
3'b	140	45	<40	c	c	c	0.4	a	A	B	1
4'	60	35	<5	d	d	d	0.7	e	C	C	3
5'	140	45	<30	b	b	b	0.4	e	C	C	2
6'	300+	300+	<5	a	a	e	0.1	b	C	C	1

* The RCI given is the minimum probable value during the wet season; correlate with California Bearing Ratio equivalent. These features must, in general, include slopes greater than 1 ft in height and steeper than 60%. The scale of value is as follows:

- a: Numerous.
b: Common.
c: Present, but not common.
d: Rare.
e: Absent.

† Mean distance in miles between gullies, ditches, or cut and fill banks along a random straight line.

†† The scale of values for tree density is:

- A: Dense; passable, but path tortuous.
B: Moderately dense; passable, but path length substantially extended.
C: Patches and rows; path length slightly extended.
D: Rare or absent; no appreciable effect on path length.

‡ The scale of values for shrub density is:

- A: Dense; visibility seriously inhibited; path selection difficult.
B: Moderately dense; visibility somewhat inhibited; path selection not seriously inhibited.
C: Rare or absent; visibility not appreciably affected; path selection easy.

‡‡ The scale of values for hydrographic features is:

- 1: Surface water absent.
2: Small ponds, easily bypassed.
3: Unfordable water barrier subdivides region.
Curbs, terraces, walls, etc.

§

1/ Area A 1'a, 4', 2'b; Area B 1'a, 1'b, and 2'a

8. MATRIX DATA FROM LIBRARY SYSTEM OF ANNOTATED REMOTE SENSING IMAGERY

A system of recording, indexing, and storing information for rapid and efficient retrieval by an analyst is most advantageous in the development of a complete matrix designator of terrain.

Basic recording techniques can serve other military applications such as site selection, if reliable data are stored and properly indexed. The data storage could be on punched or marked cards or in folders, handbooks, or folios.

The indexing of a terrain environment would include all the terrain factors and related information by location, subject, photography, maps, reports, and other sources of data related to the specific problem. Refer to the report, "Handbook for Producing a Folder for a Library of Annotated Aerial Photographs", by H. T. Leibowitz, University of Oxford, December 1966 (AD 814 934) for comprehensive recording procedures that can provide other types of useful data to supplement a terrain matrix designator.

APPENDIX D

Optimum Remote Sensing System

The designation of an optimum remote sensing system for determining, measuring, and monitoring natural terrain properties and conditions depends on its proposed applications and on available resources for system development. Many surveys and feasibility studies have been made, and tabulations prepared, regarding the capabilities of various sensors, either singly or grouped, to obtain the necessary data. In actual usage problems of weight and volume, power requirements, mutual interference, and output format must be carefully considered.

It is generally recognized that photography is the most useful sensor system, as its output is most familiar to the human senses and its interpretation has been most highly developed. Extending to either side of the narrow visible and photographic wavelengths of the electromagnetic spectrum are ultraviolet and infrared, both of which can be used to record valuable data. The existence of "atmospheric windows", permitting the transmission and recording of longer wavelength infrared energy, makes the use of infrared scanners very profitable.

Further into the microwave region of the spectrum, the use of passive microwave radiometry and active or passive radar (both imaging and non-imaging) becomes of value. Radar imagery can reveal much information regarding geologic formations and both surface and sub-surface earth properties, and its interpretation is fairly well developed in the geoscience community. Radar altimeters in particular are of value in studies of the regional relief or topography of the earth's surface.

At the opposite end of the spectrum, gamma-ray sensing is used in mineral exploration and shows much promise for determination of soil type and moisture content. Airborne use of this technique requires low-level surveys and quite large arrays of detectors.

The natural force fields of gravity and magnetism also offer clues as to the existence and extent of geologic materials and subsurface conditions. Airborne use of these techniques is quite standard, and data interpretation is well developed.

Droppable sensors for determining soil properties such as strength are well developed, and the Sandia Corporation's use of deep-penetrating projectiles is an advanced technique worthy of use in an optimum sensing system.

The recent development of lasers has a most useful application in very-high-resolution airborne profile recorders for measuring microrelief within 12 in. of accuracy. Studies of laser reflection "signatures" on rock and soil material are underway, which ultimately should permit material identification and discrimination.

Figure D-1, prepared for NASA purposes, presents an overall view of sensors that have varied uses in the earth sciences. The resolution of sensors at spacecraft altitudes is necessarily less than at aircraft altitudes, but the sensors can obtain some useful geophysical data.

In general, an optimum system should contain a metric or mapping camera using standard black and white film to obtain an overall view of the terrain being surveyed; a panoramic camera to extend the view of the area to include surrounding terrain; a multispectral camera system to exploit the spectral reflectance signatures of terrain material; and other mapping cameras simultaneously collecting data on color and infrared films. An additional camera using ultraviolet sensitive film would be a valuable additional source of data for experimental studies. Spectrally filtered photometers bore-sighted with the cameras would also be desirable.

Three optical-mechanical scanners are considered necessary in an optimum system. Two of these should operate in the 3 to 5 μ and 8 to 14 μ infrared regions, respectively, and the other should provide multi-wavelength scanning throughout the visible spectrum.

A high-resolution, side-looking, imaging radar, a radar scatterometer, (Moore, 1966) a long-wavelength radar, a laser altimeter, and an all sweeping-frequency radar should provide both surface and sub-surface data.

A passive microwave imager with a multi-frequency microwave radiometer having dual-polarization capability would provide additional data.

An airborne magnetometer and airborne gravimeter would acquire useful supplementary information on the existence of geologic conditions revealed in the force field anomalies. Airborne electromagnetic sensors would detect changes in conductivity or the dielectric constant associated with variations of sub-surface formations.

An array of gamma-ray detectors and scintillometers is needed to enhance the measurement of soil types and their extent and to provide needed data on mineral deposits.

A capability to airdrop contact sensors should be part of an airborne system, as well as an extensive telemetry recording capability to obtain supplementary "ground truth" data.

Inherent in all the above discussion is the necessity for precise navigation of the aircraft carrying the remote sensing system, the existence of suitable viewfinders and driftmeters for photographic positioning control, and an overall time-marking system for precisely coordinating all navigation data, sensor outputs, and events. On-board processing of film, for at least test strips, is seen as valuable but not mandatory.

The various sensors have widely diverse output formats, such as film recording, strip charts, tape records, and telemetry voltages. Digitizing as much as possible of the output format and recording the signal on multi-channel tape recorders is seen as a feasible present approach. In the future, the development of automated, real-time, photo-processing and recording of data by flying-spot scanners and densitometers should enable the consolidation of all sensor outputs and a computer correlation with known pattern recognition techniques into near-real-time presentation. A digitized total "terrain data bank" stored in a ground computer station could provide quantitative values of terrain factors such as type, slope, moisture, temperature, etc., for any required application from such digitized interpretive processes shown in Figure D-2 and in Figure 31 of the report.



Figure D-2. Optimum Terrain Analysis by Orbital and Airborne (Non-Contact), Ground (Contact), and Intuitive (Indirect) Methods

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13. ABSTRACT A survey of the state-of-the-art in the evaluation of natural terrain by earth-science techniques and measurement systems is presented in response to a need that existed for many years. This report considers the terrain as an envelope of the environment and all related parameters that are basic in an evaluation for relevant military applications such as unimproved landing areas, trafficability, site selection for operational facilities, terrain reconnaissance and surveillance, and target detection within a marked terrain complex. Methods of terrain-data acquisition, analysis, and evaluation and their limitations are reviewed. The status of research and development, specifying the gaps in technology, is summarized with accompanying conclusions. The report forecasts the requirement for an automated terrain-data acquisition, storage, and display system. Recommendations are suggested for further investigation to advance technology that will provide quantitative terrain factor values. A simplified matrix method of digitizing terrain data is described in the appendix as a necessary intermediate step to the computerization of pertinent data. Information pertaining to the classification of terrain data, field devices to measure bearing strength, and a visualized optimum remote sensing system is also given in the appendix. A glossary and a comprehensive bibliography are included.		

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14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	BT	ROLE	BT	ROLE	BT
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	Climatology						
	Data Acquisition and Processing						
	Earth Sciences						
	Geography						
	Geology						
	Geophysics						
	Hydrology						
	Landforms						
	Mapping						
	Military Construction						
	Military Geographic Information						
	Physiography						
	Remote Sensing						
	Research and Development						
	Rocks						
	Soils						
	Terrain						
	Terrain Analysis						
	Terrain Applications						
	Terrain Classification						
	Terrain Factors						
	Terrain Matrix						
	Terrain Model						
	Terrain Parameters						
	Vegetation						

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Terrain Analysis



JULY 1990

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Headquarters,
Department of the Army

Terrain Analysis

Preface

SCOPE

Terrain analysis, an integral part of the intelligence preparation of the battlefield (IPB), plays a key role in any military operation. During peacetime, terrain analysts build extensive data bases for each potential area of operations. They provide a base for all intelligence operations, tactical decisions, and tactical operations. They also support the planning and execution of most other battlefield functions. Because terrain features continually undergo change on the earth's surface, data bases must be continuously revised and updated.

PURPOSE

This field manual prescribes basic doctrine and is intended to serve as a primary source of the most current available information on terrain analysis procedures for all personnel who plan, supervise, and conduct terrain analysis. The manual discusses the impact of the terrain and the weather on operations.

USER INFORMATION

The proponent of this publication is the US Army Engineer School. Submit changes for improving the publication on DA Form 2028 (Recommended Changes to Publications and Blank Forms) to Commandant, Directorate of Training and Doctrine, US Army Engineer School, ATTN: ATSE-TDM-P, Ft. Leonard Wood, MO 65473-6500.

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Unless otherwise stated, whenever the masculine gender is used, both men and women are included.

*This publication supersedes FM 21-33, 15 May 1978, and FM 30-10, 27 March 1972.

CHANGE
NO. 1

HEADQUARTERS
DEPARTMENTS OF THE ARMY
Washington, DC, 8 September 1992

Terrain Analysis

1. Change FM 5-33, 11 July 1990, as follows:

Page 10-1. Table 10-1, 2. Circles, change formulas to read:

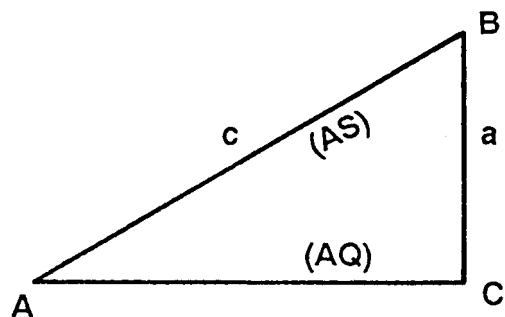
$$A = \pi r^2$$

or

$$A = \frac{\pi d^2}{4}$$

Page 10-3. Table 10-3. Change entry in last line, last column, to "118 lb."

Page 10-4. To the second paragraph under the subheading "Six Functions" add the following drawing:

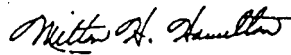


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Natural Terrain

Chapter 1

SURFACE CONFIGURATION

Maneuver commanders must have accurate intelligence on the surface configuration of the terrain. Ravines, embankments, ditches, plowed fields, boulder fields, and rice-field dikes are typical surface configurations that influence military activities. Elevations, depressions, slope, landform type, and surface roughness are some of the terrain factors that affect movement of troops, equipment, and material.

Landforms

Landforms are the physical expression of the land surface. The principal groups of landforms are plains or plateaus, hills, and mountains. Within each of these groups are surface features of a smaller size, such as flat lowlands and valleys. Each type results from the interaction of earth processes in a region with given climate and rock conditions. A complete study of a landform includes determination of its size, shape, arrangement, surface configuration, and relationship to the surrounding area.

Relief

Local relief is the difference in elevation between the points in a given area. The elevations or irregularities of a land surface are represented on graphics by contours, hypsometric tints, shading, spot elevations, and hachures.

Slope or Gradient

Slope can be expressed as the slope ratio or gradient, the angle of slope, or the percent of slope. The slope ratio is a fraction in which the vertical distance is the numerator and the horizontal distance is the denominator. The angle of slope in degrees is the angular difference the inclined surface makes with the horizontal plane. The tangent of the slope angle is determined by dividing the vertical distance by the horizontal distance between the highest and lowest elevations of the inclined

surface. The actual angle is found by using trigonometric tables. The percent of slope is the number of meters of elevation per 100 meters of horizontal distance. Slope information that is available to the analyst in degrees or in ratio values may be converted to percent of slope by using a nomogram.

VEGETATION FEATURES

Plant cover can affect military tactics, decisions, and operations. Perhaps the most important is concealment. To make reliable evaluations when preparing vegetation overlays, analysts must collect data on the potential effects of vegetation on vehicular and foot movement, rover and concealment, observation, airdrops, and construction materials.

Types

The types of vegetation in an area can give an indication of the climatic conditions, soil, drainage, and water supply. Terrain analysts are interested in trees, scrubs and shrubs, grasses, and crops.

On military maps, any perennial vegetation high enough to conceal troops or thick enough to be a serious obstacle to free passage is classified as woods or brushwood. Although trees provide good cover and concealment, they can present problems to movement of armor and wheeled vehicles. Woods also slow down the movement of dismounted troops. Individual huge trees are seldom so close together that a tank cannot move between them, but the space between them is often filled by smaller trees or brush. Closely spaced trees are usually fairly small and can be pushed over by a tank; however, the resulting pileup of vegetation may stop the tank. Trees that can stop a wheeled vehicle are usually too closely spaced to bypass. The pileup effect from pushing over vegetation is greater for wheeled vehicles than for tanks.

Trees are classified as either deciduous (broadleaf) or coniferous (evergreen). With the exception of species growing in tropical areas and a few species existing in temperate climates, most broadleaf trees lose their leaves in the fall and become dormant until the early spring. Needleleaf trees do not normally lose their leaves and exhibit only small seasonal changes.

Woodlands or forests are classified according to the dominant local tree type. A forest is classified as either deciduous or coniferous if it contains at least 60 percent of that species. Wooded areas that contain less than a 60 percent mixture of either species are classified as a mixed forest.

Scrubs include a variety of trees that have had their growth stunted because of soil or climatic conditions. Shrubs comprise the undergrowth in open forests, but in arid and semiarid areas they are the dominant vegetation. Shrubs normally offer no serious obstacle to movement and provide good concealment from ground observation; however, they may restrict fields of fire.

For terrain intelligence purposes, grass more than 1 meter high is considered tall. Grass often improves the trafficability of soils. Very tall grass may provide concealment for foot troops. Foot movement in savannah grasslands is slow and tiring; vehicular movement is easy; and observation from the air is easy.

Field crops constitute the predominant class of cultivated vegetation. Vine crops and orchards are common but not widespread, and tree plantations are found in relatively few areas. The size of cultivated areas ranges from paddies covering a quarter of an acre to vast wheat fields extending for thousands of acres.

In a densely populated agricultural area where all arable land is used for the crop producing the highest yield, it may be possible to predict the nature of the soils from information about the predominant crop. Rice, for example, requires fine-textured soils, while other crops generally must have firm, well-drained land. An area of orchards or plantations usually consists of rows of evenly spaced trees, showing evidence of planned planting. This can be distinguished on an aerial photograph. Usually such an area is free of underbrush and vines. Rice fields are flooded areas surrounded by low dikes or walls.

Some crops, such as grain, improve the trafficability of soils, while others, such as vineyards, present a tangled maze of poles and wires and create definite obstacles to vehicles and dismounted troops. Wheeled vehicles and some tracked vehicles are unable to cross flooded paddy fields, although they can negotiate them when the fields are drained and dry or frozen. Sown crops, such as wheat, barley, oats, and rye, will have a different impact on movement and concealment than those crops planted in furrows, because they are on a flat surface.

Photographic Texture

Texture is influenced by several variables, including crown shapes, tree spacing, and tree height. Texture interpretation as a means of identifying forest type requires knowledge of the texture often associated with each forest type. This knowledge is acquired through hands-on experience or the use of vegetation keys. With hands-on experience working with aerial imagery over along period of time and through the process of trial and error, an analyst can develop a mental catalog to relate texture in a given geographic area to a specific forest type.

Vegetation keys have been developed through the same trial and error process but have been documented and are available in the literature. They can be very useful in certain instances (see Chapter 3 for examples). However, one must remember that background knowledge of the area of interest is essential and most keys are specific to tree species, geographic area, time of year, film type, and photoscale. When using color or color infrared film, tone is often referred to as hue and is represented as shades of the color image.

Photographic Tone

Tone is also very important and is often applied to the problem of forest type identification. Tone is influenced primarily by stand density, reflectivity, and location of the tree stand with respect to the photographic center. When using panchromatic and black and white infrared film, photographic tone is represented by shades of gray. For example, in most regions of the world, needle leaf trees will appear darker in tone than broadleaf trees on panchromatic film given equivalent stand density. This tone difference is due to higher reflectivity of broadleaf trees in the region of the electromagnetic spectrum to which the film is sensitive.

SOIL FEATURES

Since soils vary in their ability to bear weight, their ability to withstand vehicle passes, and their ease of digging, military planners rely heavily on soil analyses. Soil type, drainage characteristics, and moisture content affect road construction, material location, and trafficability determination. The soil factor overlay breaks down the most probable soil types, characteristics, and distribution.

Describing and classifying soil normally requires exhaustive field sampling and the expertise of soil scientists. Terrain analysts, however, can produce acceptable soil factor overlays by examining maps, other factor overlays, aerial photographs, lab analyses, boring logs, and literature. The reliability of the resulting soil factor overlays will vary with the reliability of the sources used and the analyst's ability to correlate and combine the information correctly.

Determining whether a particular soil will support vehicle passage or the construction of roads and airfields is just a part of the terrain analyst's job. Since analysts also provide information on construction materials associated with roads and airfields, they need a variety of evaluation methods and a good working knowledge of the physical properties of soil.

Type Determination

For field identification and classification, soils may be grouped into five principal types: gravel, sand, silt, clay, and organic matter. These types seldom exist separately but are found in mixtures of various proportions, each contributing its characteristics to the mixture. Some soils may gain strength under traffic while others lose it.

Gravel is angular to rounded, bulky rock particles ranging in size from about 0.6 to 7.6 cm ($\frac{1}{4}$ to 3 inches) in diameter. It is classified as coarse or fine; well or poorly graded; and angular, flat, or rounded. Next to solid bedrock, well-graded and compacted gravel is the most stable natural foundation material. Weather has little or no effect on its trafficability. It offers excellent traction for tracked vehicles; however, if not mixed with other soil, the loose particles may roll under pressure, hampering the movement of wheeled vehicles.

Sand consists of rock grains from about 0.6 cm ($\frac{1}{4}$ inch) and smaller. It is classified as coarse, medium, or fine, and is angular or rounded. Well-graded angular sand is desirable for concrete aggregate and for foundation material. It is easy to drain and ordinarily not affected by frost action or moisture. Analysts must be careful, however, to distinguish between a fine sand and silt. When wet enough to become compacted or when mixed with clay, sand provides excellent trafficability. Very dry, loose sand is an obstacle to vehicles, particularly on slopes. Under wet conditions, remoldable sands react to traffic as to fine-grained soils. They feel somewhat plastic rather than gritty when rolled between the fingers.

Silt consists of natural reek grains. It lacks plasticity and possesses little or no cohesion when dry. Because of silt's instability, water will cause it to become soft or to change to a "quick" condition. When dry, silt provides excellent trafficability, although it is very dusty. However, it absorbs water quickly and turns to a deep, soft mud (a quick condition), which is a definite obstacle to movement. When

ground water or seepage is present, silt exposed to frost action is subject to ice accumulation and consequent heaving.

Clay generally consists of microscopic particles. Its plasticity and adhesiveness are outstanding characteristics. Depending on mineral composition and proportion of coarser grains, clays vary from lean (low plasticity) to fat (high plasticity). Many clays which are brittle or stiff in their undisturbed state become soft and plastic when worked. When thoroughly dry, clay provides a hard surface with excellent trafficability; however, it is seldom dry except in arid climates. It absorbs water very slowly but takes a long time to dry and is very sticky and slippery. Slopes with a clay surface are difficult or impassable, and deep ruts form rapidly on level ground. A combination of silt and clay makes a particularly poor surface when wet.

Chemically deposited and organic sediments are classified on the basis of mode and source of sedimentations. The identification of highly organic soil is relatively easy; it contains partially decayed grass, twigs, leaves, and so forth, and has a characteristic dark brown to black color, a spongy feel, and fibrous texture.

Classification

The terrain analyst uses the field classification technique to determine if the soil is fine or coarse or if it is remoldable sand. Usually the first two steps will determine the grain. If it is squeezed and rolled between the fingertips, fine-grained plastic soil will feel soft and smooth and should produce a ribbon or thread. Remoldable sands will feel coarser and more abrasive than a fine-grained material.

Unified Soil Classification System (USCS)

The Unified Soil Classification System uses a system of two-letter abbreviations to describe the soil. The primary letter identifies the predominant soil fraction. The secondary letter further describes the characteristics of the predominant soil fraction. The percent of gravel, sand, and fines provides the information necessary to choose the primary letter. See Figure 1-1.

Physical Tests

Before analysts classify soil, they must make four physical tests: gradation, liquid limit, plastic limit, and odor test.

Gradation, or grain-size distribution of a soil, is determined by a sieve analysis. A sieve analysis is the separation of soil into its fractions. It is made to determine gradation of material retained on a No. 200 sieve. It indicates whether a soil is well or poorly graded, and it will show the percentage of fines present. The sieve analysis may be performed directly on soils that may be readily separated from the coarser particles.

Sieves that military engineers commonly use have square openings and are designated as 2-, 1½-, 1-, ¾-, and ¼-inch sieves. They also use the US standard numbers 4, 10, 20, 40, 60, 100, and 200 sieves. See Figure 1-2 for an example of a sieve analysis.

PRIMARY LETTERS

- G--Gravel

- S-Sand
 - C-Clay (Used only with fine-grained soil with 50% fines or greater)
 - M-Silt
 - O-Organic
- SECONDARY LETTERS
- W-Well graded (Used to describe sands containing less than 12% fines)
 - P-Poorly graded
 - M-Silty Fines (Used with sands and gravels containing less than 5% but more than or equal to 50% fines)
 - C-Clay-based
 - L-Low Compressibility (Used to describe fine-grained soils (silts, clays, organics))
 - H-High Compressibility

As soil becomes more moist, it transforms from a plastic to a liquid state. The liquid limit is the moisture content at which a soil will just begin to flow when jarred slightly. In conjunction with the plastic limit, it is valuable in proper identification and classification of fine-grained soils. The liquid limit is usually expressed as a whole number and is obtained by performing the Atterberg liquid limit test, which is outlined in TM 5-530.

The plastic limit is the moisture content at which cohesive soil passes from a semisolid to a plastic state. A soil or soil fraction is called plastic if, at some water

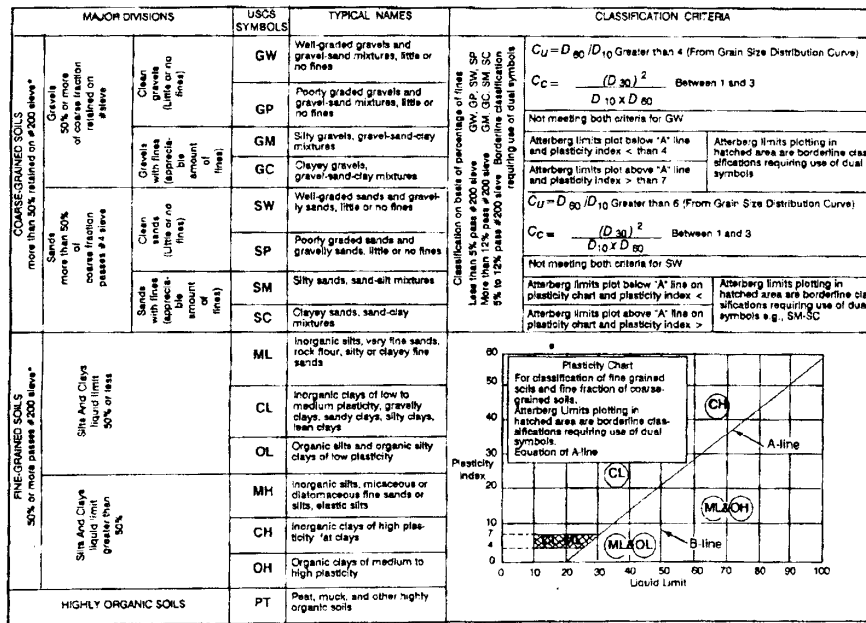


Figure 1-1. Unified soil classification system criteria

SIEVE ANALYSIS

Submitted by SFC DelosierDate performed 10 Sep 1962Description of sample Yellow white gravelly sand with a small amount of Silt Fines

Test performed by.

1 SP-5 DILLON2 E-3 COKER

3 _____

4 _____

5 _____

Wt original sample 4000 gmWt after prewashing 3855 gmWashing loss 135 gm

$$\frac{3855}{4000} \times 100 = 96.4\%$$

Sieve or screen	Sieve Opening (mm)	Wt of sieve (gm)	Wt of sieve & sample (gm)	Wt. retained on sieve (gm)	Passing sieve	
					Weight in (gm.)	Percent
				0	3964	100
2"	50.8	634.1	679.1	45	3919	98.9
1½"	38.1	598.9	649.9	51	3868	97.6
1"	25.4	540.9	646.9	106	3762	94.9
¾"	19.1	608.5	707.5	99	3663	92.4
⅝" (No. 3)	6.35	488.5	1368.5	898	2765	69.8
No. 4	4.76	510.2	773.2	263	2502	63.1
No. 10	2.00	476.4	1254.4	778	1724	43.5
No. 40	0.42	377.9	1404.9	1027	397	17.6
No. 60	0.25	366.7	615.7	249	448	11.3
No. 100	0.149	320.6	456.6	136	312	7.9
No. 200	0.074	303.9	435.9	132	180	4.5
Wt. retained in pan <u>45 gm</u>					Error=Original Wt - Total Weight of fractions <u>36 gm</u> <u>0.9%</u>	
Washing loss <u>135 gm</u>						
Pan total <u>180 gm</u>						
Total weight of fractions <u>3964 gm</u>						

*Maximum particle size (measured)
Prepared for use at USAES

Figure 1-2. Sieve analysis example

content, it can be rolled out into thin threads. The moisture content ranges between a soil sample's liquid and plastic limits. The larger the plasticity index, the more plastic the soil ($PI = LL - PL$). The percent of moisture content, by weight, at which a 1/8-inch diameter thread begins to crumble is expressed as a whole number when recorded

Note: Gravels will be retained at ¾ - to 2-inch sieves, sands at Numbers 4-100; all fines will be retained at the No. 200 sieve, allowing estimation of percentages of soil categories.

Since practically all fine-grained soils contain some clay, most of them will exhibit some amount of plasticity. Soil plasticity is determined by measuring the different states a plastic soil undergoes with changing moisture content. When a fine-grained soil or remoldable sand sample is rolled between two flat surfaces or between one's thumb and forefinger, it forms a thread. Highly plastic and nonplastic soils break into short lengths or cannot be formed into ribbons. In the field, analysts can examine the shape and mineral compositions of coarse-grained soil by spreading a dry sample on a flat surface, separating the gravel and fines as much as possible, and estimating the percentages of each. TM 5-530 gives further information.

Organic soils of the OL and OH groups usually have a distinct odor, which can be used to aid in identification. This color is especially apparent in fresh samples. It is gradually reduced when exposed to air, but can be brought out again by heating a wet sample.

Field Identification

Normally, laboratory equipment will not be available in the field, but analysts can estimate and tentatively classify without tests. Classifications made under stricter conditions will be more accurate. We classify soils by particle size distribution. Where these soil types occur and the amount of area they cover often determine the suitability of an area for military operations. In general, we prefer coarse-grained soils for construction and cross-country movements.

Well-graded and poorly-graded soils can usually be distinguished by comparing the sizes. Poorly-graded soils, however, are more difficult to classify because they lack one size particle. Principal aids to soil identification and classification are the shaking test, the dry strength or breaking test, and gully analysis.

Analysts performing the shaking test will alternately shake a wet portion of soil in the palm of the hand and squeeze between the fingers. Atypical inorganic silt will become livery, show free water to disappear from silt soil, and cause the sample to stiffen and crumble under increasing finger pressure. If the water content is just right, shaking the broken pieces will cause them to liquefy and flow together. The portion will change its consistency and the water on the surface will appear or disappear at a rapid, sluggish, slow, or no-reaction speed. A rapid reaction to this test is typical for a nonplastic, uniform fine sand, inorganic silt, or diatomaceous (algae-based) earths. A sluggish reaction indicates slightly plastic inorganic and organic silts, or very silty clays. An extremely slow or no reaction to the shaking test is typical for all clays that plot above the A-line on the plasticity chart as well as for highly plastic organic clays.

The dry strength test readily distinguishes between plastic clays and nonplastic silts or fine sands. Analysts perform the dry strength or breaking test only on a small portion of soil, about ½-inch thick and 1½ inches in diameter, that passes the Number 40 sieve. They prepare this by molding a portion of wet plastic soil into the size and shape desired and allowing it to air (NOT oven) dry. After the sample is thoroughly dry, they will attempt to break the soil using their thumbs and forefingers. If it breaks, they will try to powder it by rubbing the particles together. Typical reactions obtained in this test for various types of soil are--

- Very highly plastic soil, or very high dry strength. Samples cannot be broken or powdered by finger pressure.
- Highly plastic soil, or high dry strength. Samples will break with great effort, but they cannot be powdered.
- Medium plastic soil, or medium dry strength. Samples will break and powder with some effort.
- Slightly plastic soil, or low dry strength. Samples will break and powder easily.
- Nonplastic soil, or very little or no dry strength. Samples crumble and powder on being picked up.

Gullies, sometimes called head water channels, result from erosion caused by water runoff. They develop in places where water cannot easily filter into the ground; therefore, it collects and flows in rivulets across the land surface. Gully analysis can be of great assistance in determining soil types, since these rivulets often take the shape peculiar to the material over which they flow. Since fine-grained silts and clays are relatively impervious soils, many gullies develop on their surfaces. Sands and gravels are rather permeable, and few or no gullies form.

Other factors that govern the extent of gully formation in an area are climate, vegetation, ground slope, and gradient of individual gullies. Gradient is more important than intensity, or number, of gullies in revealing soil conditions. The types of gullies that may be formed in various soil types are--

- Gullies in clay. They have a long, uniform, gentle gradient and are smoothly rounded. Clay soils are impervious and cohesive and often have a well-developed gully system.
- Gullies in silt (primarily loess). They take the form of a U and have steep sides and generally flat bottoms. The gradient is steep at the head of the gully but becomes more gentle a short distance away.
- Gullies in sand-clay. They are similar to gullies in silts but are more U-shaped, with a rounded rather than flat bottom. The gradient is nearly vertical at the head of the gully but levels off rapidly to a very gentle slope.
- Gullies in gravel, sand, or well-graded mixtures with some clays. They are usually well-defined, short, straight notches (ditches). The cross section is a sharp V with a uniform gradient. The steeper gradients are associated with the coarser materials. See Figure 1-3.

WATER FEATURES

Safe water, in sufficient amounts, is strategically and tactically important to Army operations. Water that is not properly treated can spread diseases. The control of and access to water is critical for drinking, sanitation, construction, vehicle operation, and other military operations. Military planners are concerned with areas with the highest possibilities for locating usable ground water. They must consider all feasible sources and methods for developing sources when making plans for water supply. Quantity and quality are important considerations. Terrain analysts can use the methods and systems available to locate both surface and subsurface water resources.

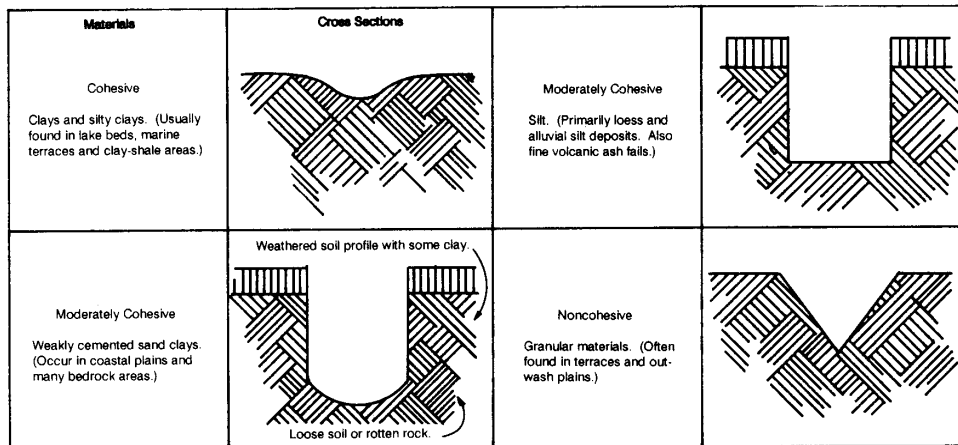


Figure 1-3. Gully profiles

Quantity

Water quantity depends on the climate of the area. Plains, hills, and vegetation are good indicators of water sources.

Large springs are the best sources of water in karstic plains and plateaus. Wells may produce large amounts if they tap underground streams. Shallow wells in low-lying lava plains normally produce large quantities of ground water. In lava uplands, water is more difficult to find, wells are harder to develop, and careful prospecting is necessary to obtain adequate supplies. In wells near the seacoast, excessive withdrawal of freshwater may lower the water table, allowing infiltration of saltwater that ruins the well and the surrounding aquifer.

Springs and wells near the base of volcanic cones may yield fair quantities of water, but elsewhere in volcanic cones the ground water is too far below the surface for drilling to be practicable. Plains and plateaus in arid climates generally yield small, highly mineralized quantities of ground water. In semiarid climates, following a severe drought, an apparently dry streambed frequently may yield considerable amounts of excellent subsurface water. Ground water is abundant in the plains of humid tropical regions, but it is usually polluted. In arctic and subarctic plains, wells and springs fed by ground water above the permafrost are dependable only in summer; some of the sources freeze in winter, and subterranean channels and outlets may shift in location. Wells that penetrate aquifers within or below the permafrost are good sources of perennial supply.

Adequate supplies of ground water are hard to obtain in hills and mountains composed of gneiss, granite, and granite-like rocks. They may contain springs and shallow wells that will yield water in small amounts.

Tree species can also indicate local ground water table presence. Deciduous trees tend to have far-reaching root systems indicating a water table close to the ground surface. Coniferous trees tend to have deep root systems, which depict the ground water table as being farther away from the ground surface. In desert environments, vegetation is scant and specialized to withstand the stress of desert life. Vegetation type is dependent on the water table of that location. Palm trees indicate water within 2 or 3 feet, salt grass indicates water within 6 feet, and cottonwood and willow trees indicate water within 10 to 12 feet. The common sage, greasewood, and cactus do not indicate water levels.

Quality

Quality will vary according to the source and the season, the kind and amount of bacteria, and the presence of dissolved matter or sediment. Color, turbidity, odor, taste, mineral content, and contamination determine the quality of water. Brackish water is found in many regions throughout the world but most frequently along sea coasts or as ground water in arid or semiarid climates.

Contamination

Potable water is free from disease-causing organisms and excessive amounts of mineral and organic matter, toxic chemicals, and radioactivity. Although surface water is ordinarily more contaminated than other sources, it is commonly selected for use in the field because it is more accessible in the quantity required. Ground water is usually less contaminated than surface water and is, therefore, a more desirable water source. However, the use of ground water by combat units is usually limited unless existing wells are available. Rain, melted snow, or melted ice may be used in special instances where neither surface nor ground water is available. Water from these sources must be disinfected before drinking.

Pollution

Water may be contaminated but not polluted. Streams in inhabited regions are commonly polluted, with the sediment greatest during flood stages. Streams fed by lakes and springs with a uniform flow are usually clear and vary less in quality than do those fed mainly by surface runoff. Generally, the quality of water in large lakes is excellent, with the purity increasing with the distance from the shore. Very shallow lakes and small ponds are usually polluted.

Porosity and Permeability

The water-bearing capability of a natural material is determined by porosity and permeability. The amount of porosity depends on the number of open spaces in the material. The permeability of rock is its capacity for transmitting a fluid. Rock types vary greatly in size, number, arrangement of pore spaces, and ability to contain and yield water. The amount of permeability depends on the degree of porosity, the size and shape of the interconnections between the pores, and the extent of the pore system. The geometric shapes of gullies can help identify the degree of permeability and porosity.

Drainage

Surface

Most military problems involving surface water arise because stream drainage conditions vary not only from place to place but seasonally as well. Military planners are concerned with the flow and channel characteristics of surface waters and their effect on military operations. The water constitutes obstacles to cross-country movement or, when sufficiently frozen, it may provide movement. They also determine the types of equipment to be used in an area.

Drainage data on all of the surface water features is significant to any aspect of military operations. Commanders must know the width and depth of streams and canals; the velocity and discharge of streams; which areas are subject to flooding, or are permanently wet, densely ditched, or canalized; the location of dams; and any other drainage feature that may be significant.

Although surface drainage is considered a standard product, subsurface drainage is not. Potential ground water indicators include the following:

- Crop irrigation
- Karst topography
- Snowmelt patterns
- Wetlands
- Vegetation
- Springs
- Soil moisture
- Surface water
- Wells/Qanats
- Built-up areas (local municipalities and populus)

Surface water resources are generally more accessible and adequate in plains and plateaus than in mountains. Large amounts of good quality water can normally be obtained in coastal areas, valleys, or alluvial and glacial plains. Although large quantities are available in delta plains, the water may be brackish or salty. Water supplies are scarce on lacustrine, loess, volcanic, and karst plains. In the plains of arid regions, water usually cannot be obtained in quantities required by a modern army; much that is available is highly mineralized. In the plains and plateaus of humid tropical regions, surface water is abundant but is generally polluted and requires treatment. Perennial surface water supplies are difficult to obtain in arctic regions; in summer it is abundant but often polluted.

Subsurface

Ground water, or subsurface drainage, is obtained without difficulty from unconsolidated or poorly consolidated materials in alluvial valleys and plains, streams and coastal terraces, glacial outwash plains, and alluvial basins in mountainous regions. Areas of sedimentary and permeable igneous rocks may have fair to excellent aquifers, although they do not usually provide as much ground water as areas composed of unconsolidated materials. Large amounts of good-quality ground water may be obtained at shallow depths from the alluvial plains of valleys and coasts and in somewhat greater depths in their terraces. Aquifers underlying the surface of inland sedimentary plains and basins also provide adequate amounts of water. Abundant quantities of good-quality water generally can be obtained from shallow to deep wells in glacial plains. In loess plains and plateaus, small

amounts of water may be secured from shallow wells, but these supplies are apt to fluctuate seasonally. Well water is usually clear and low in organic impurity but may be high in dissolved mineral content.

Patterns

The pattern of stream erosion usually gives an indication of rock structure and composition and an indication of whether the region is underlined by one or several rock types. The pattern can be dendritic, trellis, radial, annular, parallel, or rectangular.

The dendritic drainage pattern is a tree-like pattern composed of branching tributaries to a main stream, characteristic of essentially flat-lying and homogeneous rocks. This pattern implies that the area was originally flat and is composed of relatively uniform materials. Dendritic drainage is also typical of glacial till, tidal marshes, and localized areas in sandy coastal plains. The difference in texture or density of a dendritic pattern may help identify surface materials and organic areas.

In a trellis pattern, the mainstream runs parallel, and small streams flow and join at right angles. This pattern is found in areas where sedimentary or metamorphic rocks have been folded.

In a radial pattern, streams flow outward from a high central area. This pattern is found on domes, volcanic cones, and round hills. However, the sides of a dome or volcano might have a radial drainage system while the pattern inside a volcanic cone might be centripetal, converging toward the center of the depression.

The annular pattern is a modified form of the radial drainage system, found where sedimentary rocks are upturned by a dome structure. In this pattern, streams circle around a high central area. The granitic dome drainage channels may follow a circular path around the base of the dome when it is surrounded by tilted beds.

In the parallel pattern, major streams flow side by side in the direction of the regional slope. Parallel streams are indicative of gently dipping beds or uniformly sloping topography. The greater the slope, the more nearly parallel the drainage and the straighter the flow. Local areas of lava flows often have parallel drainage, even though the regional pattern may be radial. Alluvial fans may also exhibit parallel drainage, but the pattern may be locally influenced by faults or jointing. Coastal plains, because of their slope toward the sea, develop parallel drainage overboard regions.

The rectangular drainage pattern is a specific type of angular drainage and is usually a minor pattern associated with a major type such as dendritic. This pattern is characterized by abrupt bends in streams and develops where a tree-like drainage pattern prevails over a broad region. It is caused by faulting or jointing and is generally associated with massive igneous rock. Metamorphic rock surfaces, particularly those comprised of schist and slate, commonly have rectangular drainage. Slate possesses a particularly finely textured system. Its drainage pattern is extremely angular and has easily recognizable short gullies that are locally parallel.

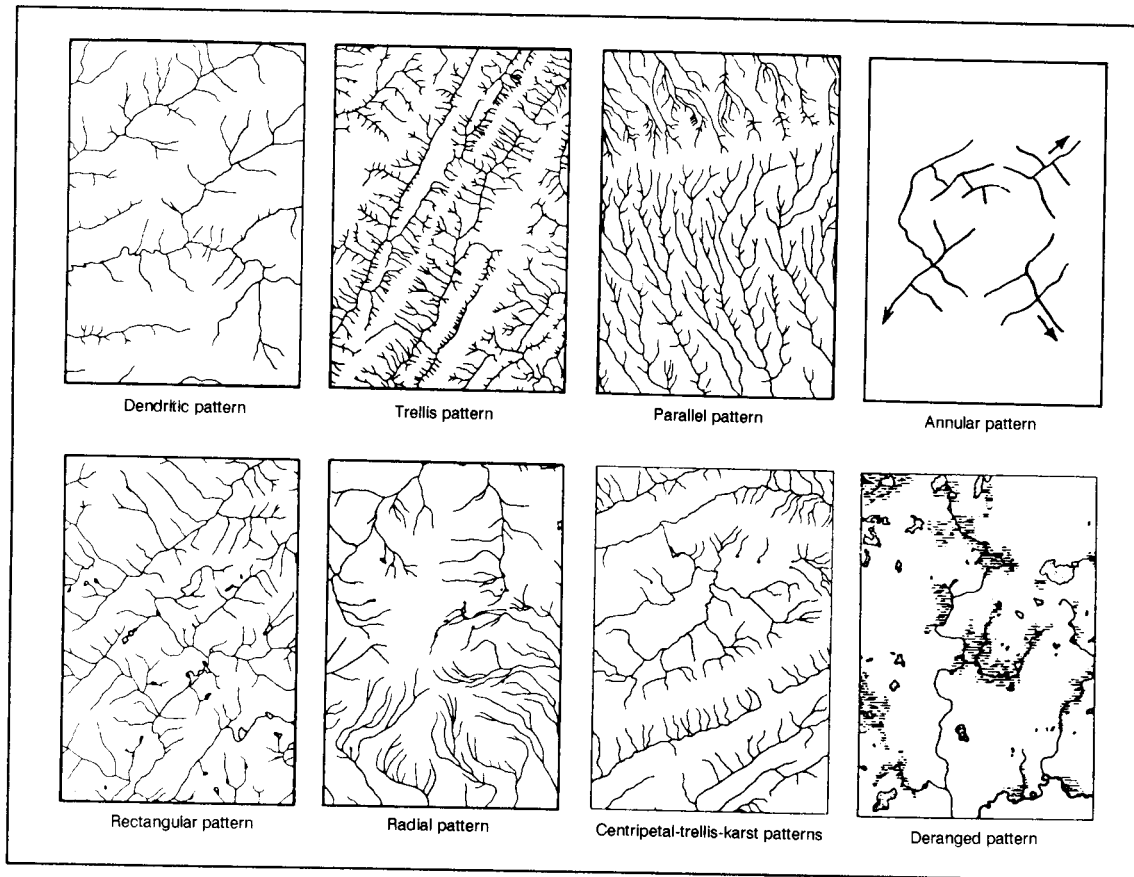


Figure 1-4. Typical drainage patterns

Density

A determination of the density of the drainage pattern, or the number of streams in a precise area, is very beneficial. The nature of the drainage pattern in an area will provide a strong indicator of the particle size of the soils that have developed.

Surface sediments have good internal drainage. Sandstone, for example, due to its porosity and permeability, has good internal drainage. Water can usually percolate down through the soil and underlying rock, and the surface runoff will be at a minimum. The texture or density of the drainage pattern that develops on sandstone will be coarse.

A porous rock is not necessarily permeable. Clay, for example, contains up to 90 percent water and is very porous but is not permeable because of the nature of its flat-lying particles.

Sands and gravels are usually both porous and permeable, depending on sorting. When precipitation occurs, some of the water can percolate down through the sediment.

Shale is a relatively impermeable rock and has poor internal drainage. Surface runoff will be at a maximum, and erosion will often be intense. The texture or density of the drainage pattern that develops on shale will be fine-textured. See Figure 1-4.

OBSTACLES

Classification

An obstacle is any natural or man-made terrain feature that slows, diverts, or stops the movement of personnel or vehicles. Obstacles are classified as natural, such as escarpments, or man-made, such as built-up areas and cemeteries. They are further categorized as existing-present natural or as man-made terrain features that will limit mobility or as reinforced-existing features that man has enhanced to use as obstacles, such as gentle slopes reinforced by tank ditches, pikes, or revetments that limit mobility of maneuver units.

For classification purposes, obstacles must be at least 1.5 meters high and 250 meters long and have a slope greater than 45 percent (that which military vehicles are unable to travel). Obstacles that will be delineated should be in areas where they are of primary importance for the diversion of crosscountry movement. Obstacles include escarpments, embankments, road cuts and fills, depressions, fences, walls, hedgerows, and moats.

An obstacle factor overlay portrays linear terrain features that form natural obstacles not normally identifiable on a topographic map. Obstacles located in areas of dense forest, on steep slopes (greater than 45 percent), or within the gap width of streams normally will not be shown on the obstacle overlay. Hydrologic obstacles such as drainage ditches, channelized streams, and water banks are shown on the surface drainage overlay.

Identification

Escarpments are terrain features similar to cliffs and ridges and appear on aerial photographs as sharp breaks in the slope separating near level or gently sloping surfaces. They are hazardous to both troop and vehicle movement due to the sharp drop in the land typical of cliffs and ridges. Embankments are artificial structures, usually of earth or gravel, constructed above natural ground surfaces such as dikes, levees, and seawalls. Escarpments and embankments are tactically significant because explosive devices can make the road, railroad, or cross-country route impassable and because they can be used as channelization factors. This is especially true if the bypass capability is restrictive to the state of the ground.

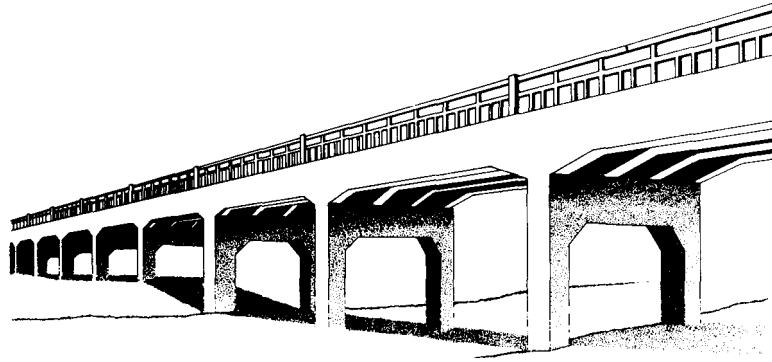
Railroad and road cuts and fills restrict military movement. Cuts are thoroughfares or passages constructed through high areas. Fills are surfaces that have been built up or raised to bring a low area up to the same level as the surrounding surfaces.

Depressions are low points or sinkholes surrounded by higher ground. They usually have slopes equal to or greater than 45 percent, which will impede movement across the terrain. Pits, quarries, and sinkholes are typical examples of depressions.

Man-made features include fences or walls, hedgerows, and moats. Fences and walls are usually constructed to separate or restrict crossings from one plot of land to another. Hedgerows are tree-type barriers that can be identified by looking for closely spaced rows of trees or bushes planted on a mound. They are so dense that they restrict vehicle movement.

European vineyards offer an excellent example of obstacles, due to the wet state of the ground and the wire used to support crop growth. Combined with the existing terrain, vineyards cause extreme difficulty in cross-country mobility.

Finally, moats are landforms that appear on photos as wide trenches or ditches which usually surround a structure or prominent feature and are inaccessible to vehicles. Moats are generally restricted to the British or European areas. Preliminary identification can be made by referring to the map legend on a topographic map.



Man-Made Features

Chapter 2

URBAN AREAS

Urban-area intelligence is important in planning tactical and strategical operations, targeting for nuclear or air attack, and planning logistical support for operations. Knowledge of characteristics in urban areas may also be important in civil affairs, intelligence, and counterintelligence operations. Although information is frequently accessible, the amount of detail required necessitates a substantial collection effort.

The first aspect of urban intelligence includes geographic location, relative economic and political importance of urban areas in the national structure, and physical dimensions such as street shapes. The six street patterns are rectangular, radial, concentric, contour conforming, medieval irregular, and planned irregular (in the new residential suburbs of some countries).

The second aspect includes physical composition, vulnerability, accessibility, productive capacity, and military resources of individual urban areas. Urban areas are significant as military objectives or targets and as bases of operations. They may be one or a combination of power centers (political, economic, military); industrial production centers; service centers; transportation centers; population centers; service centers (distribution points for fuels, power, water, raw materials, food, manufactured goods); or cultural and scientific centers (seats of thought and learning, and focal points of modern technological developments).

Buildings can provide numerous concealed positions for the infantry. Armored vehicles can find isolated positions under archways or inside small industrial or commercial structures. Thick masonry, stone, or brick walls offer excellent protection from direct fire, and ceilings for individual fire. Cover and concealment can also be provided by the percentage of roof coverage. For detailed information, see FM 90-10.

Although an urban overlay is not a standard product, it is useful for military purposes. A subdivision can describe individual categories or break down a division to more specific items as required by the user, as long as the subdivisions are outlined in the legend. The division numbers in this manual are based on the DFAD system, in PS/ICE/200. The first number describes the division as residential or industrial, the second number indicates the type of construction material,

and the third number is the type of structure. If this number or its subdivisions are not needed in particular overlays, the number will be followed by zeros.

The industrial category (code 100) consists of the area and facilities that include the buildings used by those establishments engaged in the extraction, processing, and production of intermediate and finished products or raw materials. The two plant types in industrial areas are heavy manufacturing and medium and light manufacturing. Heavy-manufacturing plants require distinctive structures, such as blast furnaces, that could be readily recognized, while medium and light plants are housed in general loft buildings from which machinery could be removed. The specific type of medium-or light-manufacturing plant is not usually apparent from the type of building.

The transportation category (code 200) consists of the area and facilities used in moving materials and people on land. Features include railroads, roads, road interchanges, bridges, bridge structures, and conduits.

The commercial/recreational category (code 300) consists of the area and buildings where the major business activities and recreational facilities comprise the congested commercial core of a city. It includes retail and wholesale establishments, financial institutions, office buildings, and hotels. Modern multistory office buildings are typical of commercial sections of large cities. More than one commercial area may exist, particularly in cities where a number of towns have merged. Recreational activities, such as amusement parks and stadiums, may also be present.

Residential areas of a city (code 400) consist of the area and associated buildings where civilians live. They include many types of dwelling structures. Buildings vary from one and two-story single family dwellings to multistory apartment houses and may be built of any materials available locally. Types and sizes of residential areas often indicate the number of people and the varying living standards throughout the city.

Communication facilities (code 500) transmit information from place to place. This category includes telephone, telegraph, and radio facilities, as well as other electronic features such as power line pylons and structures. These facilities include communication towers and buildings, as well as power transmission, observation, microwave, television, and radio towers.

The governmental and institutional category (code 600) consists of the area and facilities, primarily buildings, that constitute the seat of legal, administrative, or other governmental functions of a country or political subdivision. This category includes those buildings serving as public service institutions, such as universities, churches, and hospitals. Governmental and institutional areas may include buildings such as the capital; administrative centers such as ministries, departments, courts, legislative buildings, embassies, and police headquarters; educational, cultural, and scientific institutions such as schools, hospitals, universities, libraries, museums, theaters, research institutions and laboratories; and religious and historic structures such as churches, monuments, and shrines.

The military/civil category (code 700) consists of the area and facilities used by the air, naval, and ground forces for waging war, training, and transporting

nonmilitary goods and personnel by sea and air. Military areas usually include transportation, billeting, storage, airfields, and administration facilities. Since these are of strategic and tactical importance, they require as accurate a description as possible for urban-area intelligence.

The storage category (code 800) consists of the area and facilities used for holding or handling liquids or gases, bulk solids, and finished products. Examples are cylindrical and spherical storage tanks; closed storage such as silos and grain bins; open storage such as vehicle, ship, and aircraft storage areas and storage mounds such as coal or minerals.

The landforms, vegetation, and miscellaneous features category (code 900) describes the surface landscape characteristics or natural scenery features such as levees, walls, and fences. It includes beaches, recreation areas, farms, wooded areas, swamps, and vacant land. Extensive open areas within the city may be valuable military assets, particularly if they have roads and railroad lines nearby as well as access to electric and water supply facilities. Open areas on the outskirts of cities are the most immediately available land for military use. Features include snow or ice areas, vegetation such as orchards and vineyards, agricultural areas, and surface features such as embankments, fences, and cliffs.

TRANSPORTATION

Analysts preparing terrain studies must carefully evaluate all transportation facilities to determine their effect on proposed operations. Analysts may recommend destroying certain facilities or retaining them for future use. The entire transportation network must be considered in planning large-scale operations. An area with a dense transportation network, for example, is favorable for major offensives. Networks that are criss-crossed by canals and railroads and possess few roads will limit the use of wheeled vehicles and the maneuver of armor and motorized infantry.

The transportation facilities of an area consist of all highways, railways, and waterways over which troops or supplies can be moved. The importance of each area depends on the nature of the military operation involved. An army's ability to carry out its mission depends greatly on its transportation capabilities and facilities.

Highways

Features

Military interest in highway intelligence of a given area or country covers all physical characteristics of the existing road, track, and trail system. All associated structures and facilities necessary for movement and for protection of the routes, such as bridges, ferries, tunnels, and fords, are integral parts of the highway system. Planners must know where new routes will be needed to support an operation.

Road widths are given in meters. Measurements indicate the minimum width of the traveled way. Each road segment between intersections is assigned a width value, and that number is placed parallel to the road segment.

The severe abuse given to roads by large volumes of heavy traffic, important bridges, intersections, and narrow defiles makes them primary targets for enemy

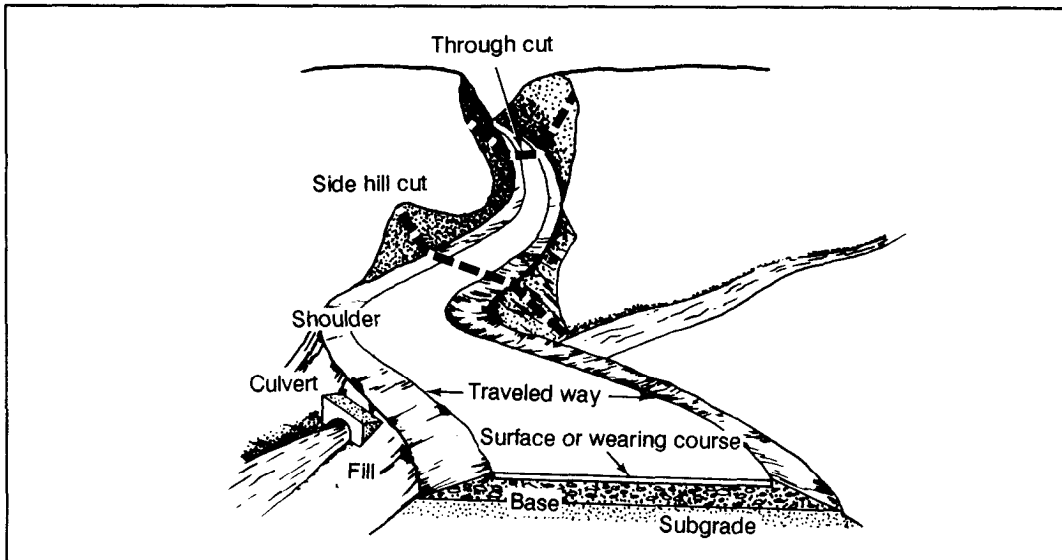


Figure 2-1. Parts of a road

bombardment. Planners must avoid maintaining unnecessary routes and must hold construction of new routes to a minimum.

Road Classification

Five road classifications are recognized on 1:50,000 scale topographic maps. They are all-weather, hard-surface dual/divided highway; all-weather, hard-surface highway; all-weather, loose-surface highway; fair-weather, loose-surface highway; and cart track.

All-weather, hard-surface, dual/divided highways normally have waterproof surfaces paved with concrete, bituminous surfacing, brick, or paving stone and are only slightly affected by precipitation or temperature changes. The route is never closed to traffic by weather conditions other than temporary snow or flood blockage. Photo interpretation keys include:

- Traveled portion of roadway is fairly straight.
- Even curves are present.
- Road width is uniform with easily seen parallel sides.
- Photo tint of road surface is an even color and varies from dark gray to white.
- Absence of ruts or holes on traveled portion of the roadway.

All-weather, hard-surface highways have waterproof surfaces of concrete, bitumen, brick, or paving stone and are only slightly affected by rain, frost, thaw, and heat. They are passable throughout the year to a volume of traffic never appreciably less than its maximum dry-weather capacity. They are never closed by weather conditions other than temporary snow or flood blockage. Photo interpretation keys are similar to those for the dual or divided highway.

All-weather, loose-surface highways are not waterproof but are graded and drained and are considerably affected by rain, frost, or thaw. They are constructed of crushed rock, water-bound macadam, gravel, broken stone and cinders, or

smoothed earth with an oil coating. The roads are kept open in bad weather to a volume of traffic considerably less than its maximum dry-weather capacity. Traffic may be halted for short periods of time. Heavy use during adverse weather conditions may cause complete collapse. Photo interpretation keys include:

- Sharp or irregular curves are present.
- Roadway meanders to avoid steep slopes.
- Gravel or crushed rock appears a uniform light gray except for low spots that collect water and appear in dark tones.
- Ruts and stones give the roadway a mottled appearance.
- Roadway edges and shoulders are not clean, sharp lines; sometimes, they are very difficult to determine.

Fair-weather, loose-surface highways are constructed of natural or stabilized soil, sand clay, shell, cinders, or disintegrated granite or rock. They include logging roads, abandoned roads, and corduroy roads which become quickly impassable in bad weather. Photo interpretation keys are similar to those for the all-weather, loose-surface highway except for less visible maintenance and narrower road widths at stream crossings.

Cart tracks are natural traveled ways including caravan routes and winter roads. They are not wide enough to accommodate four-wheeled military vehicles. Photo interpretation keys include

- Irregular turns and bends.
- Traveled roadway width varies.
- Apparent lack of direction.
- Roadway detours around wet terrain.

Railroads

Railways are a highly desirable adjunct to extended military operations. Their capabilities are of primary concern and are the subject of continuing studies by personnel at the highest levels.

Railroads include all fixed property belonging to a line, such as land, permanent way, and facilities necessary for the movement of traffic and protection of the permanent way. They include bridges, tunnels, snowsheds, galleries, ferries, and other structures.

Commanders need information on physical characteristics to determine railway capacities and maintenance or rehabilitation requirements. Railway intelligence covers all physical characteristics of the existing system and all available information pertaining to development, construction, and maintenance. Physical characteristics describe the railroad and its critical features and component parts such as roadbed, ballast, track, rails, and horizontal and vertical alignment.

Identification Keys

Railroads have definite characteristics distinguishing them from roads and highways (see Figure 2-2). Railroads often follow rivers, to take advantage of the normal gradual gradient of the valley. They follow as straight a line as possible, while roads meander. Curves are usually long and smooth, while roads may have sharp, right-angle turns and T-shaped intersections.

narrow. Wide gages are 5 feet or wider. They are mostly used by Russian, Finnish, and Spanish lines. Standard gages are 4 feet, 8½ inches. They are used for main and branch lines in the United States and the rest of Europe. Narrow gages are less than standard. Their use is somewhat limited to and usually found in mountainous, industrial, logging, and coastal defense areas and in mines and supply dumps. In South and Central America, the one-meter gage is found in many places; however, many of the countries are now adopting the standard gage because they import US-made rolling stock. See Figure 2-2.

Fixed Installations

Classification (marshaling) yards are used to sort freight cars. They are identified by a large group of parallel tracks with a restricted (one-or two-track) entrance and exit called a choke point. Active classification yards include numerous freight cars and small switch engines. Two or more classification yards are frequently found next to each other, with their entrances through a choke point. If this choke point is higher than either classification yard, it is known as a hump. Also, one yard is often placed slightly higher than the neighboring yard to allow cars to coast out of one yard through the choke point into a previously selected track of the other yard.

Service yards are normally found in or near marshaling yards and can be identified by the presence of roundhouses, turntables, service facilities, and car repair shops. Roundhouses are used for light repair and storage of locomotives. The number of roof vents on top of the roundhouse indicates the capacity of the roundhouse. Turntables are used for turning the engines around. Service facilities include coal towers, water towers, and coal piles. Car-repair shops normally appear as long, low buildings straddling one or more tracks, with cars awaiting repairs on sidings adjacent to the buildings.

Freight or loading yards are identified by loading platforms, freight stations, warehouses, and access to other means of transportation. Special loading stations are identified by grain elevators, coal and ore bins, oil storage tanks, and livestock pens with loading ramps.

Passenger stations vary from small rural depots or suburban stations to large stations and terminals. Small stations usually do not have loading docks and may not have parking areas for automobiles or trucks. They are located close to a track, and shelters may cover waiting platforms if more than two tracks pass the station. Large stations are identified by a large number of tracks leading into or past a large building that houses waiting rooms, ticket offices, and other passenger facilities. The track or boarding area is normally covered.

Freight stations may be identified by loading docks along railroad tracks on one side of a building and loading docks along a road or street on the opposite side. Freight stations are small, single structures near passenger stations designed for the temporary storage of goods received. Warehouses may be away from fixed railroad installations, and more than one may be located in an area. Freight cars loading or unloading at a freight station aid in identification of the installation. See Figure 2-3.

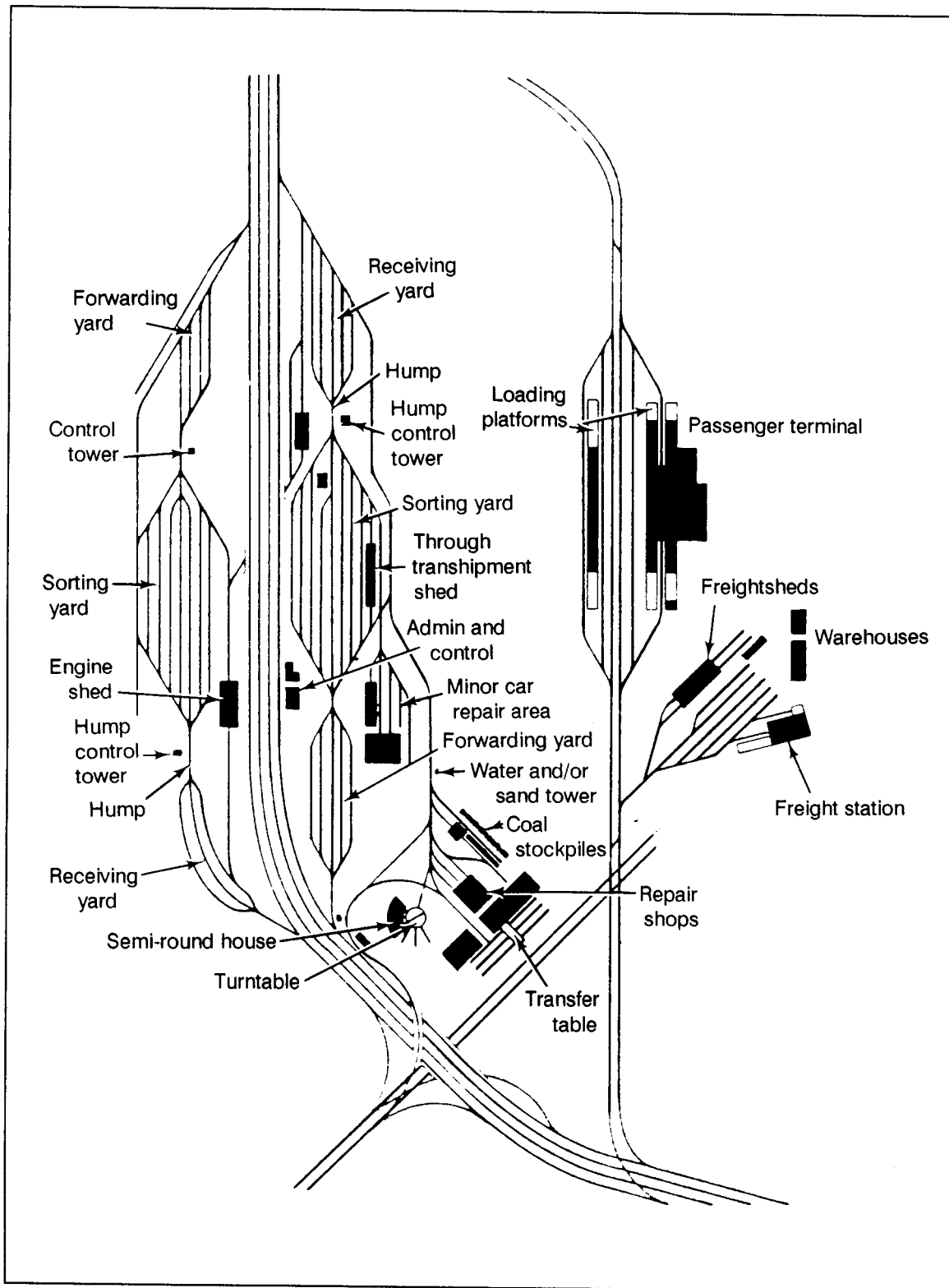


Figure 2-3. Fixed Installations

Rolling Stock

Locomotives. Locomotives vary greatly, from small switch engines 24 to 30 feet long to mainline passenger and freight locomotives 35 to 50 feet long. Locomotives longer than 50 feet are used for special purposes such as mountain climbing. Locomotives may be steam, electric, diesel, or diesel-electric. Steam locomotives are easily identified by smoke and steam around an operating locomotive, a smokestack, and a fuel tender attached just behind the locomotive. Electric locomotives have no fuel tender or smokestack and may be identified by overhead antennae if they receive their power from overhead lines. The lines may be evidenced by the shadows their support poles cast. Diesel locomotives lack a fuel tender and are usually identified by their streamlined appearance.

Freight cars. The boxcar is the most frequently found freight rolling stock, recognized by its rectangular shape and little roof detail. The round-topped freight car differs only in its top. These cars average 40 to 45 feet in length in the US, 25 feet in Europe. Other freight cars are the gondola and hopper cars, which are used for coal, ore, and other bulky material or large freight that cannot be loaded into a boxcar. Shape and shadow aid in identification. Refrigerator, stock, and automobile cars are so close in appearance to boxcars that low-level oblique arcs are usually necessary to distinguish them. Caboosees, not always found on foreign railroads, appear as small cars attached to the end of freight trains, usually with a visible cupola.

Passenger cars. For identification purposes, the outstanding characteristic of passenger cars is their length, especially when compared with freight cars. They vary from 50 to 80 feet. Normally, it is not possible to distinguish a coach from a sleeping or dining car.

Special Equipment. Railroads have a variety of special equipment in their rolling stock. The railcar is a self-contained unit with its own power plant as well as space for passengers or mail and baggage or all three. Cranes, snowplows, and drop-center flatcars are sometimes present on rolling stock.

Railheads

Railheads are points of supply transfer from railroads to other transportation and are generally found in small towns or cities where sidings and storage space already exist. Characteristics of a railhead are spurs and sidings from a main line; a road net, including narrow gage railroads, leading away from the area; piles of materials stacked near the track trucks or wagons or both, either without order or organized into convoys or trains; and temporary dwellings, such as tents or Quonset huts, for housing troops guarding and handling supplies.

End Points

System. A railroad system is a network of railroads operated by a single management entity, government or corporate. System end points are the points where a railroad system begins, ends, or changes identification. There may be no system end points within many map sheets, but system end points will always coincide with route and segment end points.

Route. A route is the portion of a system providing through lines between selected points. Routes are usually specified by the system management, but it

may often be convenient or appropriate for the analyst to select others. The route will be identified on the factor overlay by abbreviations of the two endpoints placed in parentheses. There may be no route end points within the area of a 1:50,000 factor overlay. Route end points always coincide with segment end points and may coincide with system end points. Kilometer distances are always measured from route end points.

Segment. A segment is the portion of a route characterized by uniform load-bearing, traffic capacity, and operating characteristics. Analysts will number segments sequentially along a route within a map sheet, starting at the segment nearest the zero kilometer point. End points of segments are defined by nodes along the route, at which anyone of the following conditions occurs:

- A change in the number of tracks (points where passing tracks or sidings start or end do not constitute nodes).
- A change in the gage of the track.
- A route or system terminal.
- The point where the route crosses the neat line of the factor overlay.
- A terminal or junction where traffic may be diverted onto another route.
- A change in the type of construction such that the load-bearing capacity, speed or traffic capacity is altered.
- A point where electrification starts, ends, or changes method of power transfer.
- A point where a change in traffic control methods occurs, such as international boundary crossings.

Number of Tracks

Analysts indicate the number of tracks for single- and double-track lines by the number of ticks used with the gage symbol. Routes with three or more tracks are symbolized by the double-track symbol supplemented by a *T* and a number, which indicates the actual number of tracks. Lines operated by different systems that closely parallel each other or share a common right-of-way are in juxtaposition (side by side) and are indicated by separate symbols. Symbols for such lines will be sufficiently displaced from the centerline to make it clear that two distinct lines exist.

Bridges

Features

Structures and crossings on highways or railways include bridges, culverts, tunnels, galleries, ferries, and fords. For the purpose of terrain intelligence, they also include cableways, tramways, and other features that may reduce or interrupt the traffic flow on a transportation route. Bridges and culverts are the structures most frequently encountered; however, any feature that may present a potential obstacle is significant in a military operation. See Figure 2-4.

Any type of structure or crossing on a transportation route is an important portion of the route regardless of the mode of transportation. Maps, charts, photographs, and other sources contain valuable information that analysts should exploit.

Highway and railway bridges and tunnels are vulnerable points on a line of communications. Information about prevention, destruction, or repair of a bridge may be the key to an effective defense or the successful penetration of an enemy

Structure Type	Span Type	Photo Indication	Photo Tone/Color/Texture	Probable Material Type
Bridge	 SUSPENSION BRIDGE	Towers Shadow outline of towers and suspension cables. Texture of tower surfaces.	Color: green, red, black Tone: dark gray	Steel reinforced concrete
	 TRUSS	Presence of superstructure cross hatch pattern of span members, detail visible from shadow detail.	Color: white, gray, red, silver Tone: light to dark gray Texture: rivet pattern	Steel
	 SLAB	Absence of superstructure Type of guard rails: (1) Angular (2) Rounded, smooth	Beam, girder, and slab bridge design preclude identification of construction material from vertical aerial photography. When possible the analyst should obtain low oblique photography of these types of bridges.	
	 BEAM	Absence of superstructure Type of guard rails: (1) Angular (2) Rounded, smooth, length		
	 GIRDER	Absence of superstructure Type guard rails: (1) Angular (2) Rounded, smooth, length, shadow detail		
	 ARCH (closed span/drel)	Shadow detail: massive structure	Color: white, red Tone: gray, light gray Texture: rough Joint patterns	Masonry structures are massive and usually old. Reinforced concrete spans are smaller.
	 ARCH (open span/drel)	Shadow detail: open structure, smooth, rounded span members	Color: white to light gray Tone: gray to light gray Texture: smooth	Smooth rounded span Members: reinforced concrete Angular span members: steel
Snowshed		Location: Mountainous areas Length	Color: light gray to white Tone: light gray Texture: smooth	Difficult to determine from vertical photo. Long structures (100m) are probably reinforced concrete.
Gallery		Location: limited to Mountain sides and valleys. Rock and landslide indications in area.	Roof materials not indicative of material.	Recent construction: reinforced concrete. Old structure: wood

Figure 2-4. Structure construction type identification from vertical aerial photography

area. A bridge seized intact has great value in offensive operations, since even a small bridge eases troop movement over a river or stream.

A bridge includes the substructure and superstructure. The substructure comprises the foundation and supporting elements of a bridge; the superstructure is the assembly that rests on the substructure and spans the gaps between ground supports.

Bridge superstructures take many forms, ranging from short trestle spans built into wooden stringers to large multiple cantilever spans of several thousand feet. Most have two basic components, the main supporting members and a floor or deck system. The primary exception is the concrete slab design, in which the supporting member also serves as the floor. The superstructure used depends on the loads to be carried, required span lengths, time available for erection, availability of

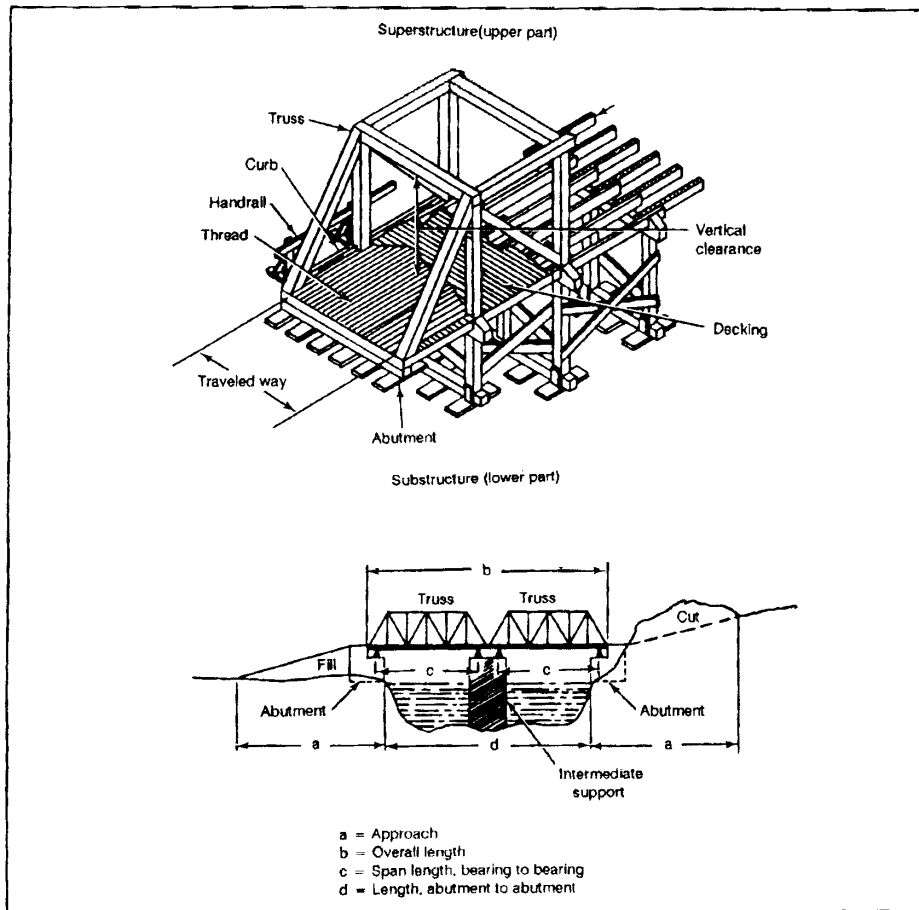


Figure 2-5. Bridge mensuration requirements

construction materials, manpower and equipment, and characteristics of the site. See Figure 2-5.

Based on their superstructures, bridges may be either fixed or movable. The five major categories of fixed bridges are beam, slab, girder, truss, and arch bridges. These types may occur alone or in combination. Movable bridges have at least one span that can be moved from its normal position to allow passage of vessels. The four general types of movable bridges are swing, lift, bascule, and retractile.

The load capacity is the most critical factor of a bridge. The most reliable capacity data comes from the standard design loadings by which most countries design their bridges. Usually a country has a number of standard design loadings for different capacity classes. Standard design loadings may be expressed by a letter, number, or symbol.

Bridge Reporting

The data base includes all on route bridges that can be identified and measured on aerial photography or derived from updated collateral sources. Structures less than 6 meters long are culverts; all others are treated as bridges. This cut-off length is flexible according to the prevalence of bridging in the study area.

All bridges present a potential restriction to traffic, and all items reflected in the collection checklist are important. Some of the basic requirements for information on any type of bridge are--

- Location, or kilometer stations from origin of section. The nearest kilometer should be given unless close spacing requires use of the nearest 0.1 kilometer for separate identifications.
- Obstacle crossed. Analysts must list the name of the stream when they know it. Other possible entries include gorge, railroad, and canal.
- Universal transverse mercator (UTM) coordinates to six places and geographic coordinates to the nearest second.
- Overall length, to the nearest meter. This should generally be the sum of the span lengths, but it should not include approaches.
- Roadway width to the nearest 0.1 meters of that portion of the deck over which vehicles normally run, excluding sidewalks, curves, parapets, truss superstructure, and so forth. Width is measured between the inside faces of the curbs.
- Horizontal clearance, or the limiting width to the nearest 0.1 meter at a point 30 centimeters above the edge of the roadway. This normally includes widths of curbs and sidewalks but excludes parapets and trusses. The horizontal clearance on a truss bridge is measured from a point 4 feet above the roadway.
- Vertical clearance, or the minimum distance between the roadway and any obstruction immediately over the roadway, to the nearest 0.1 meter. The letter *u*, for unlimited clearance, indicates no obstruction.
- Military load classification (MLC). This number indicates the carrying capacity of the bridge, including classifications for single- and double-flow traffic. The symbol to show the MLC is a circle with the bridge information on the inside. The load classification is on the top of the circle. In those instances where dual classifications for wheeled and tracked

vehicles exist, both classifications are shown. See TM 5-312 for further information. See the NATO bridge symbol on Figure 2-6.

- Spans. Both the number and length of spans need to be determined. Lengths are given to the nearest 0.1 meter and represent the distance between supports, or centers of bearing. The bridge classification is measured from center to center of supports and is based on the weakest span.
- Span construction. The construction material and type will be identified.
- Bypasses. Bypasses are local detours along a specified route that enable traffic to avoid an obstruction. They are classified as easy, difficult, or impossible according to the ease of access to the bridge bypass. See Figure 2-6.

Culverts

Culverts are grouped into four main categories of pipe, box, arch, and rail girder spans. Pipe culverts are the most common. They are usually concrete, but corrugated metal and cast iron are also used. The pipes have different shapes and range from 12 inches to several feet in diameter. Box culverts are used to a great extent in modern construction. They are rectangular in cross section and usually concrete. A large box culvert is similar to a slab bridge. Arch culverts were used frequently in the past but are rarely constructed now. They are concrete, masonry, brick, or timber. Rail girder spans are found on lightly built railways or, in an emergency, on any line. The rails are laid side by side and keyed head to base and may be used for spans of 3 meters or less.

Tunnels, Galleries, and Snowsheds

Features on a transportation route where it would be relatively easy to block traffic or that affect the traffic capacity of the road are critical. Such features include

BRIDGE RECONNAISSANCE REPORT										DATE		SIGNATURE		
For use of this form, see FM 5-33; the proponent agency is TRADOC.										23 MAR 90		[Signature]		
TO: (Headquarters, address, and reference)										FROM: (Name, grade, and unit of officer or NCO making reconnaissance)				
CDR EUGEN A. JEN GZ										GARY C. SEEBUM, 1LT 18 TH ENGR				
NAID: (Country, state, and sheet number or name)										DATE/TIME GROUP (for signature)				
BELGIUM 150,000 LIEGE										23 MAR 1440Z				
ESSENTIAL BRIDGE INFORMATION														
SERIAL NO	LOCATION	CLEARANCE			SPAN			LENGTH AND CONDITION	MILITARY LOAD CLASSIFICATION	ADDITIONAL BRIDGE INFORMATION (Add columns as needed)				
		HORIZONTAL	UNDER BRIDGE	OVER BRIDGE	NUMBER	TYPE OF CONSTRUCTION	CONSTRUCTION MATERIAL			OVERALL LENGTH	TRAVELER WIDTH	OVERHEAD CLEARANCE	BY-PASS POTENTIAL	REMARKS
1	JA 308167	52	160		2	a	18.2w	35 150	146	52	∞	IMPOSSIBLE		
2	JA 335414	∞	220		6	a	9.2w	30 30	60	40	∞	IMPOSSIBLE		
3	JA 325218	60	41		1	a	33w	80 100 60 180	33	62	4'8"	EASY		

DA FORM 1249

PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 2-6. Bridge Reconnaissance Report

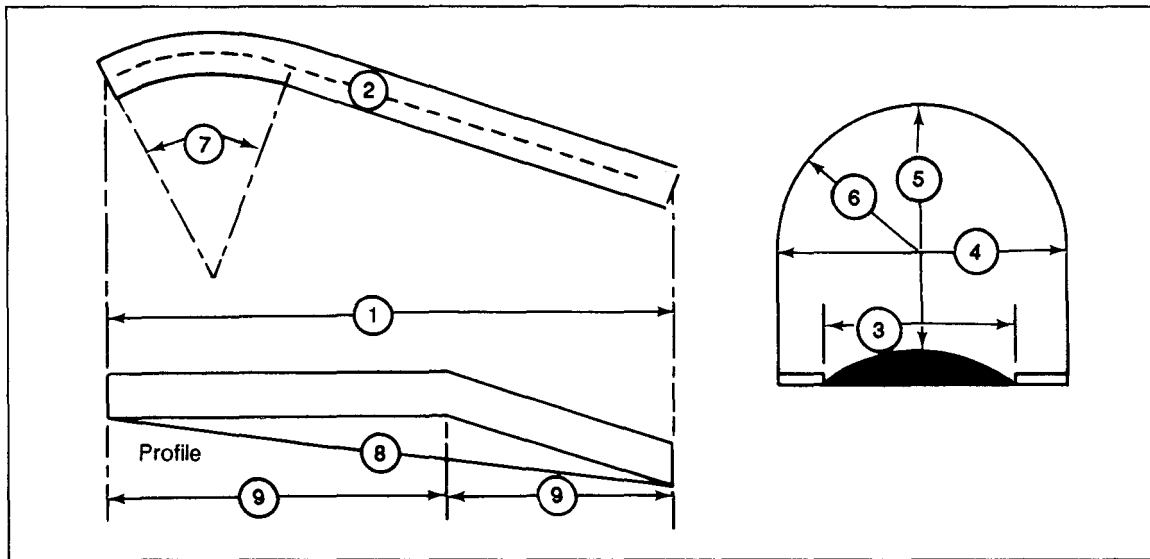


Figure 2-7. Dimensions required for tunnels

tunnels, snowsheds, and galleries. These obstructions can prevent access to vehicles with certain physical dimensions. Reductions in traveled-way widths, such as narrow streets in built-up areas, drainage ditches, and embankments, can also limit vehicular movement. This is an important aspect of transportation intelligence.

Tunnels

A tunnel is an underground section of the route that has been bored or made by cut-and-cover for a route passage. It consists of the bore or bores, portals, and possibly a liner. Tunnel bores are commonly semicircular, elliptical, horseshoe, or square with arched ceiling. Bores may be lined with brick, masonry, or concrete, or they may be unlined. Some very long tunnels on steam-operated railroad lines are artificially ventilated by blowers at the portals or in ventilating shafts above the bore. Alignment of tunnels may be straight or curved. See Figure 2-7.

Galleries and Snowsheds

Built in rugged, mountainous terrain, these protective structures are not as common as bridges or tunnels. Galleries offer protection against snow and rock avalanches. They may be cut into the side of a cliff and have a natural overhang, or the cover may be a concrete slab, either of which guides the avalanche across the track or road. One side of a gallery is usually open. Snowsheds offer protection against snow accumulations and slides on exposed sections of the permanent way.

Ferries

Ferries or ferry boats convey traffic and cargo across a river to another water barrier. These vessels vary widely in physical appearance and capacity depending on the depth, width, and current of the stream and on the characteristics of traffic to be moved. Propulsion of ferries may be by oars, cable and pulleys, poles, or stream current such as trail and flying ferries, or by steam, gasoline, or diesel

LEGEND

1. Portal-to-portal length of tunnel
2. Center line distance of tunnel
3. Effective width of the traveled way, curb to curb
4. Horizontal clearance (minimum width of the tunnel bore measured at least four feet above the traveled way)
5. Overhead clearance (minimum distance between the top of the traveled way and the lower edge of the tunnel ceiling or any obstruction below the ceiling such as trolley wires or electric light wires)
6. Rise of tunnel arch (radius of curved portion)
7. Radius of curvature of the traveled way either measured or estimated
8. Gradient (percentage of rise of the traveled way between portals)
9. Change in gradient within the tunnel (percentage of rise each way from break of grade)

engines. Construction of ferry boats varies widely from expedient rafts to ocean-going vessels.

The capacity of a ferry boat is usually expressed in tons and total number of passengers and is sometimes assigned an MLC number. When more than one ferry is employed for a given site, report the capacity of each.

Climatic conditions have a marked effect on ferry conditions. Fog and ice substantially reduce the total traffic-moving capacity and increase the hazard of the water route. Therefore, data on tide fluctuations, freezing periods, floods, excessive dry spells, and their effects on ferry operations is important.

A ferry site is the place where ferries convey traffic and cargo. Ferry slips or piers are generally provided on the shore to permit easy loading. The slips may vary from simple log piers to elaborate terminal buildings. A common characteristic of ferry slips is a floating or adjustable approach ramp that accommodates variations in ferry deck level. Analysts must consider the limiting characteristics of ferry sites, such as the width of the water barrier from bank to bank, the distance and time traveled by the ferry boat from one side to the other, and the water depth at each ferry slip.

Approach routes to ferry sites have an important bearing on ferry use. Analysts should report the condition of the approaches, including the load-bearing capacity of landing facilities.

Fords

A ford is a location in a water barrier where the current, bottom, and approaches permit the passage of personnel or vehicles and other equipment, where little or no swimming is required, where they cross under their own or assisted propulsion, and where their wheels or tracks remain in contact with the bottom.

Fords are classified according to their crossing potential, or trafficability, for foot or wheeled and tracked vehicles. Fordable depths for vehicular traffic can be increased by suitable waterproofing or, in the case of modern tanks, by adding deep-water fording kits that permit fording depths up to 4.3 meters.

Approaches may be paved with concrete or bituminous surface material but are usually unimproved. Analysts should carefully note the composition and slope of approaches to a ford to permit determination of trafficability during inclement weather and after fording vehicles have saturated surface material.

Bottom conditions are determined by checking the stability and composition of the bed. The composition of the stream bottom determines its trafficability. In some cases, the natural river bottom of a ford may have been improved to increase load-bearing capacity and to reduce the water depth. Improved fords may have gravel or concrete surfacing, layers of sandbags, metal screening or matting, or timber or wooden planking.

Climatic conditions such as seasonal floods, excessive dry seasons, freezing, and other extremes of weather materially affect stream fordability. The velocity of the current and the presence of debris also affect the condition and passability of a ford.

Current estimates are swift (more than 1.5 meters per second), moderate (1 to 1.5 meters per second), and slow (less than 1 meter per second).

Low-water Bridges

Low-water bridges consist of two or more intermediate supports with concrete decking and are located wholly within ravines or gullies. **During** high-water periods, they may easily be confused with paved fords, as both are completely submerged. **Because** of corresponding military load limitations, analysts must properly identify low-water bridges and paved fords.

Cableways and Tramways

Cableways, tramways, and so forth are not usually major factors in a military operation; however, they may be encountered in rugged mountainous regions and beach areas or used as connections between two primary supply routes. In some cases they may extend for several miles and be the best available method for moving supplies.

Pipelines

Pipelines that carry petroleum and natural gas represent an important mode of transportation. While rail, water, and road transport are used extensively for transporting fluids and gases, the overland movement of petroleum and refined products is performed most economically and expeditiously by pipeline. Crude-oil pipelines are used only to transport crude oil, while many refined-product pipelines carry more than one product. These products are sent through the pipelines in tenders, or batches, to keep the amount of mixing to a minimum. **Because** of their most vital link in an industrialized country's energy supply system, coal and ore are also carried in pipelines as slurry.

Components

Pipes are used in long-distance pipelines and in many local lines. They are composed of welded steel with diameters varying from 15 centimeters to more than 1 meter, depending upon the economies of the line's construction. The pipe may be laid either underground or above ground **and** may extend cross-country or follow the alignment of roads and railroads. When a pipeline must cross a stream, the pipes are usually laid along the stream bottom. Where streams are **swift** or where beds may shift rapidly, either the pipe is attached to existing bridges **or special** pipeline suspension bridges are built. Siphon crossings are used where necessary,

When an increase or decrease of pressure is required, regulating features such as pumps or compressors are used. Pumping stations are used for liquid fuels and compressor stations for gas. They are similar in appearance except for the cooling towers present at compressor stations.

Valves, manifolds, and meters are integral parts of any pipeline system and are located at frequent intervals along the pipeline and at terminals. Valves protruding from the ground are often the only indicators of a pipeline alignment.

Terminal Facilities

Refinery terminals consist of numerous tanks for the separate storage of crude oil and refined products. Facility size and type depends on whether the refinery is located near the source of supply or consuming center. Refined-product dispensing terminals contain a variety of products for final distribution.

Natural gas is generally stored in bulk, below the ground, and under high-pressure. Large underground gas storage pools, usually caves or quarries near consuming centers, are often used to store gas for seasonal or emergency needs. Above ground, natural gas is stored mostly under pressure in spherical tanks, but large telescoping tanks are sometimes used for low-pressure storage. Natural-gas receiving terminals are located at the producing field and contain facilities for conditioning the gas for pipeline transmission. Natural-gas dispensing terminals are located at

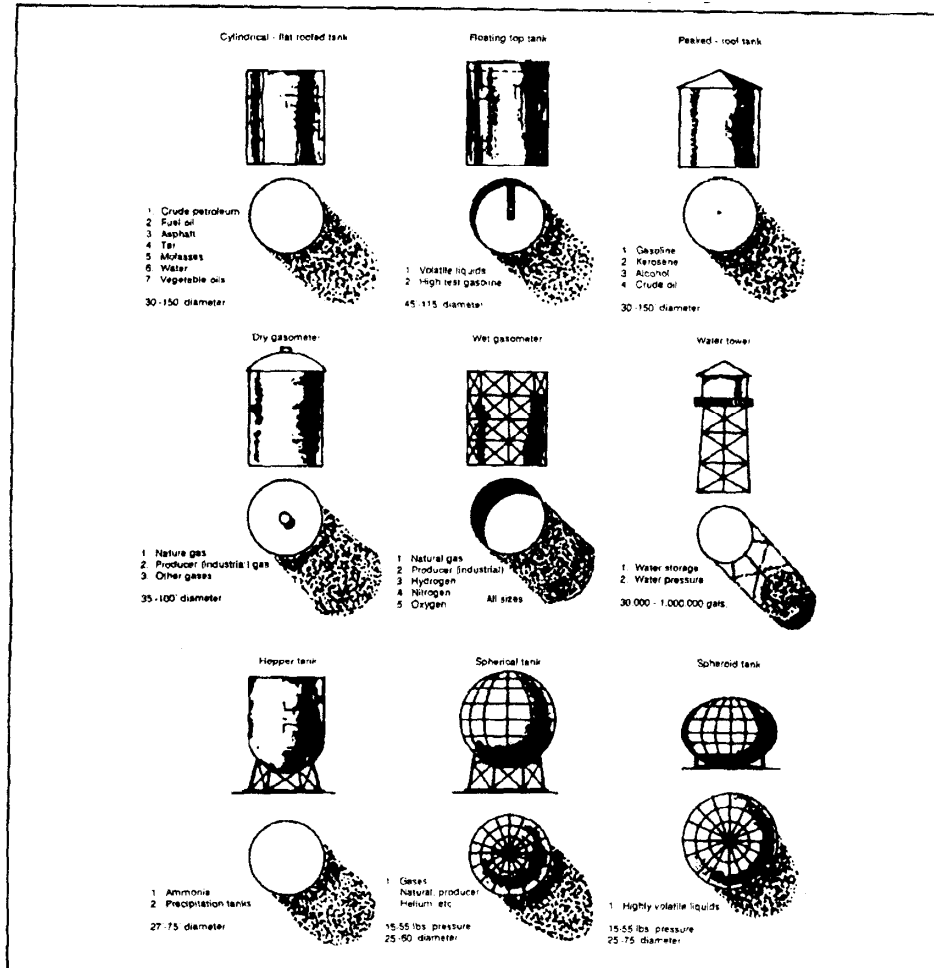


Figure 2-8. Storage tanks - Shapes

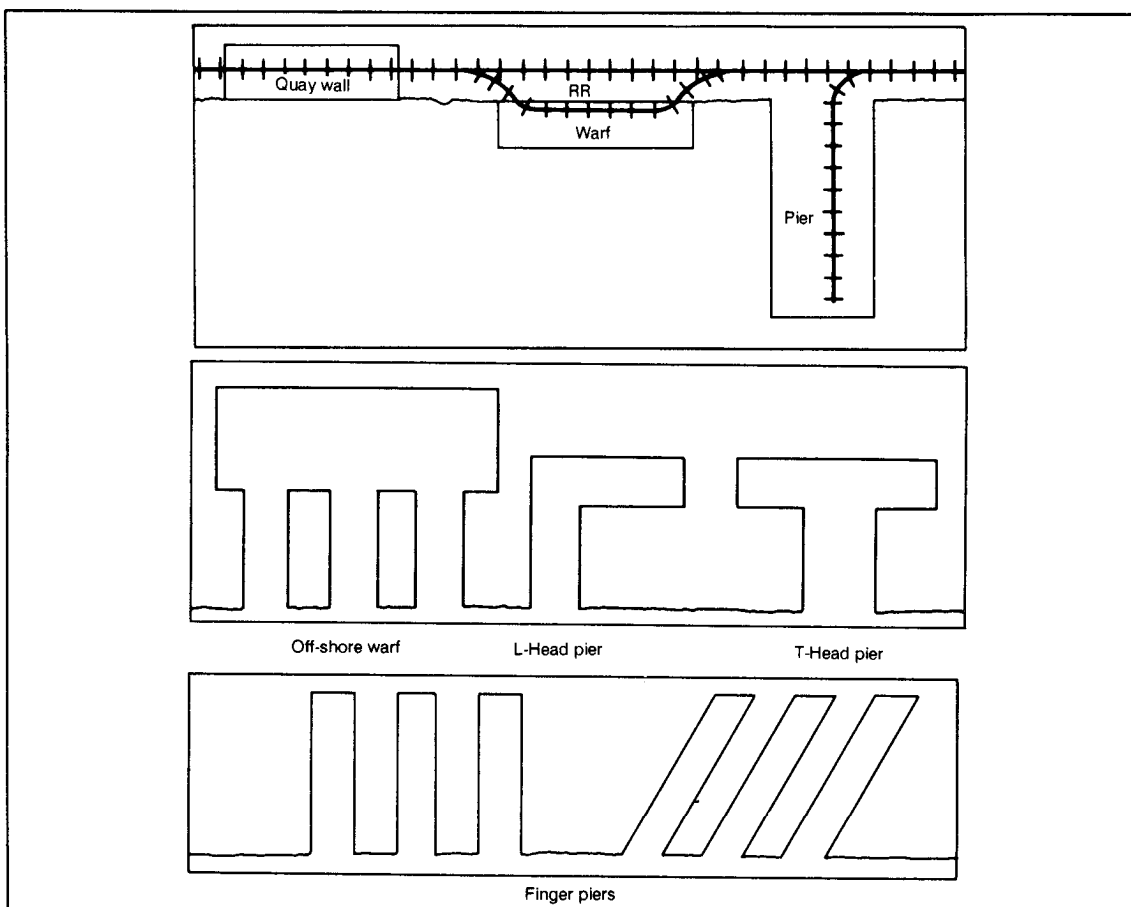


Figure 2-9. Berthing facilities

consuming centers and include dispatching and metering facilities and sufficient storage facilities to meet peak demands.

Storage tanks, found in varying numbers at all petroleum installations, are easily recognized. Volatile products such as gasoline and kerosene are generally stored in floating roof tanks. These tanks have roofs that float on the liquid to reduce space in which vapor might form. Nonvolatile products such as fuel oils and crude oil are stored in fixed-roof tanks. Petroleum gases are generally liquefied and stored under pressure in spherical tanks or in horizontal cylindrical tanks. The number and variety of tanks in a storage installation indicate the quantity and types of product stored. Areas of great extent and capacity are called tank farms. See Figure 2-8.

PORTS AND HARBORS

Information about ports, naval bases, and shipyard facilities is essential for estimating capacities, vulnerability, and other items of military significance.

Ports

Ports are settlements with installations for handling waterborne shipping. Principal port facilities are berthing space, storage space, cargo-handling equipment, cargo transshipment facilities, and vessel-servicing facilities. Ports are classified on an areawide rather than a worldwide basis, and a principal port in a small

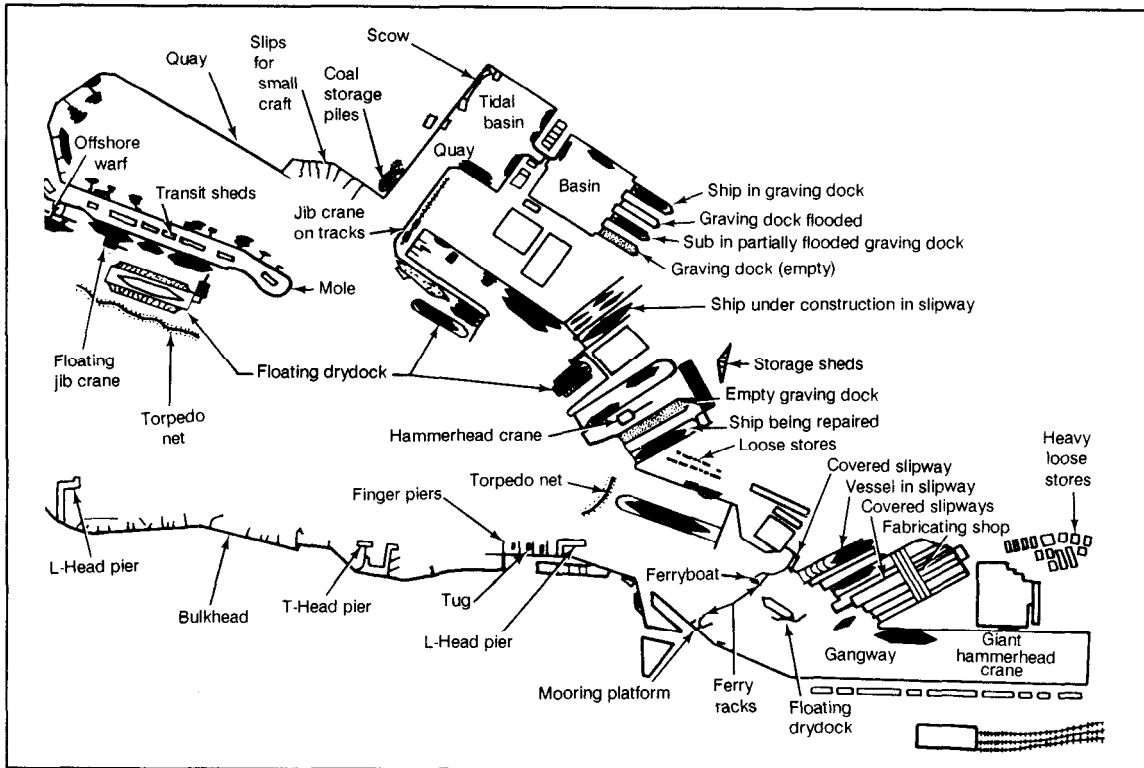


Figure 2-10. Annotated overlay of a European harbor (Kiel, Germany)

maritime nation may be equivalent to a much lesser port in the more extensive port system of another country. In wartime, principal and secondary ports and bases are prime targets for destruction, and the relative importance of minor ports increases. See Figure 2-9.

Ports may have various structures affording berthing space or may be anyplace a vessel may be made fast. These structures include piers, moles, and wharves or quays. Perhaps the most important difference between these structures is that piers are supported by pilings driven into the harbor bottom, while moles are of solid construction. In addition, wharves and quays are parallel with the shoreline, while piers and moles are perpendicular to it.

Harbors

Harbors are areas where the anchorage and shore are protected from the sea and storms by natural or man-made barriers. Areas that do not have this protection but are still suitable for vessel anchorage are open anchorages or roadsteads. A good harbor must have deep water, adequate protection from storms, enough space to accommodate large numbers of vessels, and a shoreline that can be developed as a port and as a site for industry. Harbors may be situated on the sea, estuaries, or inland lakes and rivers and may easily be recognized by abundant waterborne traffic and port facilities. See Figure 2-10.

Relatively few strategically located natural harbors are large enough or safe enough to be valuable to shipping. Many of the important harbors of the world are man-made. Most harbors have some or all of the more common artificial protective

structures. A breakwater is a massive stone or masonry structure extending across or at an angle to the entrance to the harbor. A jetty is the name applied to a breakwater that connects with the shore. A mole is a jetty that is wide enough to allow construction of a roadway along the top. A sea wall is a structure built along the coastline to prevent the sea from eroding the land.

Within the harbor itself are various types of buoys used as navigational aids. In addition, lighthouses, mooring buoys, and dolphins are often present. Mooring buoys are huge buoys located in the harbor so that vessels may tie up without dropping anchor. Only when a harbor has been developed for transacting business between ship and shore does it become part of a port. Dolphins are groups of pilings driven into the harbor bottom for the same purpose.

Dolphins usually consist of a cluster of piles lashed together at the top. They are located off shore and are used singly for mooring into or hauling out of a berth and in a series for mooring a ship alongside. Dolphin moorings conserve space in the stream and are used either for idle berthing or for loading cargo from lighters. Dolphins are often associated with a wharf either as a protective device at wharf corners or as a means of increasing the length of berthing space provided by a wharf face.

A dock, also called a slip or berth, is the water adjacent to a mole, pier, or wharf when that water area is narrow and affords berthing space. Basins are broad and expansive, artificially enclosed bodies of water that form a harbor or part of a harbor. They may be tidal basins in which water is subject to tidal influences, or controlled-level basins in which the water level is maintained irrespective of tidal change. Controlled-level basins are either wet docks or half-tide basins. A wet dock is enclosed by a gate, caisson, or lock. It may be filled by naturally impounding water at each high tide or at spring tides only. Pumping plants may be provided for initial filling or for elevations of the water above that achieved by natural impounding. The half-tide basin has gates at each end and is used in much the same manner as a large leak to increase the enormous amount of water required to raise the water level. It cannot be used at all states of the tide.

Harbor works, including protective works, are structures designed to provide shelter, control water flow, and regulate erosion for improvement of the navigability of a harbor. The principal structures are breakwaters, jetties, groins, sea walls, bulkheads, dikes, locks, and moles. Harbor works do not include port facilities that are designed specifically for transfer of cargo and the servicing ships.

Depths are important in such port topics as harbor, entrance, anchorage, wharves, and dry docks. They are computed in terms of established reference planes that are based on but do not necessarily coincide with tidal levels. The particular reference plane on which depths on a hydrographic chart are based is called chart data and is defined on the chart. Precise data is established for most ports and is a basis for soundings. Analysts should clearly indicate the reference plane when reporting depths.

The navigable waterways through the approach, the entrance to the harbor, and the harbor itself frequently determine the size of the ships (draft, length, beam, height above water) that can be accommodated in the port. Analysts should describe in detail any thruway with controlling dimensions that limit the size of

ships which can traverse it. Reports on the experiences of ships with critical dimensions that have entered are most helpful.

Cranes (Cargo-handling Equipment)

Cargo berthing space may be recognized by the presence of heavy handling equipment located on piers or wharves. However, very small ports may not have any such equipment, requiring vessels to supply and use their own. Port cargo-handling equipment includes various hoists for handling general cargo and special equipment for other cargo.

A gantry crane is a traveling crane on rails that consists of a hoist on a heavy cross girder supported at two points. Hoisting is performed by a trolley or crab that moves transversely along the bridge. Gantry cranes occasionally serve as a base for a jib crane, the latter being mounted on and capable of transverse movement along the bridge member. They are used extensively in shipyards for hull erection and in various industrial yards and shops for heavy lifting. They are almost always electrically operated. Depending on use, they may range up to 250 tons capacity. Hoisting capacity is constant regardless of the position of the crab or trolley on the bridge.

A cantilever crane consists of a base or tower structure on which is mounted a counterbalanced horizontal arm or jib. A trolley that can be racked along rails on the cantilevered jib carries the hoisting sheaves. The trolley does not carry the hoisting mechanism but merely serves to support the fall, and its transverse movement is controlled by a system of sheaves and ropes. Cantilever cranes are most commonly found in shipyards, although they may be used for cargo handling in special instances where a large working radius is required. They are normally electrically powered and range up to 250 tons or more in capacity. Capacities should be reported at maximum and minimum radius. One type of cantilever crane is the hammerhead. These cranes are supported at one point, about which the mechanism can turn. The hoisting end is balanced by a cab or counterweight. The entire machine may be mounted on rails for movement along the pier or wharf.

A jib crane consists of the primary arm on which is mounted a shorter arm, or jib, extending at an angle. At the end of the jib are sheaves through which run the fall from which the load is suspended. The fall is raised and lowered by a hoisting mechanism built into the crane. Jib cranes are frequently mounted on gantry, bridge, or trestle bases, where they are capable of transverse movement. Because of their versatility, they are the most common cranes and have a wide range of uses. They include wharf cranes for handling general cargo and many cranes used in shipyards. They are usually electrically powered and range in capacity from 3 to 5 tons. Other jib cranes may range up to 100 tons or more. Analysts customarily report the capacity at minimum working radius and at maximum radius. They must also indicate the maximum height of lift above the wharf deck for wharf cranes.

A floating crane is almost any crane mounted on pontoons or barges. The float may range from a simple wooden barge to an elaborately constructed steel hull with built-in balancing tanks and pumps. Large floating cranes, usually steam powered, are commonly used in harbor construction, salvage operations, or transfer of heavy cargo to and from ships. Capacity may exceed 400 tons. Small floating cranes, driven by internal combustion engines or operated manually, are used for many lifting tasks. The operating dimensions are reported similarly to those for shore

cranes, except that reach beyond the pontoon is substituted for radius. Dimensions of the pontoon include length, beam, draft forward, and draft aft.

A derrick consists of a vertical mast supporting a pivoting jib or boom. The mast may be stayed by cable or beams anchored to the ground, with the fall running through sheaves at the end of the jib. Large derricks are used for miscellaneous heavy-lifting tasks and run on steam, gasoline, diesel, or electricity. Small derricks are used for simple cargo handling and are operated manually or are driven by gasoline or diesel engines. Derricks and shearlegs are normally the simplest and least expensive cranes. Depending on size and type, capacity may range from 1 to 40 tons. The jib of a derrick functions similarly to that of a jib crane, and operating dimension should be reported the same way.

A shear-leg crane is a fixed hoisting device with a leaning tripod supporting the system of pulleys and cables. Heavy shear legs may range up to 150 tons capacity. In hoisting and lifting motions, the operating dimensions are comparable to those of the jib crane.

A locomotive crane may be recognized easily, because it is mounted on a special railroad flat car. A revolving elevated crane is mounted on a high, derrick-like structure that moves along rails. An overhead crane differs from a gantry crane in that the supporting mechanisms do not move as they do on the gantry. A bridge crane is constructed so that the crane may travel beyond each supporting leg.

Anchorage

Much of the anchorage data can best be shown on large-scale charts and plans. All available operational information should be reported, including anchorage designations and berth assignments by local authorities, normal anchoring practices, and ship experiences.

Fixed moorings may consist of anchored buoys or mooring posts. They are provided in harbors where space restrictions prohibit free-swinging anchorage, where the number of accommodations is limited, and when they provide a more secure berth than a ship's own anchors can provide.

Mooring buoys can provide several berth types, including free-swinging (one buoy), ship's head secured to buoy; bow and stem (one buoy), ship secured ahead by own anchors and astern to bollards ashore; bow and stem (two buoy), ship secured to buoys ahead and astern. Buoys may be held by a single anchor, but two or more anchors laid at varying angles are generally used for greater holding capacity and more precise positioning of the buoy. When more than one anchor is used, each may connect independently with the buoy secured by a pendant chain. Mooring buoys, particularly those used by naval craft, may be fitted with submarine cable connections for telephone, electricity, and water. The holding capacity of the buoy is important information.

Ships may lie infixed moorings without buoys in a variety of ways. The simplest method, that of mooring with one or both anchors ahead and stem lines to bollards ashore, is used where wharf facilities are limited, and is commonly used in Mediterranean ports.

Harbors are usually subject to sea and swell, and navigation and port operations are consequently affected. Duration and seasonal variation in sea and swell conditions are important factors to analysts, as are specific effects on lighterage and boat work on anchoring and mooring and on movement into and about the harbor.

Wharves

The majority of landing structures are either piers or wharves. Piers project into the water at an angle with the shoreline. Berthage is usually available on both sides of the pier and at the head as well, if the structure is wide enough. Variations of the simple straight pier are the T-head pier and the L-head pier. These piers are commonly used to transfer bulk petroleum, and berthage is generally confined to the pier head.

Wharves form the pivot point for port operations, and detailed information concerning them is necessary to evaluate a port's capabilities. Generally, wharves include all landing structures, even piers. Specifically, a wharf is a structure that parallels the shoreline and provides berthage at its face only. A wharf's design is determined largely by its intended use and by local conditions and engineering practice. Variations in names of landing structures cause considerable confusion, and analysts should be careful to use the proper term. The term *dock* is properly used in northwestern European countries to designate a water area; in the US, however, it is applied generally but erroneously to any and all types of landing structures. The pier structure is commonly called a jetty in British and other foreign ports, and all marginal structures are *quays*. Improper classification will often be embodied in the proper name of a wharf, but the reporting officer should not arbitrarily change the name. In describing the structure, however, the analyst should correctly indicate the wharf type.

The wharf type may be marginal, quay, or offshore. The marginal wharf and quay are both built parallel to and against the shore and differ only in construction type. The marginal wharf is constructed of open piling, while the quay is a solid wall of masonry or other material. The offshore wharf is a structure of open piling built parallel to but in an insular position off the shoreline. It may be connected with the shore by one or more approaches or gangways or pipelines. A variation of the offshore wharf commonly used in the Far East is the pontoon wharf, which consists of pontoons of various construction moored in a fixed position offshore and connected with the shore by one or more adjustable gangways. This type is used where the water level fluctuates considerably.

Two special wharf types are the mooring platform and the breasting platform. The mooring platform is a small offshore wharf with a square platform or deck. It provides berthage for a ship but is too small for cargo transfer. Mooring platforms commonly are provided in groups of two or more, and ships are berthed across the faces. One or more of a group of mooring platforms are generally connected with the shore by a narrow approach or trestle, and platforms may be connected by catwalks. The breasting platform is a small platform structure projecting from the face of the wharf bulkhead. Breasting platforms are usually provided in groups of two or more, and ships are berthed across the heads. See Figure 2-11.

An offshore pipeline berth is connected to the shore solely by a submarine or floating pipeline, which permits cargo transfer directly to storage installations on shore.

In a terminal buoy system, the terminal buoy looks similar to the standard mooring buoy but is substantially larger. It is positioned offshore in deep water with three or more chains attached to heavy anchors. The terminal buoy has a revolving platform or swivel to which the tanker is secured as are the floating hose lines for cargo, bunker oil, and fresh water. When the buoy's flexible hoses are coupled to the ship's system, this permits ship and hose lines to swing together a full 360 degrees with the wind or sea. Product transfer proceeds through submarine pipelines connecting the buoy and ashore installation.

Wharf construction and materials vary greatly; however, most structures are either open or solid construction. Open construction is used for marginal wharves, offshore wharves, and most piers. In its simplest and least permanent form, it consists of open-spaced wooden piling supporting a wooden deck. Variations designed to contribute to the strength and permanence of the open structures are

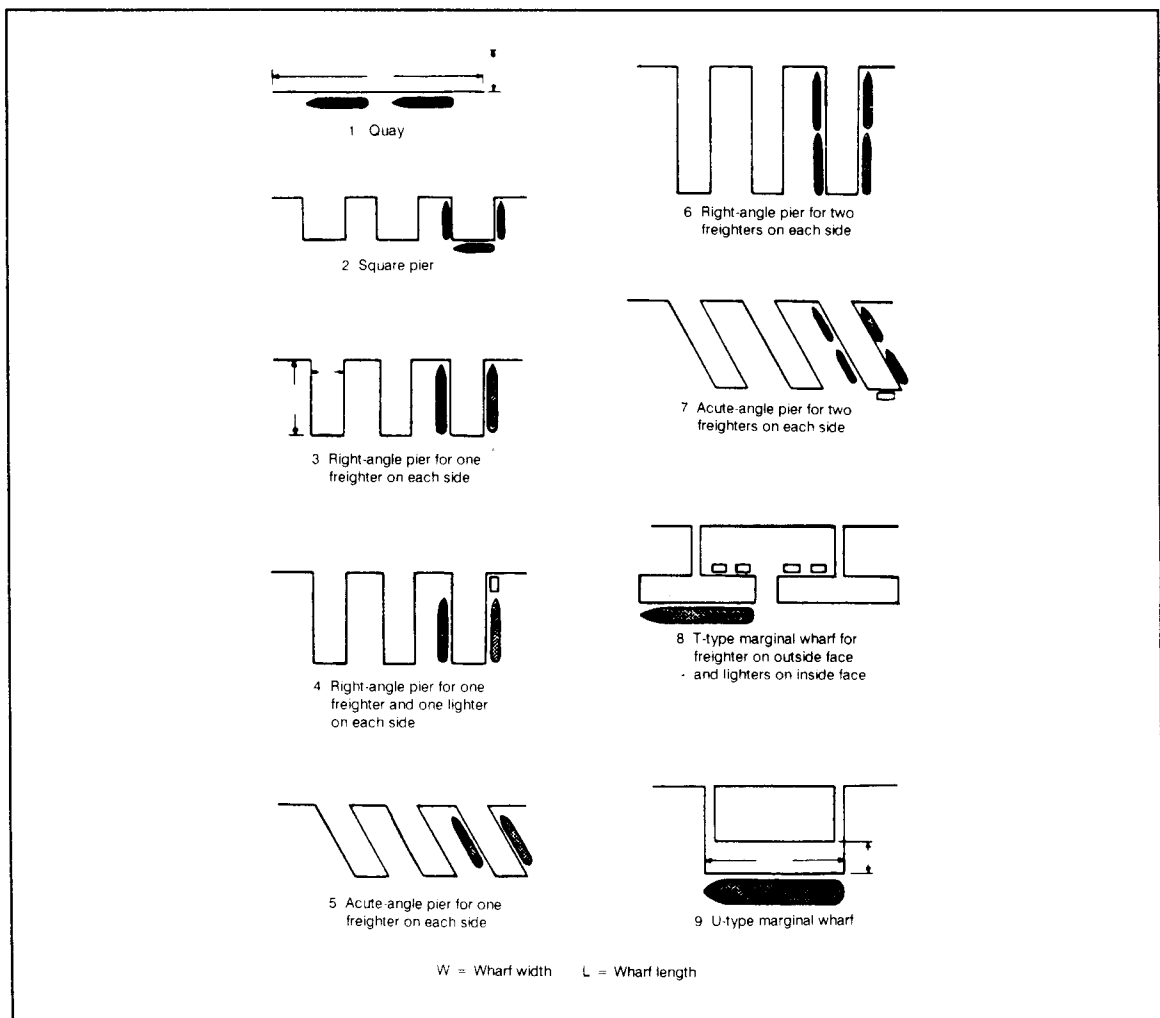


Figure 2-11. Types of wharf layout

numerous. Substructures may consist of steel or precast concrete piling. The superstructure or decking may vary from wooden joists and flooring to concrete and steel construction with an asphalt or other paved surface.

Solid construction is used in quays (and occasionally in piers) and consists of a solid backfill against a retaining wall and covered with a surfaced decking. Quay walls may be a simple facing of interlocking sheet steel piling, a monolithic concrete wall, or a masonry structure built of stone or precast concrete blocks. Many quays abroad consist of large concrete caissons sunk in line to form a wall, then filled with concrete or rubble and capped with a reinforced concrete deck.

Wharves require several basic dimensions; careful measurement and precise identification of reference points is essential. Measurement may be in either feet or meters, since conversion tables are available.

The length of one side of a pier may differ from that of the other, and both should be reported. The side of a pier or the face of a wharf may be irregular or stepped, and a dimension should be reported for each segment. Usable berthing space may or may not coincide with the overall length; shoals or other obstructions may decrease the usable length of a wharf.

The width of a marginal wharf may be difficult to determine, since the inner limit may not be defined. In such cases, the measurement points should be clearly identified. Width of apron is not to be confused with width of wharf. The apron is the working part of the wharf deck at shipside; it terminates at the transit shed or other obstruction.

The type and condition of the deck surface has an important bearing on the usability of a wharf. Analysts should indicate the layout of wharf railroad tracks with respect to the wharf deck. They should be particularly careful when reporting berthing capabilities of a wharf. Special or unusual berthing conditions include the breasting of ships off the wharf by means of pontoon, the presence of surge or swell that might require special mooring precautions, and draft limitations.

Harbor Craft

The operation of most ports requires a fleet of various harbor crafts. Although in large ports the composition of the fleet may undergo frequent changes, information about types, general numbers, and operating characteristics of harbor craft is essential.

Tugs are generally seagoing or harbor. Analysts should list the horsepower, power type, operating range of seagoing salvage tugs, and special equipment such as salvage or fire-fighting equipment. When no tugs are present, launches are important. They may be grouped by horsepower and power type.

Lighters may be broken down by size and type (self-propelled and dumb); in large ports their numbers may be given in round figures. Information requirements include such details as capacity, construction, power type, and specialized lighters for handling ammunition.

Harbor-dredging operations use dredges, hopper barges, and rock breakers. Dredges vary in type and mechanism, depending on the nature of the bottom

sediments to be worked. Hopper barges are self-propelled or dumb barges fitted with self-emptying hoppers. They haul material recovered by dredges. Rock breakers, as the name implies, are used in special cases when loosening of rock from the harbor floor is required.

Shipyards

Complete up-to-date information is required on shipyard facilities and on all firms capable of making marine repairs but lacking dry-dock facilities. Valuable information is contained in maps, yard plans, individual facility plans, shop layouts, photographs of yard facilities, and docking manuals. Each shipyard should be positively identified by position within a city or port, with references to outstanding landmarks on waterfront, rivers, and tributaries.

The principal types of dry-dock facilities are the graving dock, floating dry dock, and marine railway. The three gate types provided for graving docks are leaf gates, flap gates, and sliding caissons. Leaf gates are hinged swinging gates that fold back into recesses in the walls of the entrance when the dock is open. Flap gates are hinged at the bottom and lowered outward to a horizontal position in the approach to the dock. The sliding caisson rolls or slides on a track on the dock sill.

Ship construction and conversion are not treated in detail in port studies dealing with terrain intelligence; however, information about the physical facilities used in construction and repair are valuable to the intelligence analyst. This information includes the types of structural, engineering, electrical, and miscellaneous shops in which various shipbuilding and ship repair processes are performed; the types of ships constructed and the largest of each type constructed to date; whether repairs can be made without dry docking by means of caisson; the yard's reputation for speed in accomplishing repair work; and the general capabilities of the yard as to hull, engineering, and electrical repairs.

Naval Bases

Natural features required of a good naval-base site include a harbor with deep-water approaches; protected and spacious deep-water anchorages; positions capable of being easily defended; sufficient land for expansion; elevation of approximately 1.5 to 3 meters above mean high water at the waterfront; suitable ground for the foundation of dry docks, buildings, and heavy equipment; and an ample supply of safe, freshwater. Local labor, materials, and transportation must be adequate to support the operation. Secondary stations of the shore establishment are necessary to fleet operation.

Although they will vary in both size and relative importance, certain functional components are common to given types of naval bases. Submarine bases will almost always contain a torpedo shop, battery repair shop, electrical battery-charging equipment, and high-pressure air-charging equipment. Medical components of a large activity may contain, in addition to the normal medical and dental equipment, specialized equipment and resuscitating gear for divers. Analysts should indicate whether or not a particular component is included among the base installations.

Landings

Landings may be structures that are usable for landing, although primarily designed to serve some other function, or they may be beaches in the harbor on

which landings are possible. Landings assume particular importance when a port becomes unusable by damaged or sunken vessels and when they must serve as the supplemental or principal medium of transfer between ship and shore. These structures include breakwaters, sea walls, bulkheads, seaplane ramps, and beaching hardstands. In wall-type structures, the length, depth alongside as referred to chart data, height of the top above chart data, and batter of face wall are significant. For all structures, analysts should identify the construction type, condition of the sea and current alongside, and clearance facilities.

Airfields

Air facilities are the military and civilian installations upon which a nation's air operations depend. The fundamental air facilities are airfields, seaplane stations, and heliports. Each has its own facilities such as runways, hangars, fuel systems, maintenance ships, and crash, fire, and service equipment. At some small foreign airfields, many functions may be combined in one or two centrally located buildings.

A. Airfields:		
No.	Feature	Specifications
1.	Runways	Outline runways to scale.
2.	Taxiways	Outline taxiways connecting runways, aprons, and hardstands to scale.
3.	Aprons	Outline aprons to scale.
4.	Hardstands	Outline hardstands to scale.
5.	Airfield perimeter	Draw a boundary line representing the airfield perimeter.
6.	Structures	Outline all structures. Number each and list in the Data Table.
7.	Airfield name-elevation	Place name and elevation just outside the perimeter symbol.
8.	Runway azimuth	Place the runway azimuth at the end of the runway outline (within or just outside).
9.	Runway length and width	Place length and width designations inside, or just outside runway outline.
10.	Approach lighting	Show locations along line drawn to scale (length).
11.	Runways lights	Show locations by dot symbols along the lateral boundary of the runway.

Figure 2-12. Symbol specifications for airfields and heliports

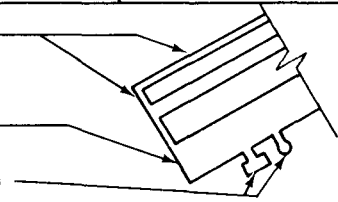
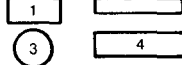
B. Heliports:			
No.	Feature	Symbol	Specifications
1.	Landing area - runways		Draw outline of the landing area or runway to scale.
2.	Taxiways		Outline taxiways connecting runways/landing areas, aprons, and hardstands to scale.
3.	Aprons		Outline aprons to scale.
4.	Hardstands		Outline hardstands to scale.
5.	Heliport perimeter		Draw a boundary line representing the heliport perimeter.
6.	Structures*		Outline all structures. Number each, and list in Data Table.
7.	Heliport name/(No.) elevation	Columbus - 200m H-1	Place name (No.) and elevation just outside the perimeter symbol.
8.	Helipad (without facilities)		Circle .4" dia Letter .3" high

Figure 2-12 continued. Symbol specifications for airfields and heliports

The most advantageous location for an airfield is an area free from natural and cultural impediments to operations. An elevated rather than low area is preferred because of the absence of terrain obstructions and generally more favorable local weather conditions. Low areas are frequently exposed to adverse wind conditions, fog, and occasional flooding. Another important factor in airfield location is its intended use. Major civil airfields will almost always be located near the cities they serve. Major military installations, which normally require more land because of their vast complex of fixed facilities, are more often constructed some distance away from large cities. See Figure 2-12.

Auxiliary airfields are normally located near major operational or training bases. Often these facilities are on caretaker status during part of the year when their additional capacity is not needed.

A helipad is an area specifically designated and marked for helicopter landings and takeoffs. The surface of the pad may be natural, temporary, or permanent. A helistop refers to a helipad with little or no facilities and is used for on- and off-loading of cargo or passengers.

An airfield runway is a flat landing surface with a true or magnetic heading, normally taking advantage of prevailing winds. The number of runways or runs may vary from one to several, which are usually oriented in different directions. Some airfields have parallel runways (two runways with the same headings - not to be confused with a parallel taxiway). Runways are the most significant features of an airfield, and detailed information concerning them, taxiways, and parking areas is essential to properly evaluate the airfield's capabilities. The length, width,

load-bearing capabilities, and pavement condition directly influence the type and amount of traffic an airfield can accommodate.

Taxiways are access paths to parking aprons, hangar aprons, and handstands or revetments. A parallel taxiway parallels the runway but is usually narrower. Under emergency conditions it may be used as a runway, but it should not be reported as a runway. Link taxiways connect the runways with other taxiways, parking and hangar aprons, or revetments. A perimeter taxiway usually starts at one end of the runway and ends at the other, and is normally oval. Loop taxiways are normally located at or on both ends of the runway, forming a loop. The alert taxiway is located at the end of the runway with clear access to the runway for a scramble by fighter interceptors.

Runways, taxiways, aprons, and revetment surfaces may be permanent, temporary, or natural. Permanent surfaces such as concrete or asphalt have distinct edges and ends, while temporary surfaces such as mixed-in-place madam or oiled earth have ragged and uneven edges and ends. Permanently surfaced runways are easily discernible and may have jet barriers or arrester gear. Jet barriers are located on the overrun, whereas the arrester gear is normally flush with the runway and located approximately 500 meters from the end of the runway. This 500 meters is usable runway and should not be confused with an overrun.

Measuring permanent or temporary surfaced runways should not be difficult. The major difficulties are locating and arriving at the measurements of natural surface marked with painted barrels, reeks, or broken white lines. Runway lengths and surfaces vary according to the use or intended use of the airfield.

The weight- or load-bearing capacity of a runway, taxiway, or apron is a determining factor in its capability to accept aircraft without damage to the aircraft or the facility. The engineering factors involved in determining weight-bearing capacity are complicated; however, other sources for this information are route manuals, air information publications, airfield managers, and engineering documents. If these sources are not available, information about the type and weight of aircraft (partially or fully loaded) operating out of a given airfield will enable the analyst to estimate the weight-bearing capacity of the runway.



Natural Terrain

Chapter 3

SURFACE-CONFIGURATION OVERLAY

The surface-configuration overlay is used to depict the inclined surface of the terrain and is expressed using percent of slope or change of elevation (rise) divided by the horizontal distance (run).

This overlay is one of the primary overlays used in determining the cross-country movement capability of troops and vehicles.

A 1:50,000 topographic map is required to construct a surface-configuration overlay using TTADB product specifications.

Step 1. Examine topographic maps. Construct a surface-configuration overlay for the TTADB using a standard 1:50,000 topographic map with a variety of possible contour intervals. A contour interval of 20 feet or less is preferred for constructing this overlay.

Register the overlay to the database or map you are using. Cover the selected topographic map with a clean sheet of mylar and tape them together. If the area of interest does not cover the entire map, outline the area of interest on the mylar in black pencil or ink and note the longitude and latitude or UTM coordinates at the corners.

Annotate the map sheet name and number, map series, map edition, scale, contour interval, factor overlay type (surface configuration) and classification, if required, on the overlay.

Step 2. Depict surface-drainage features. Trace the boundaries, in black pencil or ink, of all islands longer and wider than 250 meters (5 millimeters at the scale of 1:50,000). Show long, narrow islands (those less than 250 meters wide) only if they are greater than or equal to 1000 meters in length (20 millimeters on the map).

Trace the boundaries of all open-water bodies such as ponds, lakes, reservoirs, and double-lined streams in black pencil or ink. Label all open water with a **W**.

Step 3. Depict dissected terrain. Trace the boundaries of all naturally and/or culturally dissected land areas in black pencil or ink and label with a **G**. Dissected terrain includes, but is not limited to, pits, quarries, dumps, landfills, piles, ravines, and gorges. Many of these features are easily recognized on topographic maps.

Step 4. Outline and label slope categories. Select a slope calculator (See Figure 3-1.) that was constructed for the scale and contour interval of the map used. A slope calculator, also called a template or wedge, is an instrument for measuring the percent of slope on a topographic map. This instrument is constructed of a transparent, stable-base material and is marked with predetermined distances that correspond to the desired slope category. Ensure the slope calculator has the required slope categories established within the TTADB product specifications. If a suitable slope calculator is not available, you must construct one for the map you are using.

Example: Construct a slope calculator for slope categories of 0-3 percent and 3-10 percent, given a 1:50,000 topographic map with a contour interval of 20 meters.

a. Determine the horizontal distance required, with an elevation difference (contour interval) of 20 meters to equal the largest slope percent of a given category.

$$HD = \frac{CI \times (100)}{\% \text{ slope}}$$

HD = horizontal distance

CI = contour interval

% slope = largest slope percent of a given category

(100) = constant

Formula: Slope category A (0 to 3%)

$$HD = \frac{20 \times (100)}{3}$$

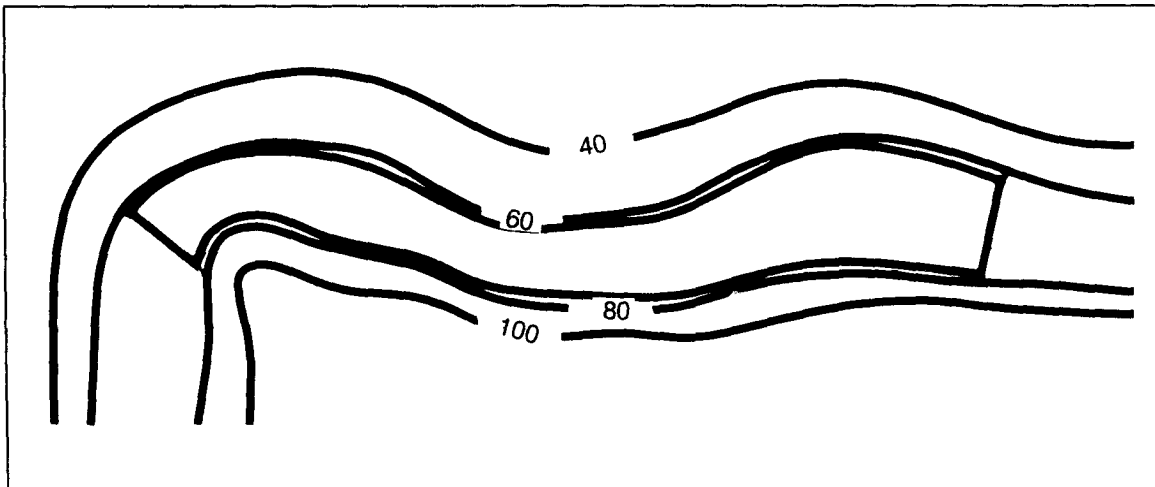


Figure 3-1.

Hd = 666.6 meters (CI was in meters)

Formula: Slope category B (3 to 10%)

$$HD = \frac{20}{10} \times (100)$$

HD = 200 meters

b. Determine the map distance, or the spacing of the contour intervals, required to construct the slope calculator for categories **A** and **B**:

$$MD = \frac{HD}{D}$$

MD = map distance

HD = horizontal distance (from previous formula)

D = denominator of map scale

Slope Category A (0-3%)

$$MD = \frac{666.6}{50,000}$$

MD = .01333 meters or (13.33 mm)

Slope Category B (3-10%)

$$MD = \frac{200}{50,000}$$

MD = .004 meters or (4 mm)

Note: You must calculate map distances for each slope category outlined in TTADB product specification (PS/3JB/020) and for any slope category required for a special-purpose product.

c. Construct the slope calculator. Construct the slope calculator using the map distance calculated from the above formulas on a clear, stable-based material. Draw several ticks representing the same slope category.

d. Outline the slope categories. Analyze the contour lines on a topographic map using the slope calculator to outline and label slope categories. Slope categories are areas on a map where the slope is the same or is in the same category.

Start the slope analysis in the upper left-hand corner of the map and determine map areas whose slope (contour interval) matches the 0 to 3 percent (or lowest category required) slope category on the calculator (See Figure 3-2). When you have outlined all areas within this category using a black pencil or ink, label all outlined areas with an A or representative symbol from your legend.

Continue this analysis for all slope categories that you have outlined and labeled. Prepare the surface-configuration legend according to TTADB product specifications.

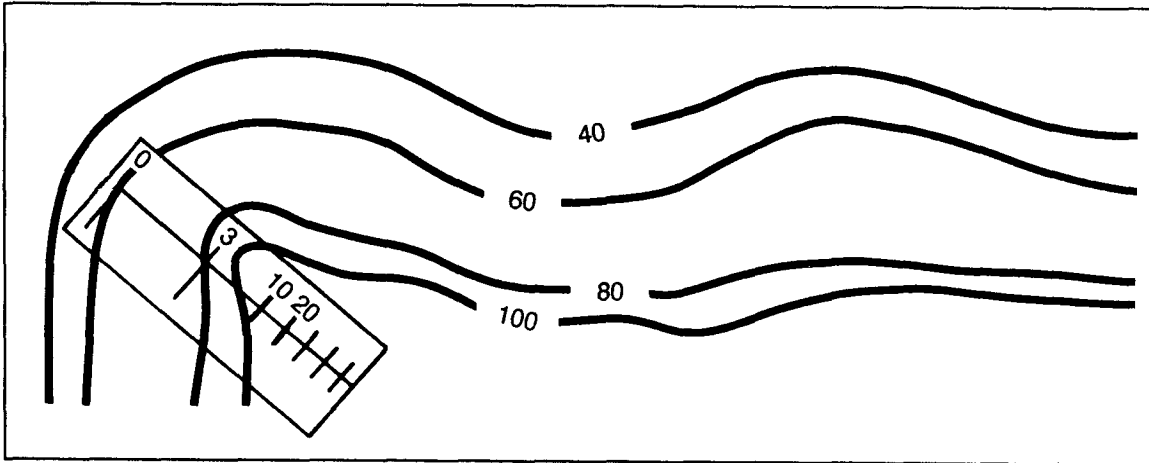


Figure 3-2. Slope example

Step 5. Determine slope from aerial photography. Determining slope from aerial photography requires complete stereo coverage. It is time-consuming and requires more skill than using a topographic map. You should use this method only if topographic maps are not available or if you need precise slope measurements from a point to a point. You cannot use this process to compile a surface-configuration factor overlay, since this overlay is keyed to a topographic base map.

Step 6. Construct the final overlay. The final step in producing a factor overlay is to put the draft manuscript overlay into a final database product. You must have support from the cartographic and reproduction elements or sections. See Chapter 8 for the final overlay procedure.

VEGETATION OVERLAY

The vegetation overlay shows natural and cultivated vegetated areas, with information about type, size, and density. This factor overlay is one of the primary overlays used in determining the cross-country movement capability of troops and equipment, cover and concealment line of sight, and location of construction resources.

A 1:50,000 topographic map and complete stereo imagery is required to construct a vegetation factor overlay using TTADB product specifications.

Step 1. Collect required collateral data. The vegetation factor overlay is one of the most complex and difficult factor overlays terrain analysts construct. No single source data can provide all of the data required to complete the vegetation factor overlay and data tables. In most cases, analysts must use different sources for different geographic areas. Unlike other factor overlays, where terrain factors are similar worldwide, geographical location, climate, soils, and the agricultural practices of the location being analyzed greatly influence the vegetation factors. Some of the major sources are maps, literature, and aerial imagery.

Military topographic maps. Standard military topographic maps differ in completeness according to scale and country of origin. The boundaries of forested areas

are generally accurate on topographic maps but size, type, and density information cannot be obtained from the map alone. See Figure 3-3.

Small-scale vegetation maps. This product can be found in any general geography text and usually depicts very broad categories of vegetation. It does not give enough of the detailed information required but will give analysts background on agricultural practices and the predominant vegetation types of the area.

Data Element	United States		Federal Republic Germany		USSR	
	1:250,000	1:50,000	1:250,000	1:50,000	1:200,000	1:50,000
1. Map unit identification/ Veg boundaries	Limited to major veg boundaries	Limited to major veg boundaries	Limited to major veg boundaries	Limited to major veg boundaries	Limited to major veg boundaries	Limited to major veg boundaries
2. Mean height to top of canopy	Woodland > 3 m, Scrub < 3 m	Woodland > 3 m, Scrub < 3 m	No	No	Yes	Yes
3. Percent canopy closure by season	Limited est for major veg type	Limited est for major veg type	Limited	Limited	Limited	Limited
4. Number of stems per hectare	No	No	No	No	No	No
5. Crown diameter	No	No	No	No	No	No
6. Mean stem diameter	No	No	No	No	Yes	Yes
7. Number of trees in each stem diameter class per hectare	No	No	No	No	No	No
8. Stem spacing	No	No	No	No	Yes	Yes
9. Species identification, seasonality, and distribution	No No No	No No No	Coniferous Deciduous Mixed only	Coniferous Deciduous Mixed only	Coniferous Deciduous Mixed only	Coniferous Deciduous Mixed only
10. Ground cover type, percent of cover, and height	No	No	No	No	No	No
11. Litter type and depth	No	No	Limited	Limited	Limited	Limited
12. Mean height to lowest branches	No	No	No	No	Limited	Limited
13. A representative transect	No	No	No	No	No	No

Figure 3-3. Map capabilities for vegetation data elements

Species distribution maps. These maps are produced under a variety of names depending on their geographical location and the type of data they present. They are produced primarily for use as forestry tools by government agencies, commercial lumber companies, and colleges and universities. They provide extremely detailed information but are produced for limited areas and specific functions. If they are not available, the analyst should query local government agencies and universities located in the area of interest. This is only feasible if the area of interest is accessible to the terrain analyst and if local agencies are friendly and willing to assist.

Literature. Literature is nearly unlimited in quantity, scope of subject matter, and coverage of geographic regions. Data from this source is usually too general to be of much use but can be used to verify other data.

Aerial imagery. Analysis of aerial imagery is the best and most accurate method of obtaining detailed vegetation information. The quality of information obtained depends largely on the skill and knowledge of the individual analyst and the type and quality of the imagery available.

Step 2. Determine data elements. After identifying and collecting sources of information, analysts must determine the data elements or essential elements of

terrain information (EETI) required to produce the vegetation factor overlay. The data elements required are--

- Vegetation-area boundaries.
- Vegetation type.
- Height to top of canopy.
- Canopy closure.
- Stems per hectare.
- Stem diameter.
- Stem spacing.
- Ground cover.
- Height to lowest branches.
- Seasonal information.

Step 3. Prepare collateral data. Gather all available data that covers the area of interest. Examine the information to ensure completeness and accuracy, to see if some of the information is old or dated, and to see if newer sources are available. Vegetation can be influenced by man's activities and can change in a relatively short period of time.

Identify information gaps. After all available information has been gathered, superimpose it on the base map to determine areas where information does not exist or is too old to be reliable.

Submit collection requirement. If information gaps exist, determine alternate available sources and submit the appropriate collection requirement. The collection request can be for new imagery or for on-site verification of dated information.

Step 4. Prepare topographic map base. Construct the vegetation overlay for the TTADB using a standard 1:50,000 topographic map. Register the overlay to the data base or map you are using. Cover the selected topographic map with a clean sheet of mylar and tape them together. If the area of interest does not cover the entire map, outline the area of interest on the mylar in black pencil or ink and note the longitude and latitude or UTM coordinates at the corners. Annotate the map sheet name and number, map series, map edition, state, factor overlay type (vegetation) and classification, if required, on the overlay.

Prepare the data table worksheets. Trace the boundaries, in black pencil or ink, of all open-water bodies such as ponds, lakes and double-lined streams and label them with a **W**.

Trace the boundaries of all built-up areas that are longer and wider than 250 meters (5 millimeters at 1:50,000 scale). Label the outlined areas with an **X**.

Step 5. Determine vegetation types and boundaries. Trace the boundaries of all forested areas. For the working overlay, label all forested areas with a **T**. Further analysis will determine type, size, density, and internal boundaries or changes.

Trace the boundaries of all agricultural areas and label the areas with an **A**. Determine the type of crops, such as dry, wet, terraced or rotating/shifting crops and add the second agricultural code (see Figure 3-4.). The analysis of collateral data will be required to determine the second code.

Trace the boundaries of all brushlands and label them with a **B1** or **B2**, depending on the vegetation category. The analysis of collateral data will be required to determine the second code.

MAP UNIT CODE	TYPE
A1	Agriculture (dry crops)
A2	Agriculture (wet crops, rice)
A3	Agriculture (terraced crops, both wet & dry)
A4	Agriculture (shifting cultivation)
B1	Brushland (< 5m high, open to medium spacing)
B2	Brushland (< 5m high, medium to dense spacing)
C*	Coniferous/Evergreen Forest
D*	Deciduous Forest
E*	Mixed Forest (Coniferous/Deciduous)
F*	Orchard/Plantation (rubber, palm, fruit, etc.)
G1	Grassland, Pasture, Meadow
G2	Grassland with Scattered Trees, some Scrub Growth
H	Forest Clearing (cutover areas, burns, etc.)
I**	Swamp (mangrove, cypress, etc.)
J	Marsh/Bog (treeless bogs, muskegs, etc.)
K	Wetlands (L.S.L., low-lying wet areas)
L	Vineyards/Hops
M	Bamboo
N	Bare Ground
W	Open Water
X	Built-up Area

*These vegetation types are given a three digit map unit code. In addition to the letter for the type code, a second digit (number) is added as the canopy closure code, and a third digit (number) is added as the height code. See Canopy Closure (%), Height (meters), and example below.

** A second digit, representing canopy closure, is added to the swamp code.

Figure 3-4. Vegetation map codes

Trace the boundaries of all grasslands and label them with a **G1** or **G2**, depending on the vegetation category. The analysis of collateral data will be required to determine the second code.

Trace the boundaries of all swamps (**I**), marshes and bogs (**J**), and wetlands (**K**) and label them accordingly.

Step 6. Determine forest type and boundaries. Since different types of trees have different characteristics and have a major impact on cross-country mobility, on cover and concealment, and on use as engineering resources, you must determine the forest type and the transition boundary of the areas already labeled **T**.

Trace the boundary of all coniferous/evergreen forests and label them with a **C**. This forest category must contain 60 percent or more species of coniferous trees. These trees are relatively easy to place within a broad classification because they tend to have definite sizes and shapes. Shadows, crown shape (see Figures 3-5 and 3-6) and photographic tone are the most common photo interpretation keys.

Trace the boundaries of all deciduous forests and label them with a **D**. This forest category must contain 60 percent or more species of deciduous trees.

Trace the boundaries of all mixed forests and label them with an **E**. Mixed forests are those forests that do not contain 60 percent or more of either coniferous or deciduous trees.

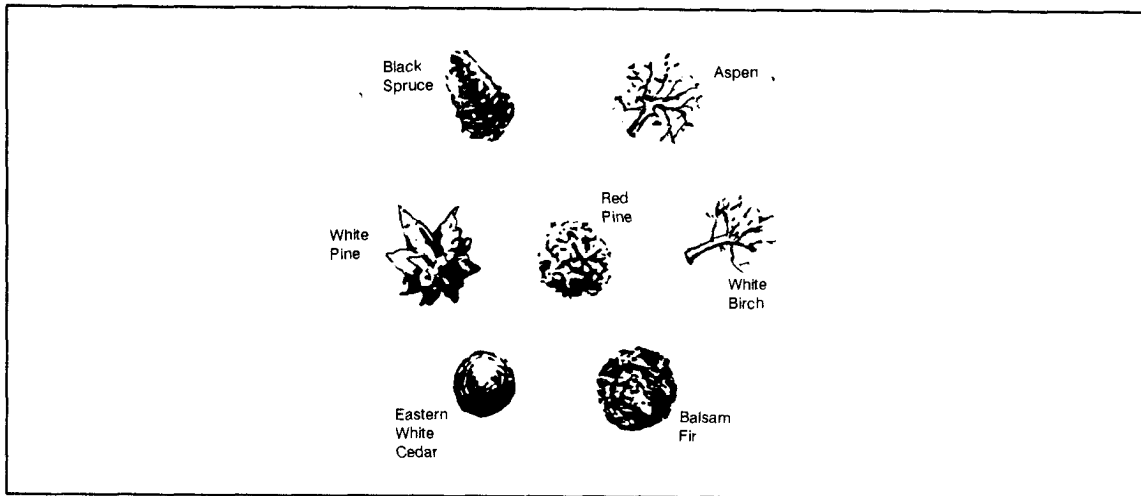


Figure 3-5. Vertical views of tree crowns

Trace the boundaries of all orchards and/or plantations and label them with a **F**. This category can be identified by the uniform rows and photographic tone and texture. Analysis of the collateral data will key analysts to look for this vegetation type and location.

Step 7. Determine canopy closure. Canopy closure is the percent of ground area covered by the tree crown and is normally computed only for forested areas. Crown area is the area covered by the vertical projection of a tree crown to the horizontal plane.

Vegetation types indicated by **C**, **D**, **E** and **F** are given two digits in addition to the letter. The letter denotes the tree type, the first number represents the canopy closure, and the second number is the height. For swamps (**I**), the third digit or height code is omitted.

Canopy closure is coded in four categories:

CODE	CANOPY CLOSURE %
1	0 - 25
2	25 - 50
3	50 - 75
4	75 - 100

Use the crown density scale to determine the canopy closure. It is made of columns of squares containing solid black circles. These circles cover and represent a percent of the area (see Figure 3-7 within the square). Match the appropriate scale to the forested area on the imagery and record the crown density for a given area.



White pine



Red pine



White spruce



Jack pine



Black spruce

Eastern
hemlock

Tamarack



Balsam fir

Eastern white
CedarWhite birch
(old)White birch
(young)

Aspen



Basswood



Sugar maple



Red maple



Silver maple



Yellow birch



Beech



Oak



Balsam poplar



Ash



Elm

Figure 3-6. Silhouettes of forest trees.

Compare only the tree crown and not the shadows visible on the photo. Factors affecting accuracy of canopy closure measurements include--

Note: When tree shadows fall on level ground, they often permit identification of individual species.

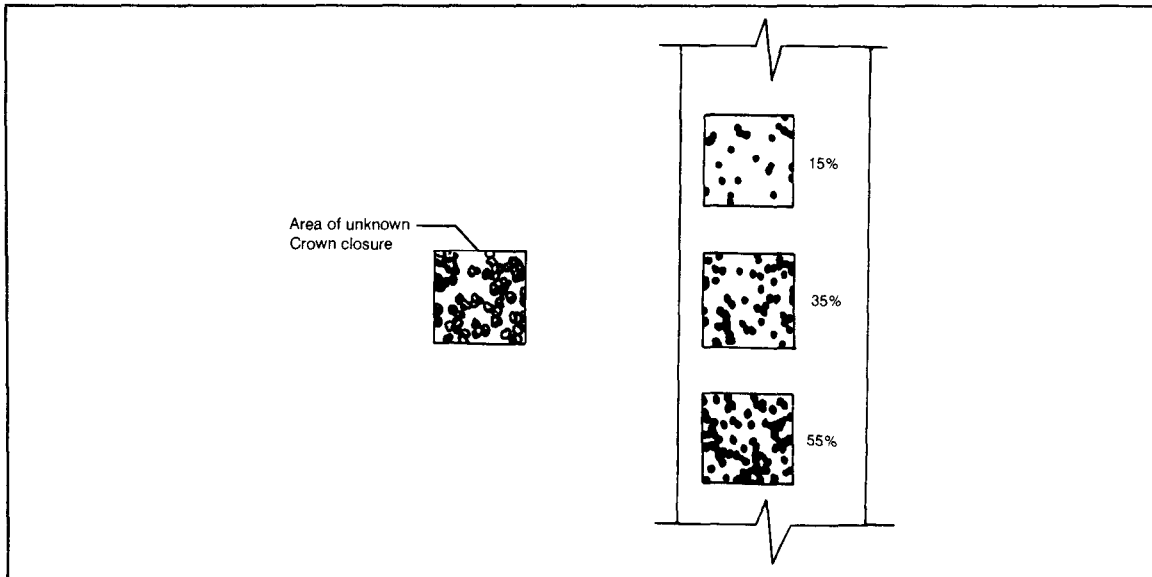


Figure 3-7. Sample crown density scale

- Image quality. Crown closure estimates of forest stands on poor quality photographs tend to be too high because of the lack of detail in photo tones and the inability of the analyst to identify small crown openings.
- Shadows. Shadows tend to mask stand openings causing the stand to appear more dense.
- Photographic scale. The minimum canopy opening that can be identified on photography is directly related to the photographic scale. Small openings which can be identified on 1:6000 scale photography cannot be seen on 1:20,000 scale photography. The net effect is to overestimate canopy closure when using small-scale photography.
- Analyst skill. An average analyst using good quality photography should produce crown closure estimates accurately to within 10 percent.

Step 8. Determine the mean height to top of canopy. The second number, or third digit, depicts the tree height (see Figure 3-8). Mean height to top of canopy is the mean or average height of a specific tree type or category. If existing data to determine and outline mean tree height does not exist, use aerial photography to measure tree height (see Chapter 9). Three methods to measure tree height from aerial photography are the parallax, shadow, and relief displacement methods. Factors affecting the accuracy of height measurements include--

- Photographic scale. Tree height measurement error generally increases when small-scale photography is used due to the inability of the analyst to identify the tree's apex.
- Character of forest. Measurement of tree height is dependent on the analyst's ability to see the ground nearby. This is closely related to the stand density and ground clearance. If a forest stand is very dense, such as a tropical rain forest, it is very difficult to find an opening large enough to permit accurate measurements.

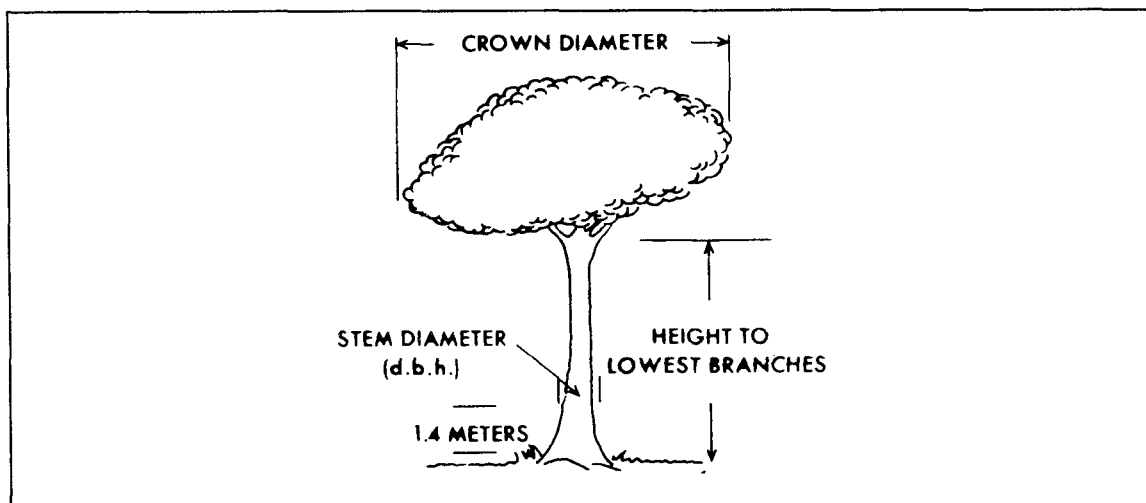


Figure 3-8. Tree mensuration

- Terrain relief. Trees growing in areas that are not level are difficult to measure accurately because of a tendency to refer measurements to canopy openings at elevations different than those at the base of the tree.
- Analyst skill. An analyst should be able to determine the height of trees accurately within each map unit. Knowledge of forest conditions and classification of specific tree type (species) can be an invaluable aid in height classification.

Step 9. Determine tree crown diameter. Tree crown diameter is the distance across the spread of a tree crown and is measured in meters. Diameter measurements of the largest, average, and smallest crowns in each category will determine the average crown diameter for a given map unit. This measurement is made using the dot-type scale or the crown micrometer wedge on the photograph (see Figure 3-9).

Select a tree for measurement. Slide the dot-type scale alongside the tree until you find a dot that is equal in size to the tree's crown. It is best not to fit the circle over the crown, because too much detail is screened by the black dot or circle.

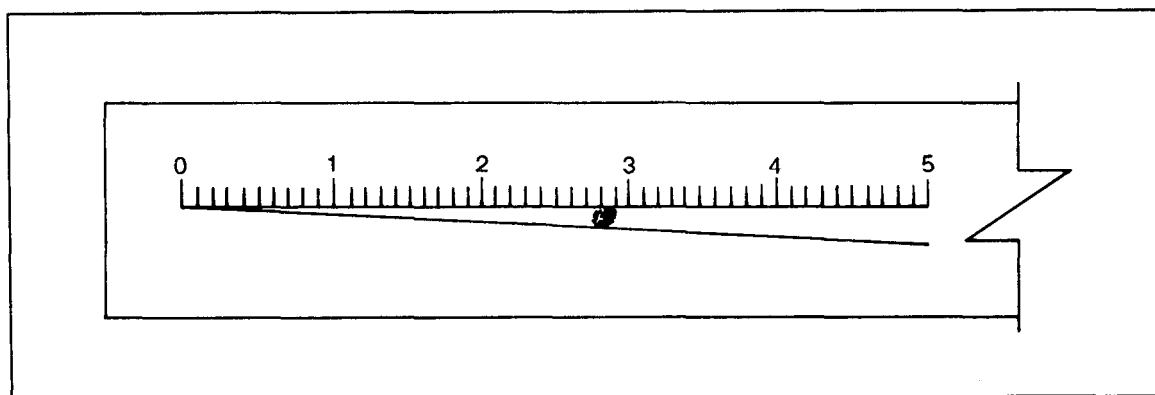


Figure 3-9. Crown micrometer wedge

Select a tree for measurement. Place the micrometer wedge so the insides of the two diverging lines are just tangent (making contact at a single point) to the tree. Take a reading at the point on the scale where the tree crown is tangent to the diverging lines.

Take an average of three measurements using either method. The answer will be in millimeters of photo distance. Convert the answer to ground distance by multiplying by the denominator of the photo scale. Convert millimeters of ground distance to meters by dividing by 1000. Factors affecting accuracy of crown diameter measurement include--

- Photographic scale. The analyst's ability to accurately identify the largest, average and smallest crowns is closely associated with the photographic scale. Small-diameter crowns cannot be detected on small-scale photographs, and clumps of closely spaced trees tend to be measured as a single crown rather than as several small ones.
- Location on the photograph. Limit tree crown measurements to the center portion of the photograph whenever possible, because the center is less affected by distortion.
- Forest density. Crown diameter measurements are most accurate in open-grown stands. Measurements in dense stands are usually limited to crown widths for dominant trees.

Step 10. Determine mean stem diameter. Tree stem diameter is the diameter of a tree at 1.4 meters (4.5 feet) above the ground. This measurement is also referred to as diameter at breast height (DBH). Calculate mean stem diameter for all vegetation units with trees 2 meters or greater in height. Record this information on the vegetation data table in centimeters.

Tree stem diameter is calculated using the mean crown diameter information obtained in step 9. If this step has not been completed, calculate the mean crown diameter for the vegetation within each map category.

When computing the stem diameter for coniferous trees, use the following formula:

$$\text{DBH (inches)} = \frac{\text{D (feet)}}{2} + 5$$

Where--

DBH (inches) = Diameter at breast height

D (feet) = Crown diameter

Example: In step 9, you have determined that a stand of coniferous trees has a mean crown diameter of 6.4 meters.

a. Convert mean crown diameter measurement to feet.

$$6.4 \text{ meters} \times 3.281 \text{ feet per meter} = 20.998 \text{ feet}$$

(Round to 21 feet)

- b. Use the above formula to determine DBH (inches).

$$\text{DBH} = \frac{21 \text{ feet}}{2} + 5 \quad \text{DBH} = 15.5 \text{ inches}$$

- c. Convert DBH (inches) to centimeters.

$$15.5 \text{ inches} \times 2.54 \text{ inches per cm} = 39.37 \text{ cm}$$

- d. Record the mean stem diameter in the vegetation table.

When computing the stem diameter for deciduous trees, use the following formula:

$$\text{DBH (inches)} = .75 \times D \text{ (feet)}$$

Example: In step 9, you have determined that a stand of deciduous trees has a mean crown diameter of 8.5 meters.

- a. Convert mean crown diameter measurement to feet.

$$8.5 \text{ meters} \times 3.281 \text{ feet per meter} = 27.885 \text{ feet}$$

(Round to 27.9 feet)

- b. Use the above formula to determine DBH (inches).

$$\begin{aligned} \text{DBH} &= .75 \times 27.9 \\ \text{DBH} &= 20.925 \text{ inches} \end{aligned}$$

- c. Convert DBH (inches) to centimeters.

$$20.925 \text{ inches} \times 2.54 \text{ inches per cm} = 53.1495 \text{ cm}$$

Round the answer to 53.15 cm.

- d. Record the mean stem diameter in the vegetation table (see Figure 3-10)

Step 11. Determine stem spacing. Stem spacing is the distance from the center of one tree to the center of the nearest adjacent tree. The easiest and fastest method to determine stem spacing is to measure directly from the photograph and convert it to ground distance (in meters).

Use the microcomparator to measure from the center of a tree stem to the center of the closest tree stem. This measurement unit depends on the scale used in the microcomparator, usually made in feet, and should be converted to meters.

If the scale is not acceptable and the distance is not measurable, use the following formula:

$$\text{SS (meters)} = \frac{12.372}{N}$$

CODE	FOREST TYPE AND CANOPY CLOSURE															
	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F1	F2	F3	F4
1																
2																
3						5.0 1.8 .80										
H E I G H T																
4																
5																
6																
7																
8																
9																

Example D23 indicates the following: 5.0 cm — Average Stem Diameter
1.8 m — Average Tree Spacing
.80 — Vegetation Roughness

Figure 3-10. Vegetation table

Where--

SS (meters) = Stem Spacing in meters

12,372 = Constant

N = Number of trees per hectare

Before you can use this formula, you must determine N. To determine N, use the following formula:

$$N = \frac{\text{TC (tree count in hectare scale)}}{0.08}$$

N = Number of trees per hectare

TC = Tree count in hectare scale

Determine TC (tree count in hectare scale) of a specific vegetation map code. Orient the stereopair for viewing. Place the transparent 0.08 hectare scale (see Figure 3-11) over the area using the appropriate photographic scale and count the number of trees enclosed within the circle of the hectare scale.

Convert the number of trees in a 0.08 hectare to the number of trees per hectare.

Example: 32 trees were counted within the 0.08 hectare circle using the 0.08 hectare circle template.

a. Use the above formula to determine N.

PHOTO SCALE	.08 HECTARE CIRCLE	CIRCLE DIAMETER	
		INCHES	MILLIMETERS
1:5,000		.253	6.38
1:6,000		.211	5.32
1:7,000		.1805	4.56
1:8,000		.158	3.99
1:9,000		.140	3.55
1:10,000		.126	3.192
1:11,000		.115	2.90
1:12,000		.105	2.66
1:13,000		.092	2.46
1:14,000		.090	2.28
1:15,000		.084	2.13
1:16,000		.079	1.99
1:17,000		.074	1.88
1:18,000		.070	1.77
1:19,000		.067	1.68
1:20,000		.063	1.60
1:21,000		.060	1.52
1:22,000		.057	1.45
1:23,000		.055	1.39
1:24,000		.053	1.33
1:25,000		.051	1.28

Figure 3-11. Sample hectare scale

$$N = \frac{32}{0.08}$$

$$N = 400$$

b. Use the above formula to determine SS, N = 400

$$SS = \frac{12.372}{400}$$

$$SS = 5.56 \text{ meters}$$

<u>MAP UNIT CODE</u>	<u>ROUGHNESS FACTOR</u>
A1	.80
B2	.95
G1	.90
G2	.60
H	.50
I	.10
J	.10
W	0
X	(not evaluated)

Figure 3-12. Vegetation roughness factors

c. Round off to the nearest 0.1 meter and record this figure in the appropriate column of the vegetation data table. Factors affecting accuracy of stem spacing measurement include--

- Tree spacing. Count only those trees that are visible from above and are sufficiently large in their exposed portion to be resolved. This problem is especially acute in tropical areas having more than one canopy.
- Photographic scale. Trees with a crown diameter of less than 0.6 meters will not be resolved at 1:12,000 scale photography. This minimum-resolved diameter increases to 1.2 meters on photo of 1:16,000 scale or smaller.
- Tree crown diameter. Tree count accuracy increases with an increase in tree crown diameter.
- Crown canopy structure. Irregularities in crown canopy tend to increase accuracy due to relief among trees.
- Terrain. If the terrain viewed in the photograph is not level, alter the area represented by a given circle or adjust the crown count to obtain the true number of trees per hectare. Compute compensation for terrain relief for every 200-foot difference in elevation.
- Analyst's skill. Inexperienced analysts may undercount the actual number of tree crowns by as much as 50 percent. For this reason, you must be careful to recognize double trees, sprout clumps, or multiple groups of trees. You can usually accomplish this by recognizing abnormally large crowns or irregularly shaped groups of crowns.

Step 12. Estimate vegetation roughness factor (VRF). The vegetation roughness factor is an estimated numerical factor that reflects the degree of vehicular speed degradation due to travel through a particular vegetation type on horizontal ground. The factor decreases from 1.0 (no speed degradation) to 0.00 (vegetation roughness does not permit off-road mobility) (see Figure 3-12). For example, grassland with little slowdown effect would have a VRF of 1.0 to 0.9, but a virtually impassable swamp with dense ground vegetation, fallen branches and trees, and exposed stumps would have a VRF of .1. The factor designated to a vegetation category is subjective and designated by the analyst. The plant's density, stem diameter, branching characteristics, root emergence, and so forth are all considered.

Step 13. Prepare the vegetation legend. Prepare the vegetation factor overlay legend according to DMA product specifications.

Step 14. Construct the final overlay. The final step in producing a factor overlay is to put the draft manuscript overlay into a final data base product. Support from the cartographic and reproduction elements/sections is required. See Chapter 8 for the final overlay procedure.

SURFACE MATERIALS ANALYSIS (SOILS)

Military planners rely heavily on soil analysis because soils vary in their ability to bear weight and withstand vehicle passes, as well as in their ease of digging. The moisture content and type of soil will affect road construction, material location, and trafficability determination. The soil factor overlay breaks down the soil types, characteristics, and distribution. Soils of the same type and quality will have similar strength and characteristics regardless of geographic location. The primary factors influencing like soil strengths are environmental changes.

Describing and classifying soil normally requires extensive field sampling and the expertise of soil scientists. The terrain analyst must be able to produce acceptable soil factor overlays by extracting information from maps, other factor overlays, aerial photographs, lab reports, boring logs, and other literature. The reliability of the soil factor overlay produced will vary with the type and reliability of the information sources. Seldom will a single source provide all of the information required.

Step 1. Collect required collateral data. Collect and analyze as many of the following sources as possible for the area of interest; maps; factor overlays; special reports, such as laboratory soil analysis reports, soil field test reports, and boring logs and well logs; literature; and aerial photographs.

The desirable scale for all source maps is 1:50,000. If 1:50,000 scale maps are not available, other existing maps should be converted to this scale.

Soil maps are produced by various organizations for specific purposes. Engineering firms may produce soil maps to support any type of construction project. Government agencies may produce soil maps for agricultural purposes, land-use planning, or special studies. The classification systems used on soil maps will vary with the producing agency and the purpose of the map. The systems must be translated into the USCS, which is the system used by the military for producing soil factor overlays. See Figure 3-13.

This table may be used as a guide in classifying soils for which no engineering test data are available. The symbol > means "greater than", the symbol < means "less than", and the symbol ≤ means "less than or equal to".			
USDA Texture Class and Symbol	Unified Symbol	AASHTO Symbol	Soil Properties Related to Classifications
Clay, silty clay C, sic	CH MH CL	A-7 A-7 A-7	High shrink-swell clays Mica, iron oxide, kaolinitic clays Low LL, Generally < 45 pct clay
Silty clay loam scl	CL ML-CL CH MH	A-7 A-7 A-7 A-7	Low LL, Plastic (A-6 if clay < 30 pct) Low LL, Moderately plastic (A-6 if clay < 30 pct) High LL, High shrink-swell clays High LL, Mica, iron oxide, kaolinitic clays
Clay loam cl	CL ML-CL CH MH	A-6 or A-7 A-6 A-7 A-7	Low LL, Plastic Low LL, Moderately plastic High LL, High shrink-swell clays High LL, Mica, iron oxide, kaolinitic clays
Loam l	ML-CL CL ML	A-4 A-6 A-4	Moderately plastic (A-6 if clay > 21 pct) Plastic (A-4 if clay < 22 pct) Low plasticity (A-7 if clay > 21 pct)
Silt loam sil	ML-CL ML CL	A-4 A-4 A-6	Moderately plastic (A-6 if clay > 21 pct) Low plasticity (A-7 if clay > 21 pct) Plastic
Silt, si	ML	A-4	Low plasticity
Sandy clay sc	CL SC	A-7 A-7	Fines > 50 pct Fines ≤ 50 pct
Sandy clay loam scl	SC SC CL	A-6 A-2-6 A-6	Plastic Fines 36-50 pct Plastic Fines ≤ 35 pct Plastic Fines > 50 pct
Sandy loam sl	SM SC SM-SC	A-2-4 or A-4 A-2-4 A-2-4	Low plasticity Plastic Moderately plastic
Fine sandy loam fsl	SM ML ML-CL SM-SC	A-4 A-4 A-4 A-4	Nonplastic Fines ≤ 50 pct Nonplastic Fines > 50 pct Moderately plastic Fines > 50 pct Moderately plastic Fines ≤ 50 pct
Very fine sandy loam vfsl	ML-CL ML	A-4 A-4	Moderately plastic Low plasticity
Loamy sands ls, lfs lvfs	SM SM-SC SM ML	A-2-4 A-2-4 A-4 A-4	Nonplastic Fines ≤ 35 pct Moderately plastic Fines ≤ 35 pct Low plasticity Fines > 35 pct Little or no plasticity
Sand, fine sand s, fs	SP-SM SM SP	A-3 A-2-4 A-3	Fines approximately 5-10 pct Fines approximately > 10 pct Fines < 5 pct
Very fine sand vfs	SM ML	A-4 A-4	Low plasticity Little or no plasticity
Coarse sand cs	SP-GW SP-SM SM SM	A-1 A-1 A-1 A-2-4	Fines < 5 pct Fines 5-12 pct Fines 13-25 pct Fines > 25 pct
Gravel, G 50 pct passes No 200 50 pct of coarse passes No 4 sieve	GP-GW GM or GC GM or GC GM GC	A-1 A-1 A-2 A-4 A-6	Fines < 5 pct Fines 5-25 pct Fines 26-35 pct Fines > 35 pct Fines > 35 pct

Figure 3-13. General relationship of systems used for classifying soil samples

Some vegetation features symbolized on topographic maps can provide clues to soil characteristics. Contours and land-use patterns can help define landforms and identify soil types. See Figure 3-14.

Geological maps may or may not be useful form soil analysis. Those maps which show the surface profile to bedrock usually define the type and depth of soil, as well as the parent material or bedrock.

In some cases, vegetation (or change of vegetation) can be an indicator of a specific soil type, change of soil type, or change of soil depth.

Climatic maps provide annual variations in temperature and moisture conditions. Of particular interest is information concerning the state of ground; for example, wet, dry, moist or frozen. This information is important in determining the stability of a soil or changes of stability with seasonal changes.

Literature reports are published by academic institutions, government agencies, or private firms on soil-related subjects such as soil, topography, geology, and vegetation.

Analysis of air photographs is the best overall method for obtaining soil information for large and inaccessible areas.

Step 2. Determine data elements. Once you have identified and collected the sources of information, determine the data elements, or EETI, required to produce the soils factor overlay. The data elements required are--

- The soil profile, which is a description of the soil with depth, including identification of soil layers; depth ranges for each horizon layer in

Landform/Bedrock	Climate	Commonly Associated Soils	
		Horizon	USCS Symbol
Sandstone	unspecified	surface (A) parent material (C)	SM, SM-SC, ML, SP, SW SM, SM-SC, GM, SC, GC, ML
	humid	A	SM
		B C	SM, GM SM-GM
Shale	unspecified	surface (A) parent material (C)	CH, CL, CL-CH ML, CL, MH, CH, CL-CH, SC CL-SC, GC
	semi arid or humid	A	CL, CH
		B C	CL, SC, CL-SC CL, SC
Limestone	unspecified	surface (A) parent material (C)	ML-CL, ML, CL, GM CL, CH, MH, ML, CH-MH ML-CL

Derived from D.S. Way, *Terrain Analysis: A Guide to Site Selection Using Aerial Photographic Interpretation*, 2nd Ed., McGraw-Hill Book Co., N.Y. 1978 and modifications to Way made by A. Reimer, ETL-TAC, 1979 & O. Mintzer, Ohio State, 1979.

Figure 3-14. Landforms and commonly associated soils

Landform/Bedrock		Climate	Commonly Associated Soils		
			Horizon	USCS Symbol	
Limestone (continued)		tropical	lower horizons (B & C)	CH, MH, GC, GM	
		humid		A B C	ML-CL CH CH
Interbedded, sandstone shale, limestone					
	Flat-lying	unspecified	unspecified	CL, ML, CH, MH, ML-CL SC, GM, SM,	
	Tilted	unspecified	unspecified	ML, MH, ML-CL	
Intrusive	Granitic rock*	unspecified	surface (A) subsurface (B)	SM, ML, SC, ML-CL SC, CH, CL, CL-CH	
	Granite	humid		A B C	SM, ML, CL SC SC, CL
Extrusive, Basaltic & Volcanic		humid		A B C	ML, CL CH, MH ML-MH, MH, CH
		tropical or subtropical			
		arid		A B	ML-CL, ML, GM CH, CL, MH, ML-CL, GC
Slate		unspecified	unspecified		GM, GC, GM-GC
		humid		A B C	SM SM, ML-CL SM, GM
Schist			humid		A B C
Gneiss		humid		A B C	SM, SM-SC, ML-CL, ML MH, CH, SC SM, ML CL, MH-CH, ML-CL MH,CH
Glacial Tilt/Ground Moraine		humid/derived from soft sedimentary rock		A B C	ML, CL, ML-CL, OL CL, CH, CL-CH CL, CH, ML Note: A much wider range of texture is possible as in North Central U.S.A.
		humid/derived from igneous-metamorphic rock (crystalline)		A B C	SM, ML, SC SM, ML SM, ML, GM Note: A much wider range of texture is possible as in North Central U.S.A.
Glacial/Moraines		humid/derived from soft sedimentary rock		A B C	CL, ML, CL-CH, CH, GM, GC CL, CH, GC CL, CH, GC
		humid/derived from igneous-metamorphic rock (crystalline)		A B C	SM-SP GW, GC-GP, SC-SP SM-SC, SW, SP, GM, GC, SM, SC

Figure 3-14 continued. Landforms and commonly associated soils

Landform/Bedrock	Climate	Commonly Associated Soils	
		Horizon	USCS Symbol
Drumlins	unspecified/ derived from soft sedimentary rock	surface or subsurface (A or B)	ML, ML-CL, GM, GC
		C	CL, GM, GC
	humid/derived from igneous- metamorphic rock (crystalline)	A	GM-GC, SM
		B C	GM-GC, SM GM, SM-SC, ML
Eskers	unspecified	unspecified	GM, GM-GC, GP, SP, GW, SW SW-SM
Kames	unspecified	unspecified	GP, SP, GP-GM, GM, GM-GC SM-SC, SP-SM, SM
Glacial Outwash	unspecified	unspecified	GW, SW, GP, SP, GM, SM CL, GM-GC
Silt/Clay Lakebeds	unspecified	A	ML-CL, CH
		B	CL-CH
		C	CL-CH, ML-CL, MH-CH
Sandy Lakebeds	unspecified	unspecified	SM, ML, ML-MH, ML-CL
Sand Dunes	unstabilized	no horizons	SP
	stabilized	unspecified	SM, SP SP
Loess deposits	unspecified	unspecified	ML, ML-CL, CL
	semi arid	A	ML-CL
		B C	ML-CL ML-CL
Flood Plains	unspecified	unspecified	GW, SP
	unspecified	unspecified	SW, SP, GW
	unspecified	unspecified	SM, ML
	unspecified	unspecified	ML, CL, MH, CH, MH-CH
	unspecified	unspecified	OL, OH, PT, ML, CL, CH
	unspecified	unspecified	ML SC, GW, GP
	unspecified	unspecified	ML SC, GW, GP
Deltas	unspecified	surface (A) subsurface (B)	ML, CL, MH, CH GP, SP, GM, GC, SM, SC, GM-GC
	Arc delta	A	ML
		B	absent
		C	GM-GC
	Bird's-foot delta	A	OH
		B	CH-OH
		C	CH
Alluvial fans	unspecified	unspecified	GP, SP, SW, GW, GM, GC SM, SC, ML, CL
	semi arid	A	GM-SM
		B	SM, ML
		C	GM, SM, ML

Figure 3-14 continued. Land forms and commonly associated soils

Landform/Bedrock	Climate	Commonly Associated Soils	
		Horizon	USCS Symbol
Valley fills	unspecified	unspecified	GP, SP, GW, SW, GM, GC SM, SC, CL, ML, CL-CH, CH
	semi arid	A	SM
		B C	SM ML-SM, SM, GM, SM, ML
Continental alluvium	unspecified	unspecified	CL, SC, CL-CH, CH
	semi arid	A	CL
		B C	CL CL
Playas	unspecified	unspecified	ML, CL, SM, SC, MH, CH
Swamps, Bogs & Marshes	unspecified	unspecified	PT, OH, CH, MH, OL
Coastal Plain Uplands	unspecified	subsurface (A) subsurface (B)	SM, SP-SM SM, SC, SP-SM
	humid	A	SM
		B C	SC, SM SC, SM
Coastal Plain Depressions	unspecified	unspecified	OL, ML, CL, ML-CL, MH CH, OH, PT
Beach Ridges	unspecified	surface (A) subsurface (B)	SM, GM SP, GP, GP-GM, SP-SM, SW
	humid	A	SM
		B C	Absent SP, SM
Tidal Marsh	unspecified	surface (A) subsurface (B)	PT OL, OH, MH
Mud Flat	unspecified	unspecified	CH, CH-MH, CH-OH
Sand Flat	unspecified	unspecified	SP

Figure 3-14 continued. Landforms and commonly associated soils

Note: *Granitic rock includes rhyolite porphyry, trachyte porphyry, dacite porphyry, basalt porphyry, augite porphyry, granite, syenite porphyry, syenite, diorite porphyry, diorite, gabbro porphyry, gabbro, pyroxenite porphyry, pyroxenite, periodotite

meters; and identification of soil type for each horizon with one of the 15 USCS symbols.

- Depth to bedrock, or the total thickness of soil in meters.
- State-of-ground, or the average monthly moisture condition of the soil.
- Stoniness, or the estimated number of stones of a given diameter per volume of soil, which may be expressed as a percentage of the volume.
- The rating cone index (RCI), an on-site or estimated value of soil strength derived from the cone index multiplied by the remolding index.
- The cone index (CI), the field measurement indicating the shearing resistance of soil, obtained with a cone penetrometer.

- The remolding index (RI), a ratio that expresses the proportion of original strength that will be retained by a fine-grained soil or a sand with fines, poorly drained, after being subjected to vehicular traffic.

Step 3. Prepare collateral data. Gather all available soil maps that cover the area of interest. Examine their scales and legends. Extract those at 1:50,000 scale or larger that use the USCS. If any of these maps are based on field surveys (field classification), they may be used as the soil factor overlay base. Further data analysis or extraction may be unnecessary if the soil maps can produce all the information required by the data elements.

Step 4. Prepare topographic map base. Extract the topographic maps that cover the area of interest. A scale of 1:50,000 with a contour interval of 20 feet or more is preferred.

Cover the selected topographic map with a clean sheet of mylar and tape them together. If the area of interest does not cover the entire map area, outline the area of interest on the mylar in black pencil or ink and note the longitude and latitude or UTM coordinates at the corners. Register the overlay to the data base or map you are using.

Annotate the map sheet name and number, map series, map edition, scale, factor overlay type (surface materials) and classification, if required, on the overlay.

Trace the boundaries of all open-water bodies such as lakes, ponds, and double-line streams in black pencil or ink, and label them with a W.

Trace the boundaries of all built-up areas that are longer than 250 meters (5 millimeters at 1:50,000 scale). Label the outlined areas with an X.

Trace the boundaries of all permanent snowfields in black pencil or ink, and label with a them PS.

Trace the boundaries of all areas of salt evaporators and salt encrustation in black pencil or ink, and label them with an EV.

Step 5. Determine soil types and boundaries. Evaluate collateral source material for soil boundaries and types. If data does not already exist, analyze landforms, vegetation, and geology information to determine USCS type and boundary.

Trace the boundaries of all areas of exposed bedrock or void of surface soils in black pencil or ink, and label them with an RK.

Evaluate the soil factors and place appropriate boundaries on the overlay in black pencil or ink, using the topographic map as a base.

Label all evaluated areas with the appropriate USCS symbol. If information conflicts exist between different source materials, use the most reliable and current information available. Assign to each different area (soil type) a map unit number, numbering from top to bottom and left to right. Areas with the same surface soil type and identical horizon information will have the same map unit number. Do not assign map unit numbers to RK, PS, EV, X and W areas. The third digit after the USCS symbol shows the surface roughness factor.

EXAMPLE

TRAFFICABILITY TEST DATA									
PROJECT LOCATION PDG 488519					TYPE OF VEHICLE M26A1, TRK, TRACTOR, 6x6				
CONE INDEX VALUES									
		DIAL READINGS AT DEPTH							
TEST NUMBERS		0"	6"	12"	18"	24"			
1		48	56	64	70				
2		42	50	58	64				
3		41	49	57	63				
4		46	54	62	68				
5		47	53	60	66				
AVERAGE		44.8	52.4	60.2	66.2				
CI ₁ = Normal 49 Abnormal 56		49	56	63					
CI ₅₀ = 56									
CRITICAL LAYER FOR 1 VEHICLE 0-6"				CRITICAL LAYER FOR 50 VEHICLES 6-12"					
REMOULDING INDEX VALUES									
		LAYER 0-6"		LAYER 6-12"		LAYER		LAYER	
DEPTH		BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
0"		57	50	54	47				
1"		59	53	56	50				
2"		62	55	59	51				
3"		66	57	64	53				
4"		71	59	67	54				
AVERAGE		63.0	54.8	60.0	51.0				
RI = $\frac{A}{B}$		$\frac{54.8}{63.0} = .869$		$\frac{51.0}{60.0} = .850$					
REMOULDING INDEX FOR 1 VEHICLE .87				REMOULDING INDEX FOR 50 VEHICLES .85					
RATING CONE INDEX				NOTES: 1. Soil Condition: MOIST 2. Weather Conditions: FAIR					
RCI ₁ = CI ₁ X RI ₁ = 49 x .87 = 43									
RCI ₅₀ = CI ₅₀ X RI ₅₀ = 56 x .85 = 48									
VEHICLE CONE INDEX									
VCI ₁ = 35				Will 1 vehicle pass ? <u>YES</u>					
VCI ₅₀ = 79				Will 50 vehicles pass ? <u>NO</u>					
Type of soil: FG <u>XXX</u> CG <u> </u> Soil strenght profile: <u>Normal</u> <u>XXX</u> Abnormal <u> </u>									
Technician:		Computed By:			Checked By:				
Pvt. Snodgrass		C.E.P.			P.H.L.				

FB FM 348 1 Apr 84

Figure 3-15. Sample data table

Step 6. Determine surface roughness. Surface roughness factors are estimated factors used to compute the degree of degradation of the rate of vehicle movement caused by surface characteristics. These factors are tailored for each job by listing only those features encountered. Surface roughness is that aspect of the surface materials (such as boulder fields, gullies, and rugged bedrock.) which reduces vehicle speed.

Factors can be any number from 0.00 to 1.00 in 0.05 increments. The surface roughness factor of 1.00 for a vehicle class would indicate no degradation while a 0.80 factor would degrade vehicle speed by 20 percent. In estimating the magnitude of the factor, consider all physical characteristics of the feature as well as vehicle characteristics such as ground clearance and wheel size.

Surface roughness is classified for five types of movement categories: medium and large tanks, large wheeled vehicles, small wheeled vehicles, small tracked vehicles, and foot troops. Surface roughness factors often vary from one vehicle class to another.

Step 7. Prepare surface materials legend. Prepare a soil data table with RCI values for wet and dry seasons (see Figure 3-15). Using all available information, annotate the data elements required to complete the soil data table. This information can be used to increase the database for an area of operations.

Prepare the surface materials legend. The legend will contain only USCS soil categories with the appropriate surface roughness information. Depict additional information, such as soil depths and soil moisture from the soil data table, in the legend and within the factor overlay.

Step 8. Construct the final overlay. The final step in producing a factor overlay is to put the draft manuscript overlay into a final data-base product. Support from the cartographic and reproduction elements or sections is required. See Chapter 8 for the final overlay procedures.

OBSTACLE OVERLAY

The obstacle overlay is used to show the location and type of linear obstacles to movement. These obstacles can be either man-made or natural. This factor overlay is used with other primary factor overlays to produce cross-country mobility products and to assist military planners in developing barrier plans to tie planned obstacles into existing obstacles.

A 1:50,000 topographic map and complete stereo imagery are required to construct an obstacle factor overlay using TTADB product specifications.

Step 1. Collect required collateral data. Some of the major sources for data are maps and aerial imagery.

Standard military maps differ incompleteness and accuracy according to scale, currency and country of origin. Most existing obstacles are shown on topographic maps and can be plotted by the analyst.

Large-scale city maps can be used to plot the obstacles in and around built-up areas. The United States Geological survey (USGS) produced 1:24,000 maps show more detail than smaller scale maps. Use them as source material if they exist in your area.

Analysis of aerial imagery is the best and most accurate method of beating and plotting obstacles. Most natural obstacles, such as escarpments and embankments, are not high enough to be shown by the contour interval of a map, but they can be identified using aerial photos. Use imagery to locate and identify fences, walls, and hedgerows, which are not usually shown on standard maps.

Step 2. Prepare topographic map base. Register the overlay to the database or map you are using. Cover the selected topographic map with a clean sheet of mylar and tape them together. If the area of interest does not cover the entire map, outline the area of interest on the mylar in black pencil or ink. Mark and label the longitude and latitude or UTM coordinates of the corners.

Step 3. Identify and plot existing obstacles. Identify and plot all road and railroad cuts and fills greater than 250 meters in length and 1.5 meters in height. Start by following all of the ground lines of communication and look for areas where the terrain was altered to build a stable road or railroad. Railroads will normally have more cuts and fills to maintain a relatively flat gradient. Photo-check the cuts and falls plotted from the map and look for roads or railroads not shown on the maps. Plot the cuts and fills according to TTADB product specifications.

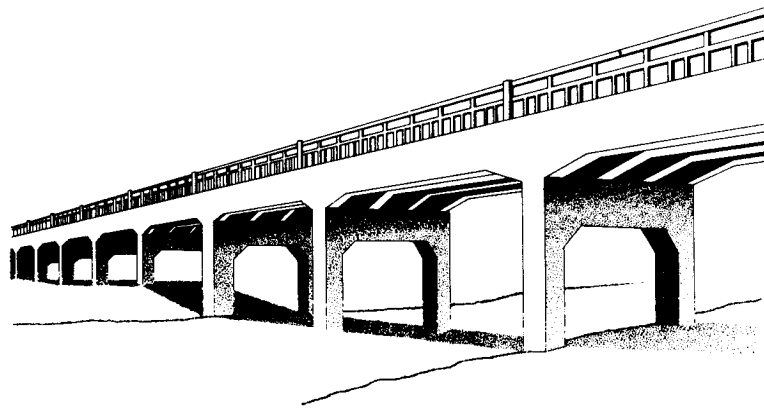
Identify and plot escarpments and embankments greater than 250 meters long and 1.5 meters high. Start by following all streams and rivers and look for areas where the contour lines converge. Look for areas where flat terrain transitions into more rugged, steep terrain. Photo-check these areas and mark the areas where escarpments, embankments, cliffs, ravines, and old stream banks exceed 45 percent. Plot the obstacles using the appropriate symbols.

Identify and plot depressions. Check geologic formations to determine if natural depressions are present. Sinkholes are commonly found in areas containing flat-lying limestones (karst topography) with historically wet climates. Topographic maps show most large depressions. Photo-check these areas and look for new pits, quarries, and open-pit mines. Plot all depressions which are greater than 250 meters long and 1.5 meters high and have slopes greater than 45 percent with the appropriate symbol.

Identify and plot other man-made features and any unique feature which can be classified as obstacles.

Step 4. Prepare the obstacle legend. Prepare the obstacle factor overlay legend according to DMA product specifications.

Step 5. Construct the final overlay. The final step in producing a factor overlay is to put the draft manuscript overlay into a final data-base product. You must have support from the cartographic and reproduction elements or sections. See Chapter 8 for the final overlay procedures.



Man-made Features

Chapter 4

Transportation Identification

Using a 1:50,000 scale map of the area, register the mylar to the base map and annotate the marginal information.

Roads

Step 1. Use the legend of the base map to locate the road classification and type of route. The route identification numbers will be located astride each road inside the route symbol. In some areas where the local government does not assign the roads identification (ID) numbers, you will need to assign arbitrary numbers.

Step 2. Trace all road segments onto the overlay using the proper symbol for each road classification. While tracing each road, look for points where either the classification or ID numbers change. Place a mute symbol at each point of change and annotate the classification and ID numbers as needed. As you trace each road, consider that interstate and federal routes do not change when crossing state or county boundaries. State roads change both classification and ID numbers when crossing state boundaries, and county roads either change classification or are terminated when crossing county or state boundaries. See Figure 4-1.

Step 3. Carefully study the base map legend and compare it the 1:50,000 (TTADB) and 1:250,000 (PTADB) product specifications to determine which factor overlay symbol to use for each map symbol.

Step 4. The surface material of each road is located in the legend across from the appropriate classification symbol. Determine which base map symbol is used in making the factor overlay and record the feature for each symbol in the legend of the factor overlay.

Step 5. Determine the width of the traveled way. Your accuracy in this will vary with the topographic map available. The FRG, USSR, and other European maps indicate the width in meters, but US maps indicate it by the number of lanes or a range of widths. Each road segment between intersections is assigned a width

SYMBOL	HIGHWAYS
	All weather, dual highway
	All weather, hard surface
	All weather, loose surface
	Fair weather, loose surface
	Cart tracks
	Width in meters (Δ denotes travelled way width change)
	Constriction (width in meters)
	Grade > 7%
	Sharp curve (radius < 30 meters)
	Ferry
	On route ford
	Feature under construction
	Bridge or tunnel (≥ 100m length)

Note: Only a representative pattern of major through routes and secondary roads are annotated.

Figure 4-1. Transportation legend (highways)

value, with that number placed parallel to the road segment. Table 4-1 below indicates lane widths currently shown on US military maps.

	Meters	Feet
Trail	Less than 1.5	Less than 5
Track	At least 1.5 but less than 2.5	At least 5 but less than 8
One lane	At least 2.5 but less than 5.5	At least 8 but less than 18
Two lanes	At least 5.5 but less than 8.2	At least 18 but less than 28
More than two lanes	At least 8.2	At least 28

Table 4-1. Lane widths currently shown on US military maps

Follow each route and determine the number of lanes and widths. Convert the lane width to meters to indicate the minimum width of the traveled way. Lightly record this value along the road outlined on the overlay.

Always use a decimal point when recording the road width, for example, 5 meters = 5.0 meters. Assign each road segment between intersections a width value, then place that number on the road segment. Note every point at which a change in width occurs and place a segment symbol at each of those points.

When dual routes occur, indicate the width of each route. If the source map gives only the overall width, assume each side has half the width.

Step 6. Depict gradient or percent of slope on the overlay when it exceeds 7 percent. The flat end of the first arrowhead is at the bottom of the grade, and the point of the last arrowhead is at the top. Measure the gradient from the topographic base map.

To determine percent of slope, measure the change in elevation (vertical distance or rise) and divide it by the horizontal distance (run), then multiply by 100.

$$\frac{\text{Rise} \times 100}{\text{Run}} = \text{percent slope}$$

Step 7. Show a constriction when the road narrows to less than 4 meters. Indicate the width measurement adjacent to the arrowhead symbol.

Step 8. Record all sharp curves with a radius of 30 meters or less.

Step 9. Depict all features that are currently under construction with the circled symbol *UC*.

Step 10. UTM coordinates are given for key reference points and features. See FM 21-26, which discusses map-reading instructions.

Bridges, Tunnels, Galleries, and Snowsheds

Step 1. All bridges are not usually drawn to their true scale on US military maps. Bridges less than 100 meters long are shown as point features, and bridges greater than or equal to 100 meters are symbolized by wing ticks. The only bridges not shown are located on roads that are not depicted. Plot the length between wing ticks to scale; minimum length between wing ticks is 2.0 millimeters. Point features are less than or equal to 2.0 millimeters. Draw all other features to scale.

To determine the true length of a structure, use a microcomparator and measure the feature. Multiply the length of the feature as measured by the microcomparator using the map scale to get the feature length. Record all structure lengths in the data table.

Step 2. Determine structure width. Using the road symbol, establish the width of all structures of one or more lanes directly from the map. For tunnels and fords, use only half the width indicated by the symbol, unless other information sources indicate differently. This width reduction is necessary because some structures are built with only one lane to reduce the cost of construction. See Figure 4-2.

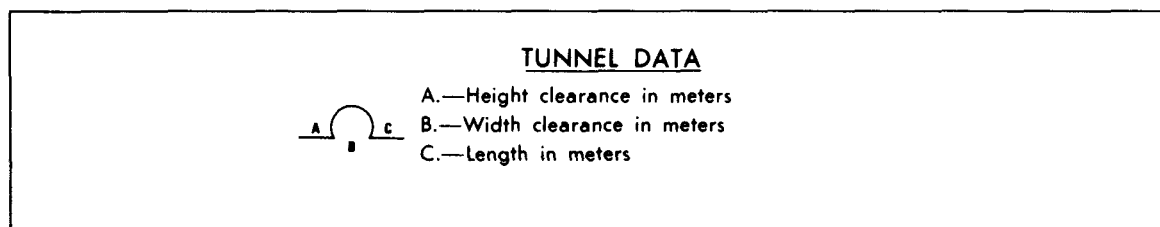


Figure 4-2. Transportation legend (tunnels)

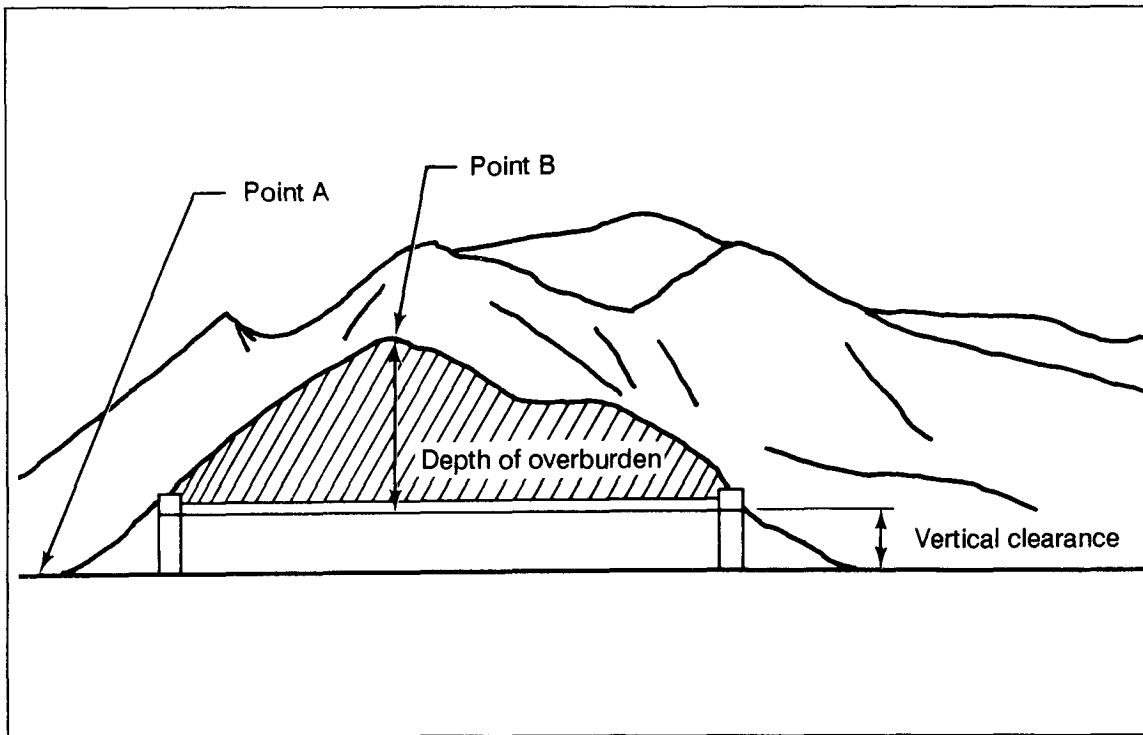


Figure 4-3. Depth of overburden for tunnels

Step 3. Determine the depth of overburden. The depth of the tunnel overburden has tactical significance due to the ability to render road or railroad routes impassable to tactical units, especially if bypass capabilities are restrictive. Tunnel overburden is the material, such as soil and rock, that is directly over the tunnel structure. See Figure 4-3. You can obtain true depth determination of the tunnel overburden only by ground measurements or from DA Form 1250, Tunnel Reconnaissance Report. See Figure 4-4. You can estimate depth using aerial photography or mensuration techniques. The least effective method is to use contour lines on a topographic map. If using a topographic map, the maximum depth of the material (for example, soil or rock) laying directly over a tunnel can be estimated.

a. Determine the elevation of the road surface where it intersects with each tunnel portal. Select the portal with the lowest elevation.

b. Locate the highest contour line that passes directly over the tunnel symbol and determine its elevation.

c. Subtract the elevation determined in Step 3a from the elevation determined in Step 3b. This number is an estimated depth of the tunnel overburden. Record it on DA Form 1250 as an estimate.

Step 4. Determine bypass conditions of bridges. You can determine bypass conditions from a detailed study of the total area extending a distance of 2 kilometers on either side of the bridge. Look for the following factors when evaluating bypass conditions: steepness of bank slopes, depth of water, denseness of vegetation, roughness of surface, presence of boulders or approaches, and wet or soft ground.

TUNNEL RECONNAISSANCE REPORT				DATE	
For use of this form, see FM 5-36; the proponent agency is TRADOC.				18 November 1982	
TO: (Headquarters ordering reconnaissance)		ATTN:		FROM: (Name, grade and unit of reconnaissance officer)	
CDR 84th Engr BN		S2		John H. Doe, 1Lt, Co. B 84th Engr	
1. ROUTE OR LINE		2. FROM (Initial Point)		3. TO (Terminal Point)	
HIGHWAY MO 83		DL 677332		DL 678339	
4. DATE/TIME (Of signature)		5. MAP SERIES NR		6. SHEET NUMBER	
18 1630 Nov		V734		5133II	
7. GRID REFERENCE		8. TUNNEL NUMBER		9. LOCATION FROM NEAREST TOWN	
TYPE 1:50,000		COORDINATES DL 677337		T-1	
10. TYPE (Subaqueous, Rock, Soil)		11. NAME (Mountain or Water feature)		12. LENGTH	
Rock		Blue Springs		135m	
13. NUMBER OF TRACKS		14. ROADWAY WIDTH		15. CLEARANCE	
N/A		8.5m		16. GRADE (Percent)	
17. ALINEMENT (Straight or radius of curve)		18. LINING (Material)		19. PORTALS (Material)	
Straight		Stone		Concrete	
20. VENTILATION (Type)		21. DRAINAGE		22. CHAMBERED FOR DEMOLITION	
Natural		Adequate		☒ YES ☐ NO	
23. COMPLETED (Year)		24. CONDITION (Check appropriate box)		25. BYPASSABILITY	
1921		☐ EXCELLENT ☐ GOOD ☒ FAIR ☐ POOR		Difficult	
26. ALTERNATE CROSSING		27. APPROACHES		28. IN-TUNNEL RESTRICTIONS	
MO 671 to MO 83		Good 2%		None	
29. GEOLOGIC DATA		30. COMMENTS		31. SIGNATURE	
Limestone					

DA FORM 1250
1 JAN 55

Figure 4-4. Sample tunnel reconnaissance report

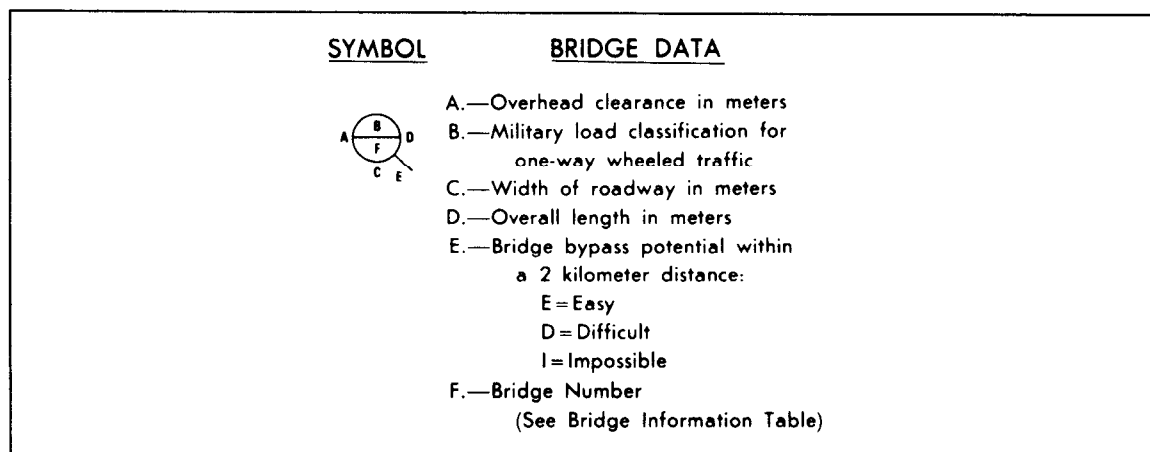


Figure 4-5. Transportation legend (bridges)

Identify each bypass as easy (E), difficult (D), or impossible (I) on the line extending from the NATO bridge symbol to the map location. Easy obstacles can be crossed within the immediate vicinity of the bridge by a US 2 1/2-ton 6 x 6 truck (or NATO equivalent) without improving the bypass. Difficult obstacles can be crossed within the immediate vicinity of the bridge, but some work will be necessary to prepare the bypass. Impossible obstacles can only be crossed by repairing the existing bridge or constructing a new bridge. See Figure 4-5.

Fords

A ford is a location in a water barrier where the physical characteristics of the current, bottom, and approaches permit the passage of personnel and/or vehicles.

Estimate the crossing length of a ford from the map symbol by measuring the distance between the stream margins. Streams that show only one line are 25 meters or less in width and cannot be used as fords. See Figure 4-6.

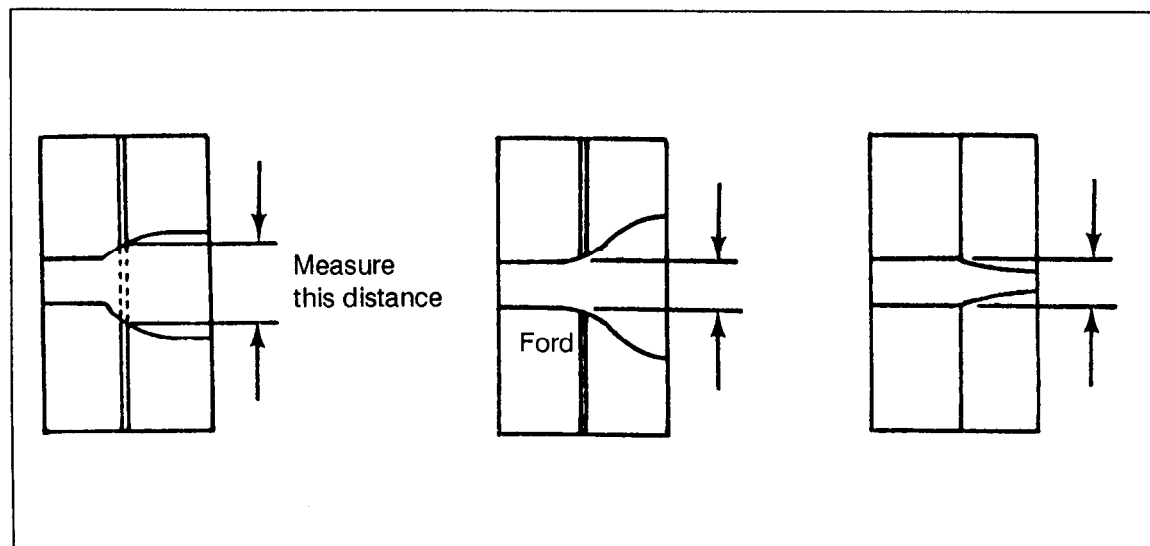


Figure 4-6. Estimating stream margins

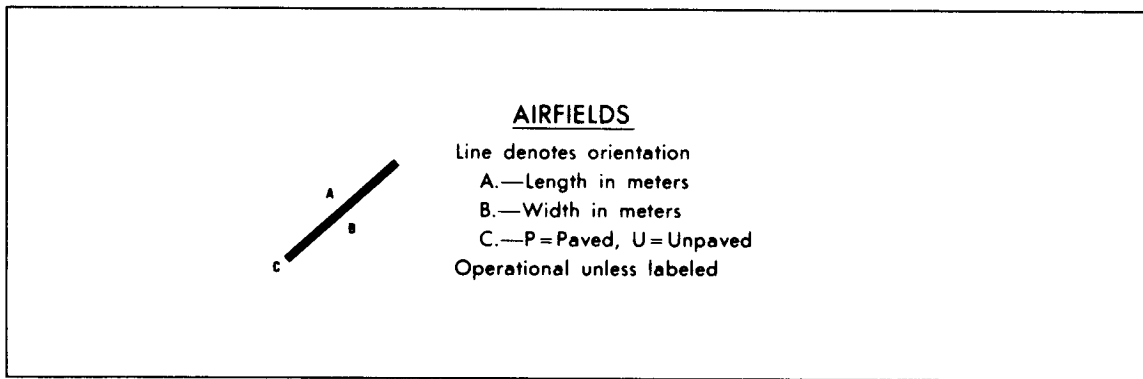


Figure 4-7. Transportation legend (Airfields)

$$\text{Estimated Ford Length} = \frac{\text{Map Scale} \times \text{Ford Length}}{1,000}$$

Divide estimated length by 1,000 to change the length to meters.

Ferries

Step 1. Determine travel distance. You cannot determine the actual distance of ferry travel by analyzing the map, because the route indicated on the map is usually an approximation. When ferry terminals are directly opposite each other, you can use the width of the river as an approximate travel distance. If the terminals are located on different maps, determine the straight line open water distance and record it on DA Form 1252, Ferry Reconnaissance Report. When you approximate distances, note this fact adjacent to the length in the reconnaissance report.

Step 2. Sketch the dimensional plan of terminals. US military maps often indicate the plan view of large ferry terminals. Sketch the dimensions of wharves, buildings, and parking lots in plan view on the ferry reconnaissance report indicating all true distances.

Airfields

The four types of data shown for airfields are length, width, pavement status, and orientation.

Step 1. Trace over the runway to show which direction the runway is oriented. At the end of each runway, indicate its azimuth to the nearest 10 degrees by dropping the zero from the numerical value and deriving a one- or two-digit number. For example, if the azimuth is 260 degrees, the number recorded on the runway is 26. Record the azimuth on the overlay.

Step 2. Measure the length and width of the runway using the map scale. If the runways are not wide enough to permit this procedure, you may place the numerals immediately adjacent to the runway. The runway length measurement should exclude the overrun area. Add the information as to whether the runway is paved (P) or unpaved (U), if you know it. See Figure 4-7.

Heliports

Heliports with runways offer evidence that they are designed for heavier wheeled cargo or passenger helicopters, while helipads accommodate rotary wing aircraft

<u>SYMBOL</u>	<u>RAILROADS</u>
	Single track, normal gauge
	Multiple track, normal gauge
	Narrow gauge
	Broad gauge
	Electrified line
	Dismantled line
	Passing track (≥ 280 meters)
	Siding (≥ 280 meters)
	Yard (total track length in meters)
	Bridge length and overhead clearance
	(U = Unlimited overhead clearance)

Figure 4-8. Transportation legend (Railroads)

that do not require a takeoff ground run to become airborne. Label the azimuths of heliports that have distinct runway orientation. Record the dimensions for width and length using the map scale and the procedure shown above in Step 2 of Airfields.

Railroads

Step 1. Determine the correct category from the map legend for railroads and select the proper symbol for each type. Then draw the railroad symbol on the overlay for each railroad in the same category. Follow the railroad throughout its length on the map, looking for points at which either the category or the ID number changes. Position the symbols to conform with mapping standards. See Figure 4-8.

Step 2. Examine the map and legend and determine the track route, gages, and locations of bridges, facilities, and crossings. Note tunnels and spurs as well as suspected crossings.

Step 3. Start tracing the alignment of the railroad across the entire sheet. Continue this process until you have traced all railroad tracks onto the overlay. Where the tracks intersect with a built-up area, continue tracing the railroad through the area. Mark lightly all pertinent features such as bridges, tunnels, and crossings. If the sheets show a track siding, trace it to its end. Measure the length of the siding in meters and record it on the overlay. If the siding has a building or facility indicated or suspected, trace and annotate its location. Certain facilities may sometimes provide electrical tracks for their privately-owned siding or spur. The

track may also become multiple along the siding or spur, if so, you must note this on the overlay.

Step 4. Whenever the route crosses a stream or creek, note the possibility of a culvert on the overlay. You must also identify all road or highway crossings on the overlay, using the proper symbol.

Step 5. Rarely will a railroad grade exceed 3 percent. If the contour interval suggests a greater gradient, note this on the overlay. A slope overlay may be available with the surface configuration overlays, if previously compiled.

Step 6. Locate and trace all railroad cut and fill areas. Much of this data will be deleted from the final overlay. Cuts are potential railroad traffic interdiction sites because of the possibility of slides induced by demolition of steep side slopes.

Step 7. Railroad bridges are normally symbolized on topographic maps. Unfortunately, the type of bridge or construction material is seldom stated. Locate all highway bridges that intersect the railroad route, as well as all railroad-carrying bridges. Draw the bridge symbol on the overlay adjacent to the site. Measure the bridge length in meters and note. This will be relevant bridge data for DA Form 1249, Bridge Reconnaissance Report.

Step 8. Identify the railroad structures. The map legend or map area may have printed data labeling various railroad facilities such as water towers and switching pits.

PHOTO ANALYSIS OF TRANSPORTATION

Oblique Aerial Photography

The scale of oblique photography is difficult to determine, because it constantly varies from the foreground to the background of the photo. If vertical aerial photography is not available and you must use oblique photography to obtain the necessary data, consult the appropriate references.

Aerial Photographic Measurements

Step 1. Determine horizontal measurements. With a magnifier, carefully determine the location of the traveled way of the bridge. Determine the distance between the curbs of the traveled way with the microcomparator, and take the measurement using the metric scale. Multiply the image measurement by the photo scale to determine the true measurement. Record this value on the bridge cross-sectional sketch on DA Form 1249. Determine the length of bridge number 1 by first locating, under stereo viewing conditions, the abutments at each end of the bridge. With the microcomparator, measure the distance between the abutments. Multiply this image distance by the photo scale and record it at the proper place on your sketch. If the bridge is composed of a number of spans, record them on the sketch and in the Bridge Reconnaissance Report.

Step 2. Determine vertical measurements. Obtain vertical measurements, such as the vertical clearance of the bridge and the under-bridge clearance, from stereo aerial photography by using a parallax wedge or bar. Measurements made with these instruments are more accurate than those obtained from a map, but they are

not as accurate as those obtained from on-site measurements or from as-built drawings. Record the distance on the cross-section sketch on the Bridge Reconnaissance Report.

Step 3. Determine under-bridge clearance. Determine the under-bridge clearance (using the same method) by measuring the difference in elevation between the bridge deck and the surface of the feature passing beneath the bridge. Since the bridge substructure will not be visible to you, you will need to estimate the height of the substructure and subtract it from the computed under-bridge clearance distance. Record the under-bridge clearance distance on the sketch on the Bridge Reconnaissance Report.

Step 4. Determine height. Use the parallax bar to determine height. Orient photos and secure them with tape.

Surface Materials and Conditions

Step 1. Estimate surface materials. Figure 4-9 lists the general air photo characteristics of road surface materials. Compare the photo appearance with the table, and estimate the surface material during the map analysis. Consider the route category when the type of material is not readily apparent. For example, national routes are usually concrete or bitumen, while country roads are often gravel.

Step 2. Estimate surface conditions. Surface condition is difficult to estimate except from very large-scale photography. Look for evidence of frequent patching, checks, broken edges, potholes, ruts, and frost or heat heaving.

Step 3. Determine surface materials of medians and shoulders. These materials may be bare ground, grass, trees, shrubs, gravel, bitumen, or concrete. In some instances, the median may be only a wall or barrier and will be difficult to detect. Therefore, use the largest photos and the highest practical magnification available.

Bridges

Step 1. Identify structure features, using oblique photography. Because they provide a side view of the structure, oblique photos are the best some to determine construction type, material, length, overhead and under-bridge clearances, number and type of span, and length of individual spans. Measurement is dependent on careful, accurate determination of the scale. When practical, make duplicate measurements on vertical photography and average the results.

Step 2. Measure bridge features using vertical photography. Measurements on vertical photos are usually more accurate than similar measurements made on oblique photographs, but vertical photos do not provide the side view so useful in determining the type of construction. A definite shadow of the bridge often provides much of the same information available from oblique coverage. When no shadow of the bridge exists, examine the surrounding vertical photographs and look for an image of the bridge that falls near the edge of the photograph. Images near the edge of vertical photos are often displaced or tilted so that the side of the object is visible.

Step 3. Determine the military load class. You cannot determine the military load class directly from aerial photography, but you can roughly estimate it from vehicles that were using the bridge at the time the photo was taken. Examine the

AIR PHOTO CHARACTERISTICS OF ROAD SURFACE MATERIALS					
FILM TYPE	CONCRETE	PAVING STONE	BITUMEN	GRAVEL	SOIL
Panchromatic	- Center line present - Definite margins - Light tone	- Center line present - Light to dark tone depending on materials - Pattern of blocks may be detectable	- Center line present - Indefinite margins - Dark tone	- No center line - Indefinite margins - Light to dark gray tone	- No center line - Indefinite margins - Tone dependent on soil color
Black and white infrared	- Center line present - Definite margins - Light tone	- Center line present - Light to dark tone depending on material - Pattern of blocks may be detectable	- Center line present - Indefinite margins - Dark tone	- No center line - Indefinite margins - Light to dark gray tone	- No center line - Indefinite margins - Tone dependent on soil color
Color	- Center line present - Definite margins - Light tone	- Center line present - Light to dark tone depending on material - Pattern of blocks may be detectable	- Center line present - Indefinite margins - Dark tone	- No center line - Indefinite margins - Light to dark gray tone	- No center line - Indefinite margins
Color infrared	- Center line present - Definite margins - Light tone	- Center line present - Light to dark tone depending on material - Pattern of blocks may be detectable	- Center line present - Indefinite margins - Dark tone	- No center line - Indefinite margins - Light to dark gray tone	- No center line - Indefinite margins

Figure 4-9. Air photo characteristics of road surface material

photos and identify any vehicles on the bridge. If you can estimate the load class of the vehicle, you can assume that the class of the bridge is at least the same. If no vehicles are actually on or approaching the bridge, the load class cannot be estimated.

Step 4. Identify construction type and materials. On large-scale aerial photography (1:2000 to 1:15,000) such as panchromatic and color, you can easily identify construction type and materials such as masonry, wood, steel-reinforced concrete, and steel by indicators on the photos. These indicators include shadow and photographic tone, color, and texture. With detailed study of the photographs, especially under stereo conditions, you should be able to determine not only the type of construction but also the major structure composition.

Step 5. Determine bypass conditions. The standard topographic map will supply all the necessary information to determine bypass conditions for each bridge and LOC structure. However, you must use aerial photography to continuously update the map, particularly under combat conditions. To determine bypass conditions from aerial photography, study the area adjacent to the structure under stereo conditions and note any indications of shallow water, such as sandbars or rocks, that are visible through the water surface. In addition, look for vehicle tracks along the river bank that indicate the location of an existing ford. When the structure is a dam used as a bridge, examine the downstream side of the dam, where the water is often shallow enough to be used as a bypass. Because dams are almost always situated where bedrock is close to the surface, stream bottom conditions are usually firm enough to support most vehicle types.

Ford Width

Look for indications that the roadway continues across the channel, such as two faint lines that mark the sides of the traveled way. On some fords, the sides of the roadway are marked by boulders that appear on the imagery. Where the ford has been raised by adding material to the bottom of the stream, the sides may appear as lines of ripples or as eddies of a lighter tone than the surrounding water. Measure the width.

Ford Bottom Characteristics

Determining ford bottom characteristics such as paved, rocky, and sandy from aerial photography depends on a number of factors. They include water depth and clarity, film type, and photo scale. To determine this data, orient aerial photos of the ford for stereo viewing using proper procedures. Study the area around the ford, as well as the river or stream channel both upstream and downstream of the ford.

Rapids, white water, and exposed rocks or boulders indicate a rocky bottom. Bars, braiding, and steep banks often indicate coarse-grained material such as sand or gravel. Meanders and oxbows in the immediate vicinity indicate relatively slow-moving streams with fine-grained material. Angular drainage patterns with frequent sharp changes in direction indicate rock control and a rocky bottom. In swift-flowing streams in mountainous areas, fine materials do not settle; therefore, the bottoms are usually rocky or firm.

Length of Ferry Crossing

You can easily determine ferry crossing length from aerial photography if both terminals appear on a single photograph. If two or more photos are required, construct a mosaic of several photos.

Single Photo Method

Determine the scale of the photo, using proper procedures. Locate terminals and measure the open-water distance between terminals with the microcomparator or PI scale. Multiply the measured distance by the denominator of the representative fraction to determine true distance.

Mosaic Method

Determine the number of photos required to cover the entire open-water distance between ferry terminals. Secure the photo containing the most western terminal to a suitable flat surface. Carefully place the adjacent photo over the edge of the first photo, aligning common terrain features of Photo 2 with Photo 1. Continue this process until the second ferry terminal appears on a photo. Check your work, making certain that all photos are properly aligned.

Scale the open-water distance between ferry terminals. Multiply the photo distance by the denominator of the photo representative fraction.

Ferry Terminal Layout

Step 1. Orient the photos for each terminal, using proper procedures, and examine the terminal facilities and approaches.

Step 2. Examine the land facilities. Look for large buildings, parking lots, winches, guy-line towers, and any other features that may affect the use or capacity of the site. When feasible, determine the dimensions of the site and major structures.

Step 3. Examine the water approaches. Look for obstacles, fenders, piers, pilings, and evidence of the channel.

Step 4. Analyze vessel information such as ferry length, beam, and capacity. To do so, you will need to orient photos, locate one or more of the vessels, and determine the photo scale. With the microcomparator, measure the length and width of each vessel. Multiply the photo distances by the denominator of the photo scale to determine true distances.

Step 5. Estimate the number of vessel decks capable of carrying vehicles. Assume an automobile size of 2 by 6 meters and a weight of 2 tons.

Step 6. Estimate vehicle capacity for one deck of the vessel. Multiply this number by the number of decks. If all vessels do not have the same length and beam, measure and record each vessel separately.

Step 7. Examine approach conditions for fords and ferries. Approaches are classified as easy when the slope is 7 percent or less; the surface is relatively smooth with no ruts, potholes, or other obstacles; the width is at least 3 meters; there are no sharp curves within 50 meters of the water's edge and the surface is well drained

or free of standing water. Failure to meet all of these conditions will result in the approach being classified as difficult.

Airfields

Step 1. Using the PI and photographic scales, measure the length and width of the runway. Record the measurements in meters on the factor overlay within the runway boundary lines or beside the runway.

Step 2. Determine the surface material of the runway using the information in Table 4-2. Label runways with hard or paved surfaces with a *P*, and loose or unpaved surfaces with a *U*.

AIRFIELD SURFACE MATERIALS INFORMATION			
Type of surface	Surface outlook	Color	Other
Sod	Irregular	Brown to green mottled (color photos)	Tire tracks
Graded earth, gravel, sand, coral, clay (sources of surfacing material)	May have grader marks	Light to dark color, mottled	Open pits in the vicinity
Pierced metal	Grid pattern	Brown to green, mottled	Piles of plank in area
Concrete	Smooth, surface may be patched or painted	Light gray to white, uniform	Block pattern
Asphalt	Smooth, surface may be patched or painted	Very dark to light gray, usually uniform	None

Table 4-2. Airfield surface materials information

Step 3. At most major airfields, the magnetic alignment of runways is painted in large numerals at the ends of the paved surfaces. These azimuths, contrasting with the runway coloration, may be legible on aerial photography. Transfer these values to the ends of runways shown on the factor overlay. If the numerical designations of runway azimuths do not appear or are illegible on the photography, measure the magnetic orientation of each runway and enter the values at the ends of the runways.

Railroads

Step 1. From the stereo pairs, locate the area of the railroad to analyze. Compare the date of the photographs with the date of the last map revision or update. If the photographs are more recent than the map, use them. If the map is more recent, give greater weight to the map information however, even if it is more recent, it should not always take precedence over the photographs, because map information is often general. As a result, some feature such as sidings are not shown.

Step 2. Look for any railroad sidings not shown on the map. Compare the outline of all built-up areas on the photos with the map symbols of the same areas. Lightly sketch any new alignments or built-up areas onto the overlay in pencil.

Step 3. Verify the location of each segment end point. If the end points determined from the photo differ from those obtained from the map, use the points obtained from the photos. Relocate the endpoint symbols on the overlay, renumber the segments if necessary, and determine the coordinates of the relocated points. Change entries in the railroad data tables if necessary.

Step 4. Verify the gradient of each segment that has a grade of 3 percent or greater.

Step 5. Examine aerial photography to verify the location of culverts or streams. The map indicates the location of culverts or streams passing beneath the railroad. Also check all areas on the photos where a stream or drainageway intersects a railway. If these areas indicate culverts, annotate the overlay at each location. Make notes in the data tables as necessary.

Step 6. Locate built-up areas on aerial photos that show railway through-routes. Locate any zones where buildings, walls, and so forth constrict the width of the route to less than 4 meters. Measure the constrictions, using the microcomparator or the PI scale, and record the data in the proper place on the overlay.

Step 7. Examine and verify areas previously identified as level crossings. Make additions, deletions, or changes on the overlay as required.

Step 8. Determine catenary clearance. The clearance beneath the catenary is required only if the railroad under study is electrified and uses overhead wires. The catenary clearance is seldom shown on maps. Photos may provide some indication of catenary clearance. If not, place a question mark above the crossings on the overlay to indicate there are overhead wires but the clearance is unknown.

Step 9. Assemble the vertical photos that provide stereo coverage for each bridge recorded on the factor overlay. If oblique photos are available, place them with the vertical ones. Study the material carefully to become familiar with the general characteristics of the bridge. Determine the number of spans, overhead clearance, and so forth. Measure the roadbed widths. Record all data in Railroad Data Table 2 or annotate it on the overlay.

Inland Waterways

Classify inland waterways according to their depths. Very shallow waterways have depths less than 1.4 meters. Medium waterways have depths between 1.4 and 2 meters. Deep waterways have depths greater than 2 meters. See Chapter 2 for more information.

Facilities and Installations

Step 1. Identify all wharves. Figure 4-10 shows a reference diagram of a wharf.

Step 2. Identify all locks. Common types of locks are single and multiple-chamber. See Figure 4-11. Gates are the most vulnerable features of a lock. Common types of gates are--

- Double-leaf miter gates (see Figure 4-12). A pair of hinged gates that form a V or angle across the end of the lock when closed. The apex is always upstream to use the head of water to keep the gates closed.
- Single-leaf miter gates. Hinged gates that pivot into a recess in the lock wall. See Figure 4-13.
- Vertical-lift gates. Lock gates that move in a vertical plane. Those gates are usually suspended from an overhead frame and counterbalanced.

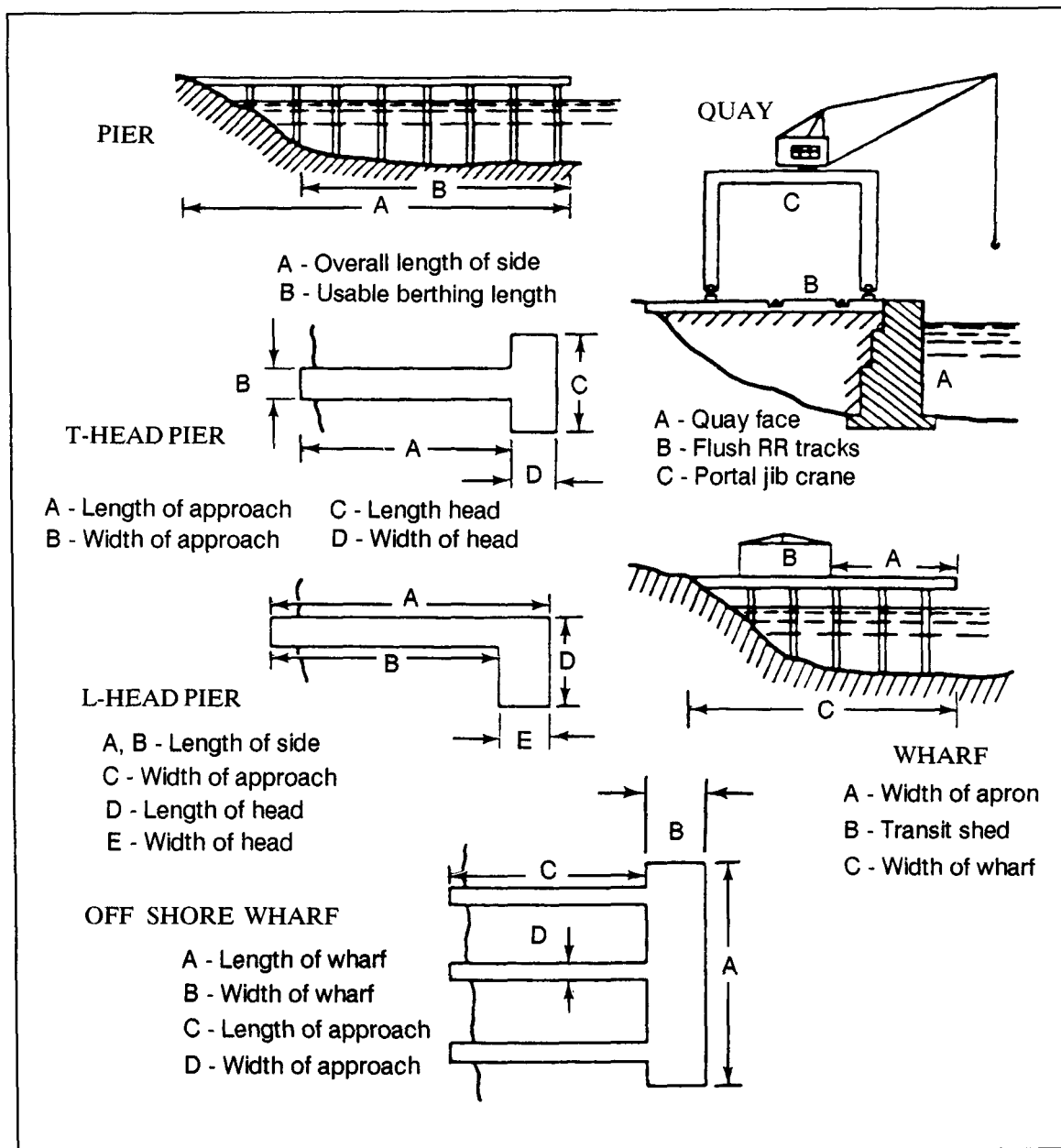


Figure 4-10. Wharf reference diagram

- Caisson or sliding (retractile) gates. Those gates move horizontally into wells or caissons when open.
- Segmental gates. A pair of gates shaped like sectors of a cylinder. They are hinged at the sides and rotate into wells.

Step 3. Prepare final overlay. See Chapter 8 for procedures.

URBAN AREAS

Step 1. Obtain a 1:50,000-scale map covering the area of interest. Register the mylar to the map or data base and annotate the marginal information. Then locate and outline all areas that cover the area to be studied.

Step 2. Establish a numerical priority listing (ranking) of urban areas to be analyzed at a scale of 1:12,500. Determine this sequence based on whether the areas are administrative centers (state and national capitals, strategic centers of

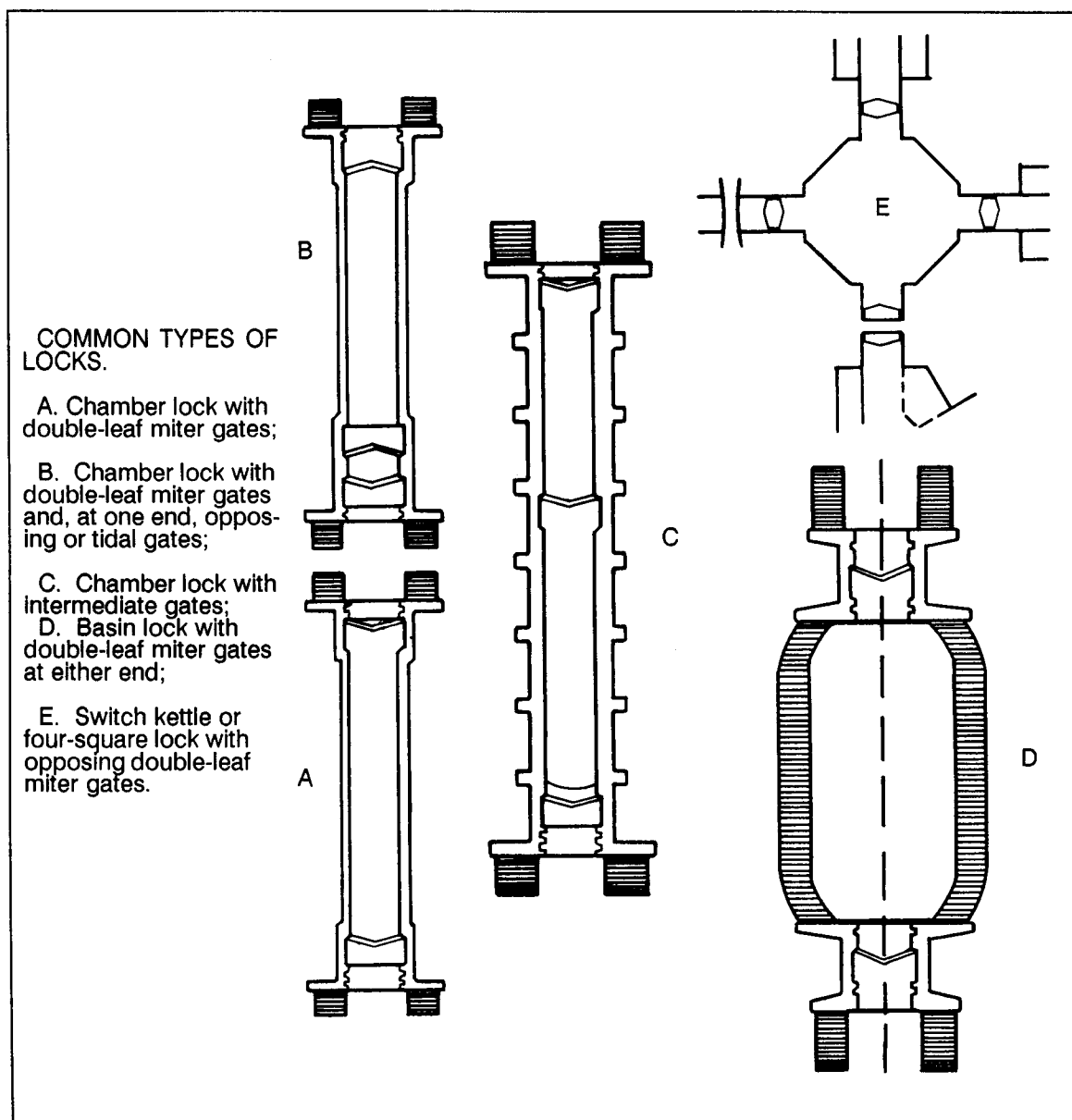


Figure 4-11. Types of locks

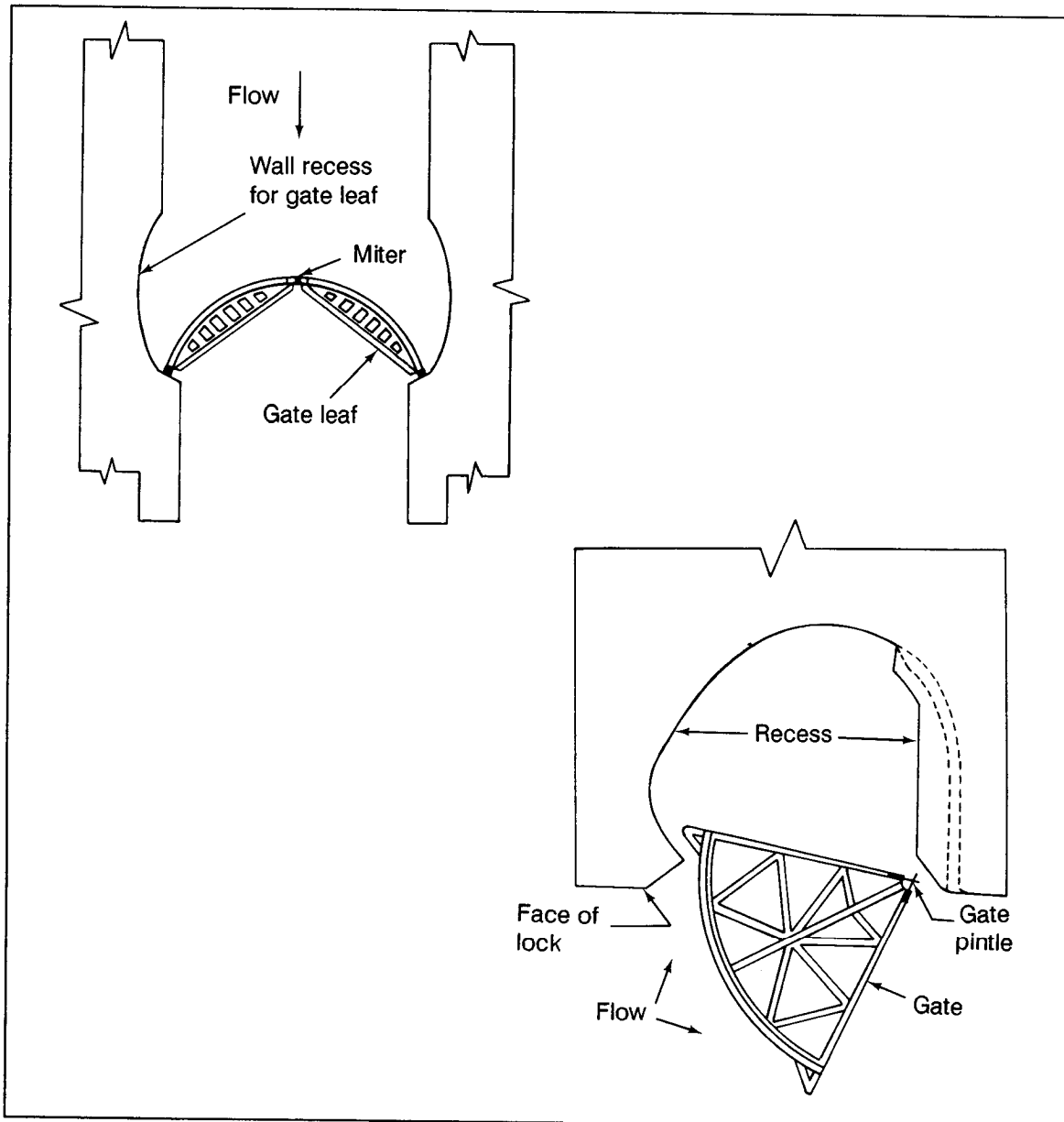


Figure 4-12. Miter gate locks

production, steel, manufacturing, and nuclear power plants), or are located on dominant ground or on major avenues of approach.

Step 3. Assign a priority number to each urban area and carry out the analysis accordingly. Where all urban areas on a 1:50,000-scale map are to be analyzed without concern for priority consideration, number each area, beginning at the top left corner of the identification overlay, and proceed across and down the map.

Step 4. Retrieve a 1:12,500-scale topographic map of the urban area. If you cannot find any, outline the desired area on the 1:50,000-scale map and enlarge this map segment by 400 percent. If a 1:25,000-scale map is available, you may enlarge

it by 200 percent. The enlarged map will become the base map to which all factor overlays will be registered.

You will require multiple overlays to extract information for the data fields documented in order to map adequately the diverse terrain features that make up the urban area. In this regard, the number of overlays to be used is considerably greater than the number used in other areas. Some topics include vegetation, roads and related structures, drainage and water resources, and railroads and related structures. Because of the larger scale of the urban-area products and the complexities inherent in this unique terrain, some elements are portrayed differently from those depicted on overlays keyed to 1:50,000-scale maps.

Step 5. Determine the area to be analyzed and gather all necessary aerial photographs in stereo pairs to cover the area. Orient them for stereo viewing.

Step 6. View the photographs in stereo and use the PI keys and text to determine the urban type in the aerial coverage. Then analyze, outline, and identify all types and label them with the appropriate urban code.

Step 7. Determine the roof coverage. Density refers to the ratio of roof area of buildings to total ground area, including streets and small open spaces. To determine roof cover percentage from aerial photography, collect the necessary stereo pairs for the area to be analyzed and note the photo scale. Measure the footage of the area, both the length and width, with a thousands-foot scale and multiply it by the photo scale.

$$GD = PD \times PSR$$

$$\text{Area} = L \times W$$

Where--

GD = ground distance

PD = photo distance

PSR = photo scale reciprocal

L = length

W = width

Step 8. Determine the roof size by measuring the average roof in the area the roofs should all be about the same size. Using the microcomparator, measure the length and width of an average roof and multiply it by the photo scale. Then count the number of buildings and multiply that number by the area of the roofs. To determine the percentage of the roof coverage, take the roof size times the number of buildings in the area, divide it by the total area, and multiply it by 100.

$$\frac{\text{Total area of buildings} \times \text{Number of buildings in area} \times 100}{\text{Total area size}} = \% \text{ Roof coverage}$$

Figure 4-13 will help determine the percentage of roof coverage and the percentage of concealment from aerial detection. Use the appropriate symbol to mark the overlay.

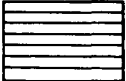
Symbol	% Roof coverage	Category	Concealment
5 	75-100	Congested	Excellent
4 	50-75	Dense	Good
3 	25-50	Moderate	Fair
2 	5-25	Sparse	Poor
1 	0-5	Open	None

Figure 4-13. Concealment from aerial detection and percentage of roof coverage

Step 9. Determine construction and building type. Make appropriate annotations for type of construction or building, using the definitions below. Note: Building types 5 through 8 are comprised of multistory office and apartment buildings. For the purpose of classification and subsequent evaluation, each category is divided into low-rise buildings of six stories or less and high-rise structures in excess of six stories.

- **Type 1.** Wood and timber frame construction. Most farm buildings and those buildings constructed prior to the late 19th century are classified as Type 1. Their ceilings with wooden rafters and weak exterior walls offer little protection from indirect or direct weapons fire. Internal communications routes are excellent since their lightly constructed walls are easy to breach; however, significant reinforcement is required to provide protective cover if such buildings are to be used as defensive positions. Within larger built-up areas, Type 1 buildings present the greatest fire hazard. See Figure 4-14.
- **Type 2.** Masonry construction. Buildings with strong walls of brick or natural stone constructed in the 19th and early 20th centuries are classified as Type 2. These buildings, typified by the old town hall, are commonly found in the central areas of towns and cities. They generally contain from two to four stories with ceilings with wooden rafters and lightly constructed tile roofs. Presenting less of a fire hazard than wood and timber frame structures, Type 2 buildings are frequently suitable as defensive positions. While internal communication routes are excellent, external walls are difficult to breach without heavy weapons or demolitions. See Figure 4-14.

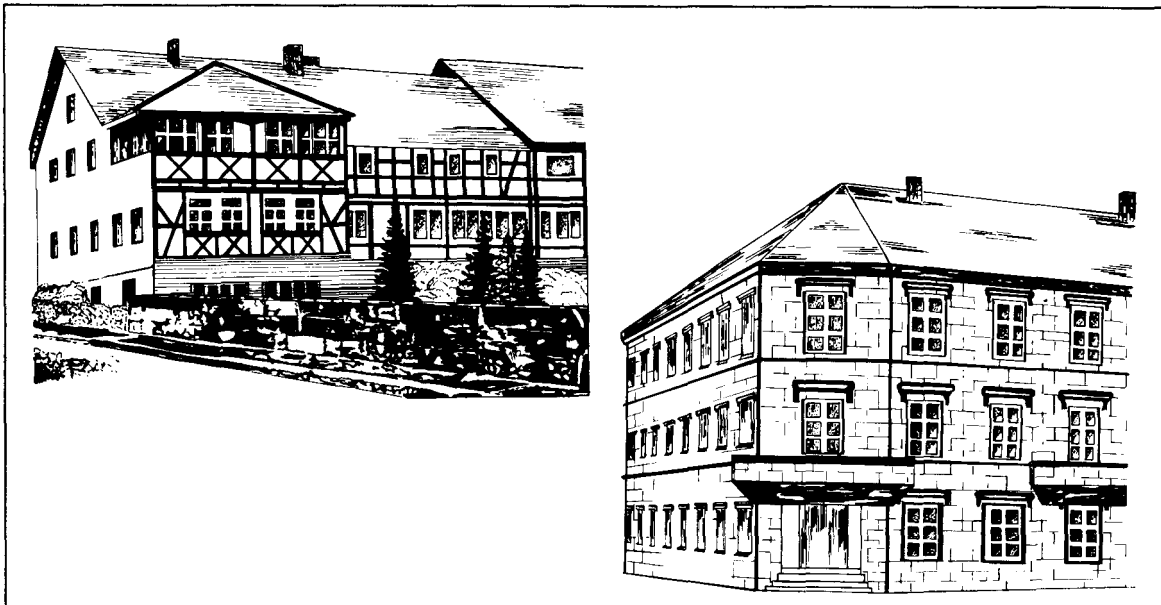


Figure 4-14. Examples of construction/building type (wood and frame and masonry)

Type 3. One- or two-family dwellings. Family dwellings constructed of solid or insulating bricks or of cinder blocks with ceilings of reinforced concrete are classified as Type 3. Such buildings frequently contain strongly constructed basements. Type 3 buildings offer significant protection and require little reinforcement if used as defensive positions. Because of Type 3 construction, fire hazards are minimal. If demolished, significant rubble is generated, offering protection to the defender or creating an obstacle to the attacker. See Figure 4-15.

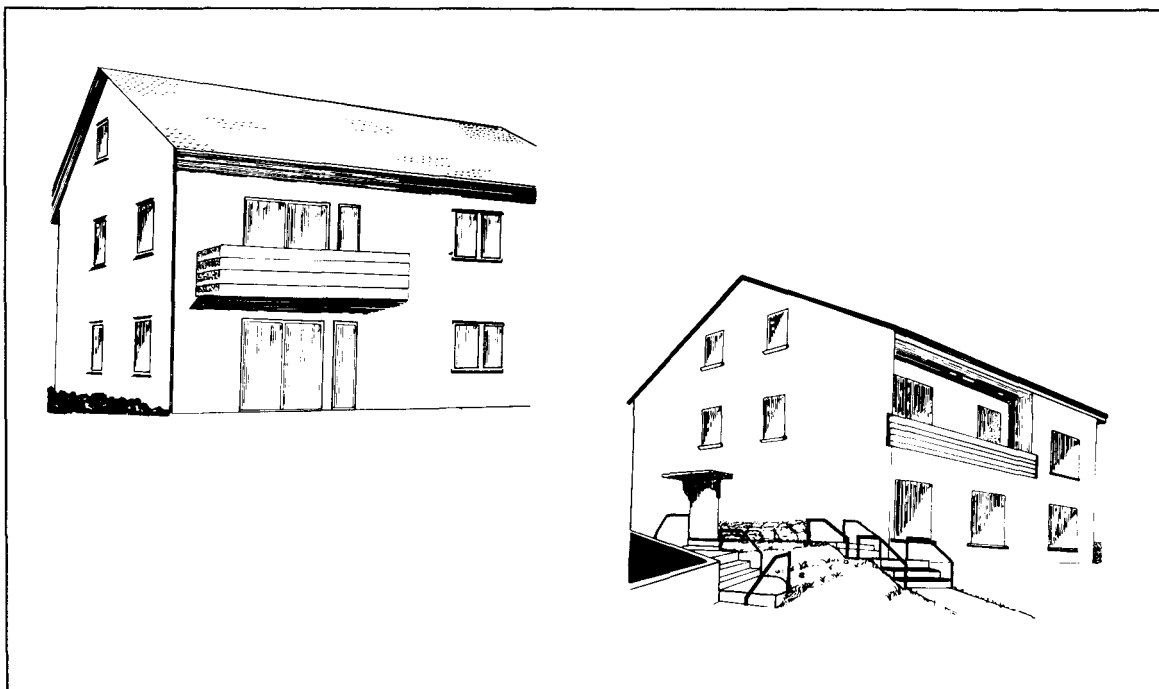


Figure 4-15. Example of construction/building type (family dwellings)

- *Type 4.* Prefabricated one-family dwellings. Prefabricated family dwellings assembled with precast and light building materials are classified as Type 4. In most cases, the cellars or basements are strongly constructed. Unlike Type 3 dwellings, these buildings require significant reinforcement if they are to be used as defensive positions. They also constitute a fire hazard in a freed defense. Rubble produced by their destruction creates an effective obstacle and additional cover for ground-level defensive positions. See Figure 4-15.
- *Type 5.* Low-rise office buildings. Multistory office buildings, with their steel frame and reinforced concrete construction, are normally characterized by large expanses of plate glass which offer little protection. See Figure 4-16.
- *Type 6.* High-rise office buildings. These buildings are also characterized by large expanses of plate glass which offer little protection, but they have six stories or more.
- *Type 7.* Low-rise apartment buildings. While similar in size to low-rise office buildings, they generally have smaller glass areas and load-bearing reinforced concrete exterior walls which provide greater protection.
- *Type 8.* High-rise apartment buildings. See Type 4, paragraph 2. See Figure 4-16.
- *Type 9.* Buildings common to newer industrial and warehouse complexes are classified as Type 9. While the type construction may vary considerably, steel framing and the use of lightweight materials for exterior walls and roofs are normal practices. Reinforced concrete floors and ceilings are frequently used in multistory buildings.

Figures 4-17 through 4-31 show examples of industrial areas that will be useful in identifying specific subdivisions of the industrial classification.

This completes the urban analysis procedure. See Chapter 8 for final overlay preparation procedures.

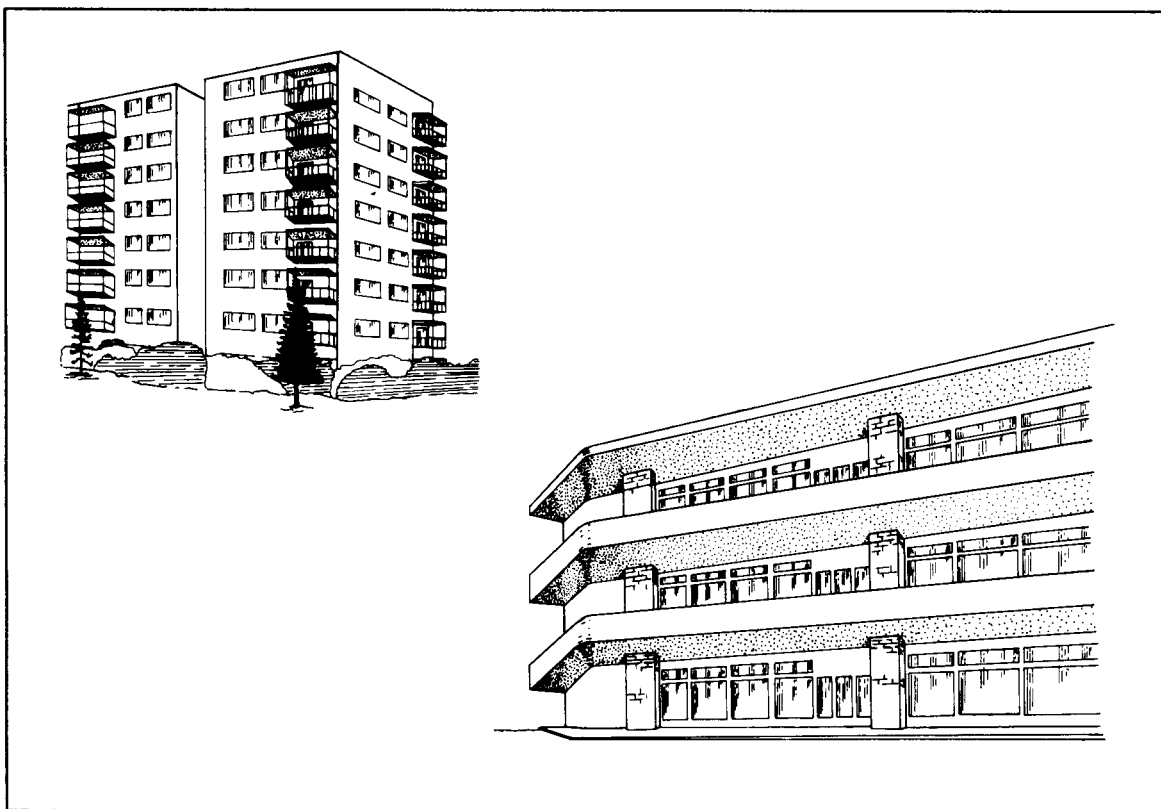


Figure 4-16. Example of construction/building types (multistory buildings)

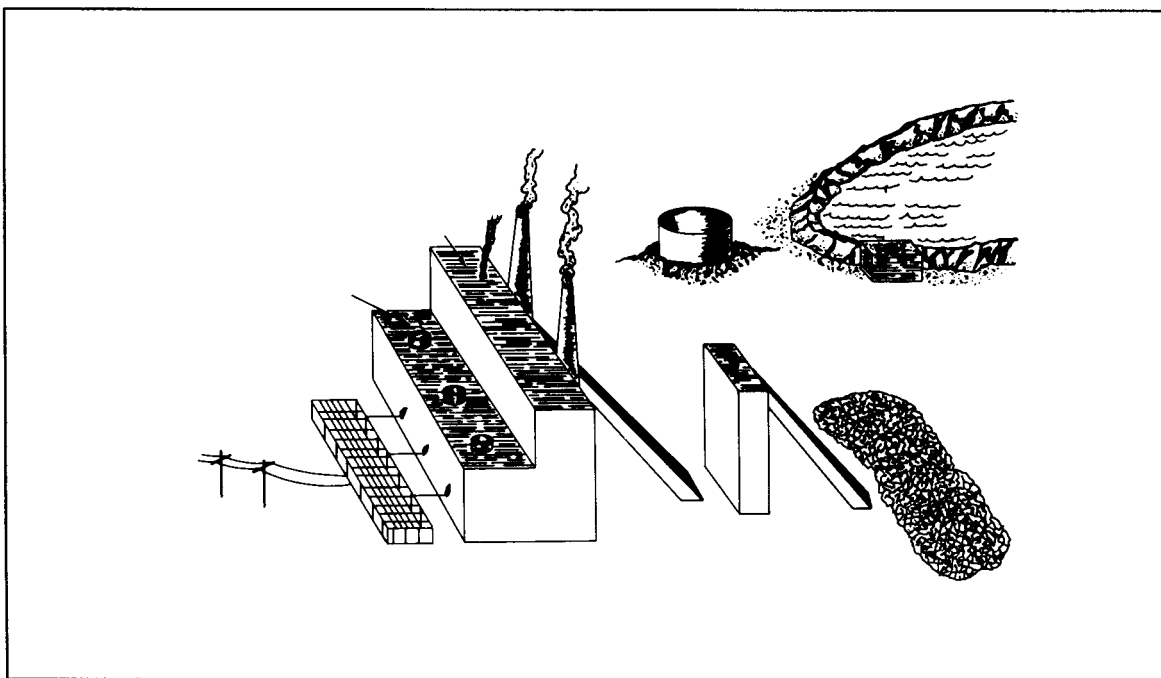


Figure 4-17. Example of a construction/building type (thermal electric power plant)

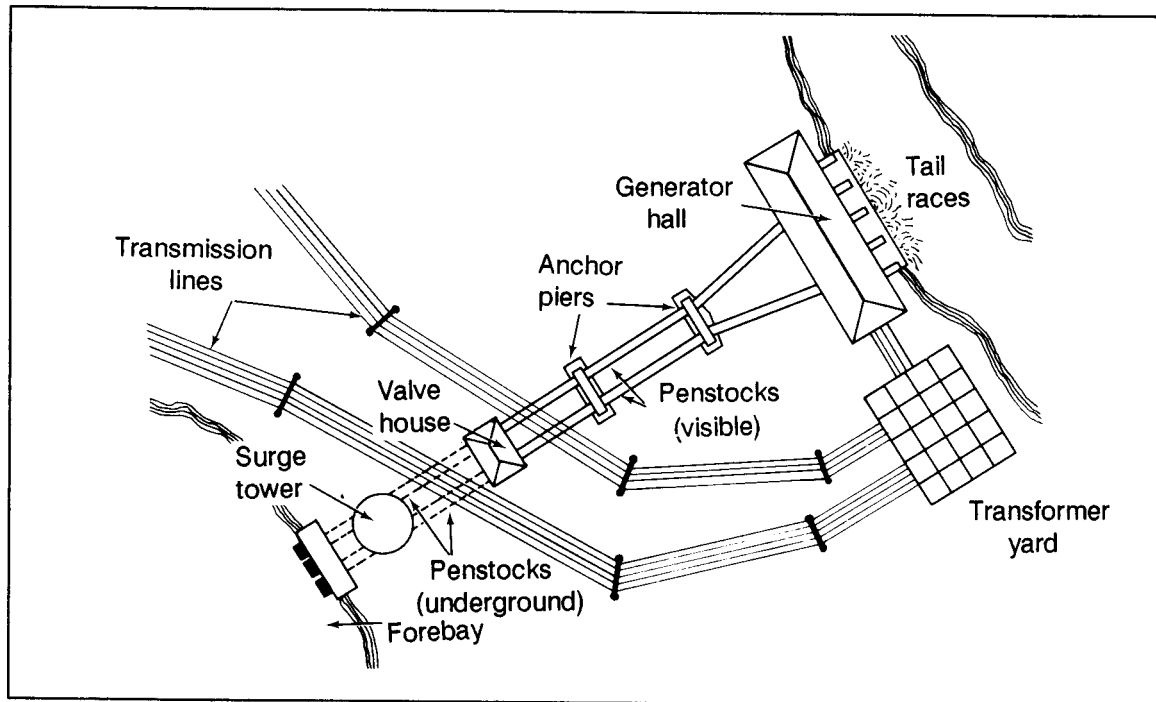


Figure 4-18. Example of construction/building type
(penstock type hydroelectric power system)

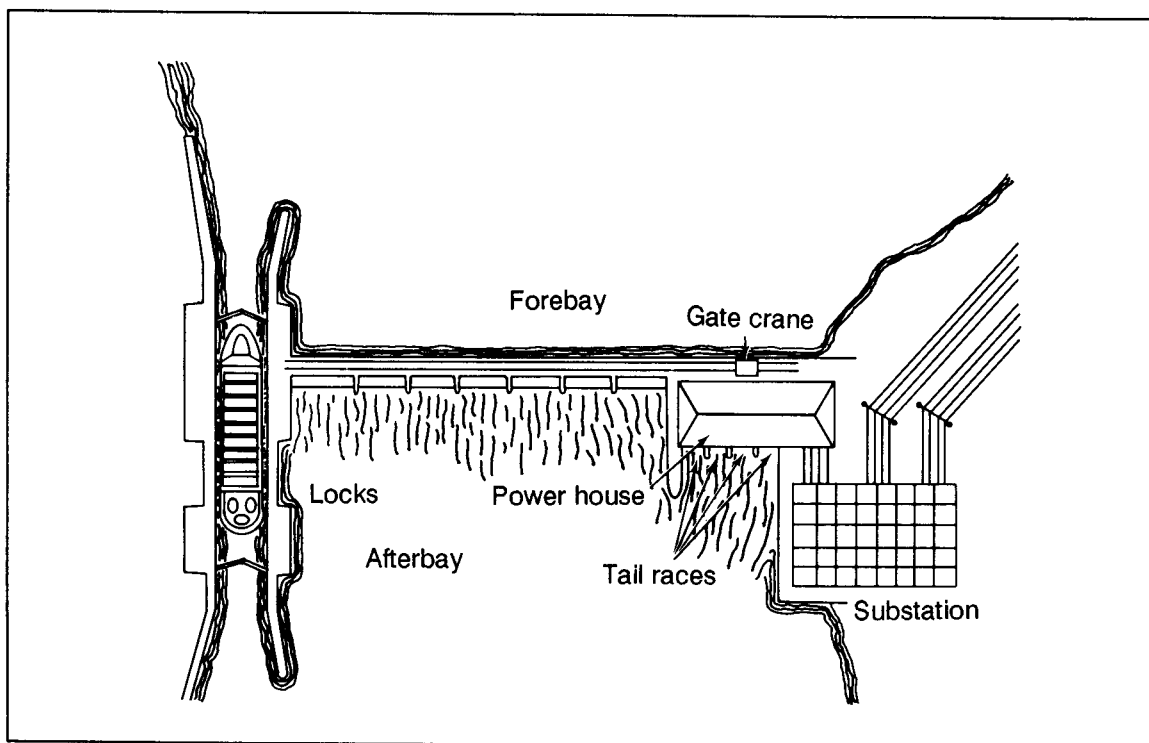


Figure 4-19. Example for construction/building type
(low dam type hydroelectric power system)

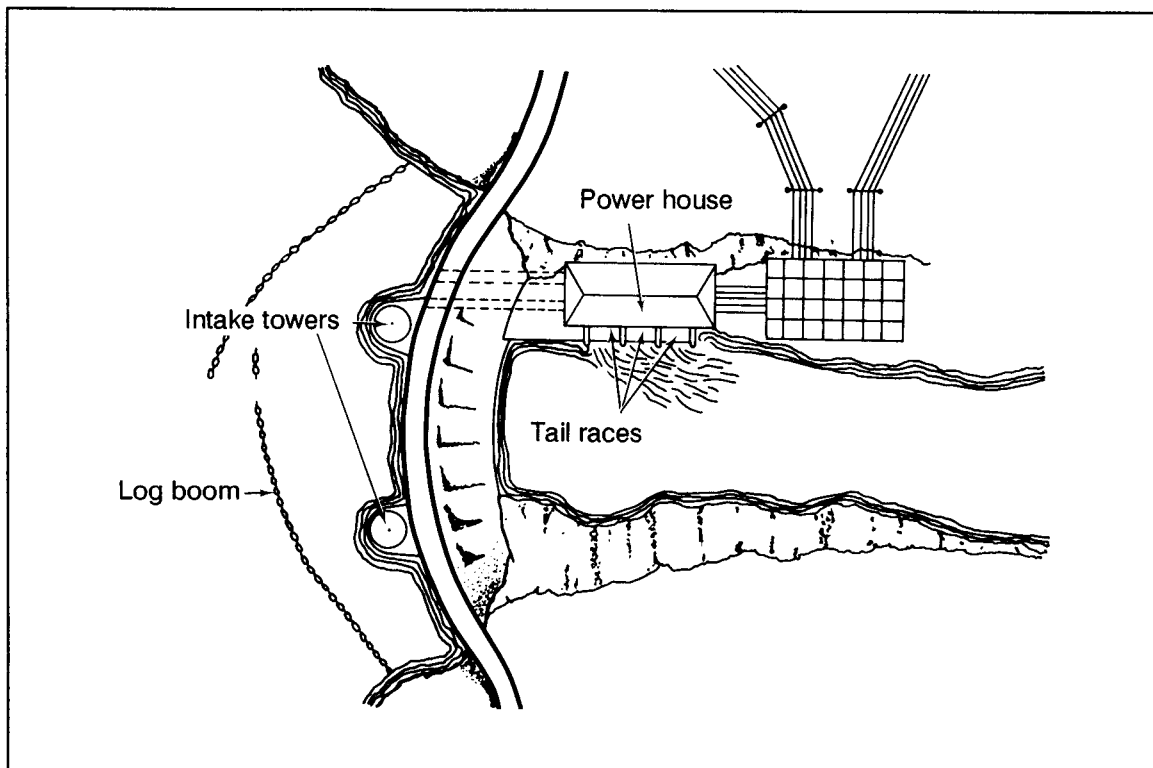


Figure 4-20. Example of construction/building type (high dam type hydroelectric power plant system)

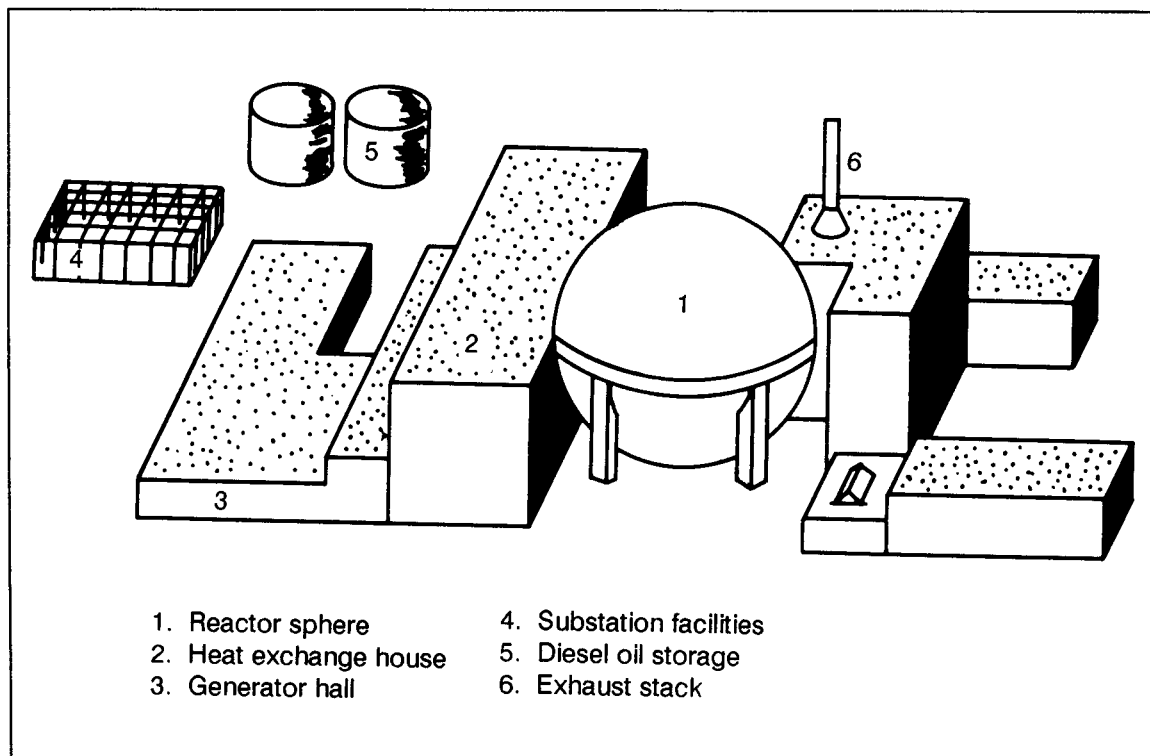


Figure 4-21. Example of construction/building type (thermal nuclear power plant)

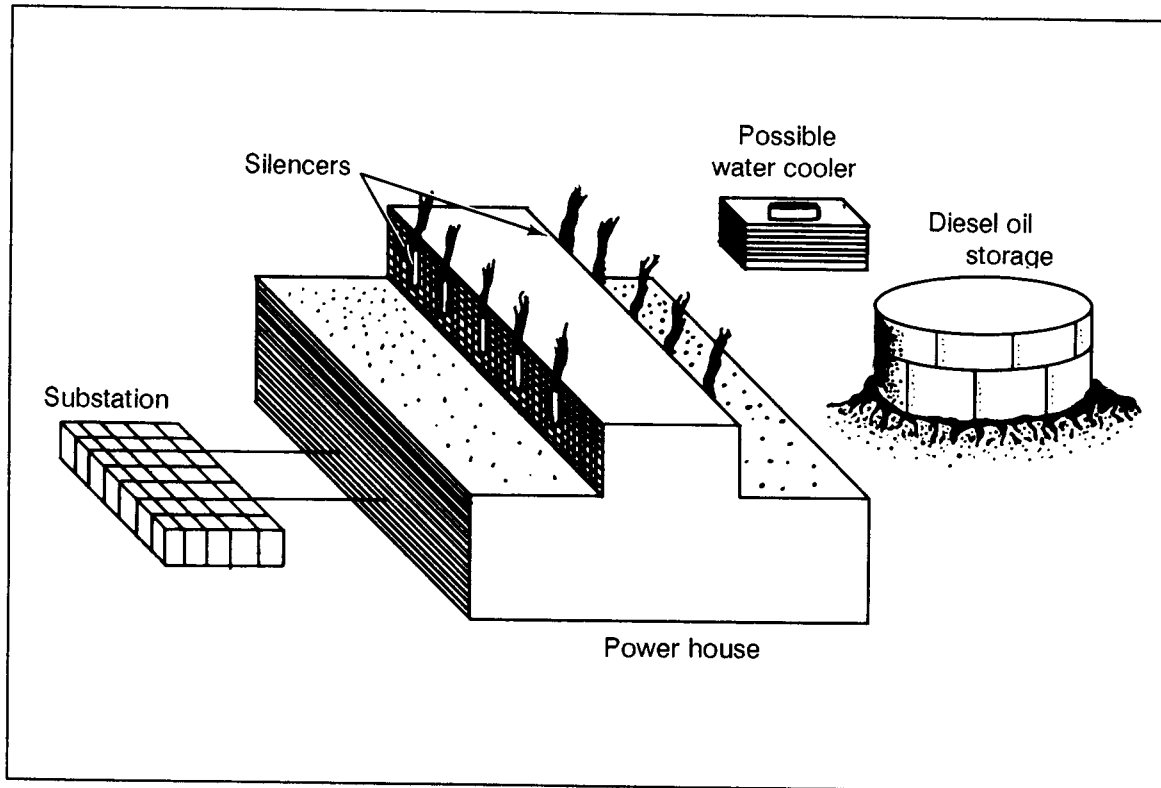


Figure 4-22. Example of construction/building type (internal combustion power plant)

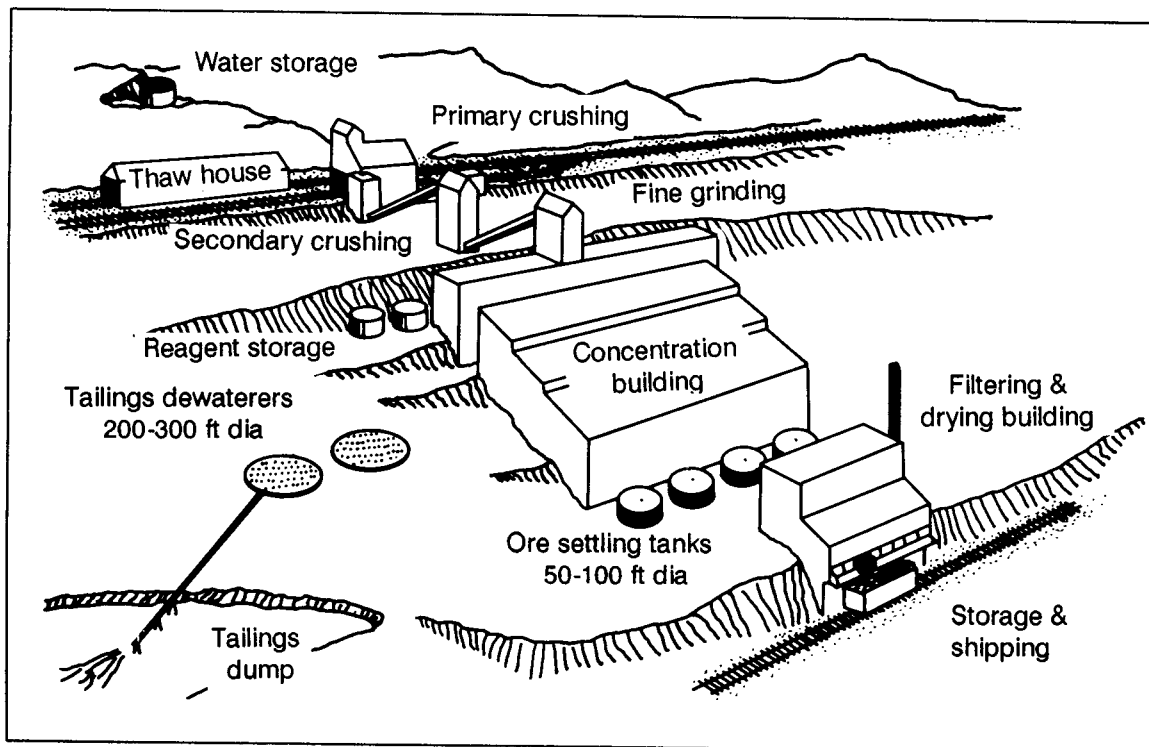


Figure 4-23. Example of construction/building type (ore processing - beneficiation)

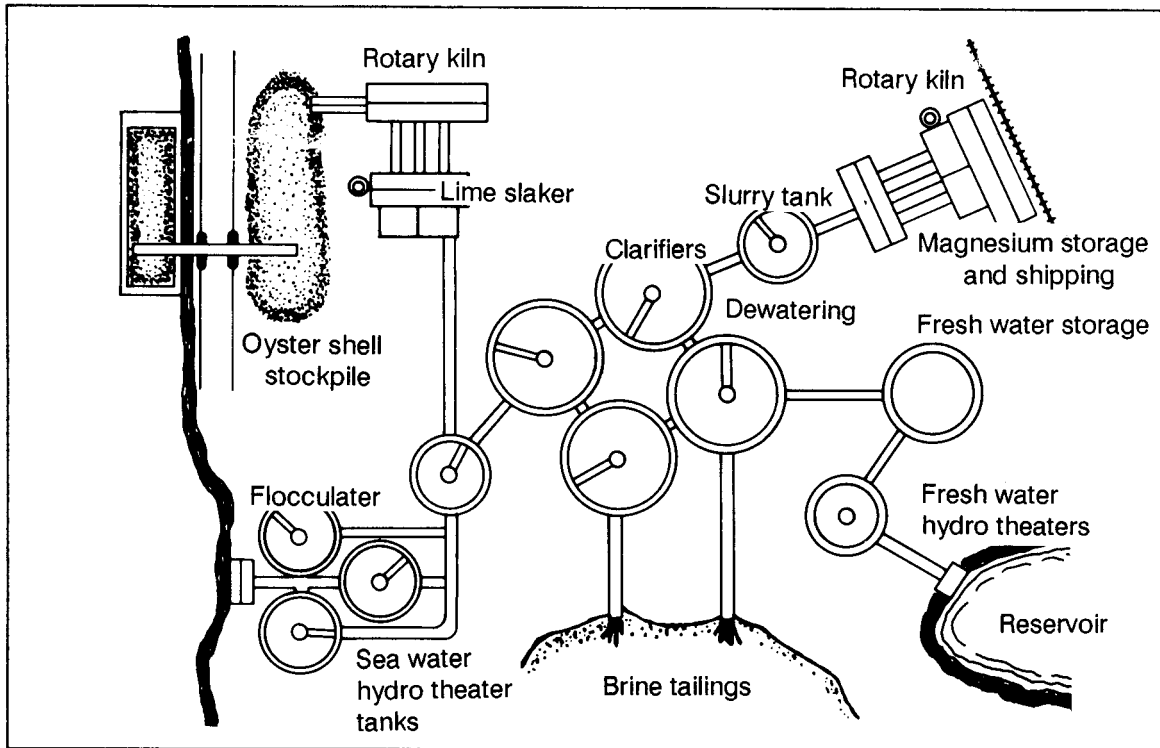


Figure 4-24. Example of construction/building (ore processing - magnesia from brines)

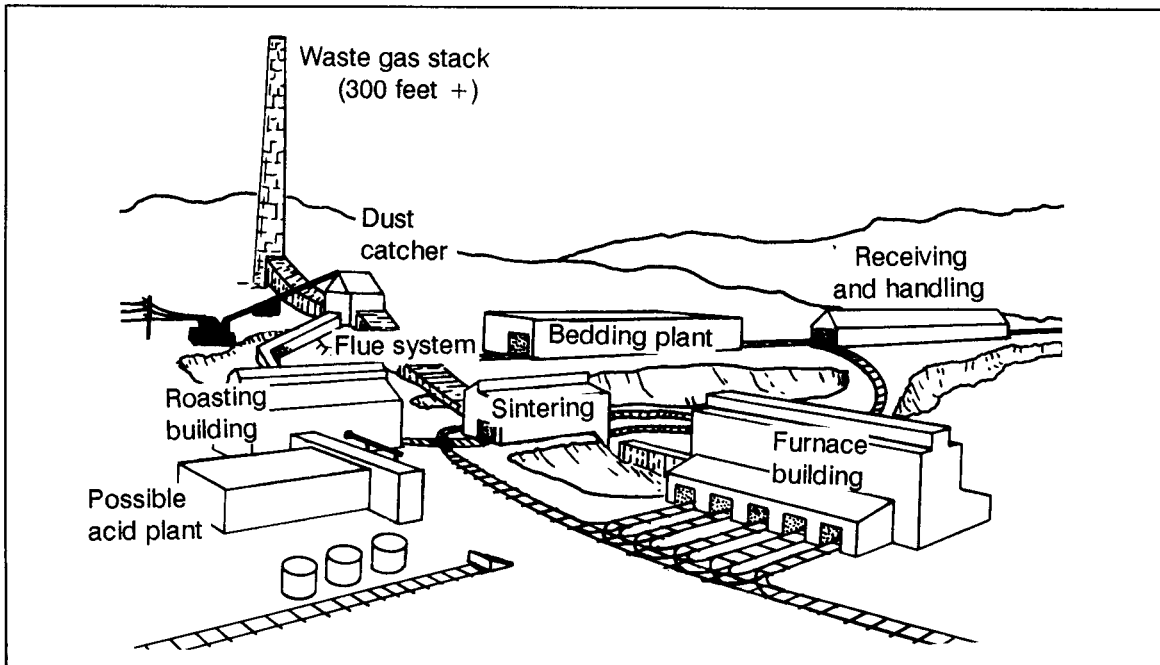


Figure 4-25. Example of construction/building (ore processing - reduction - classical smelter)

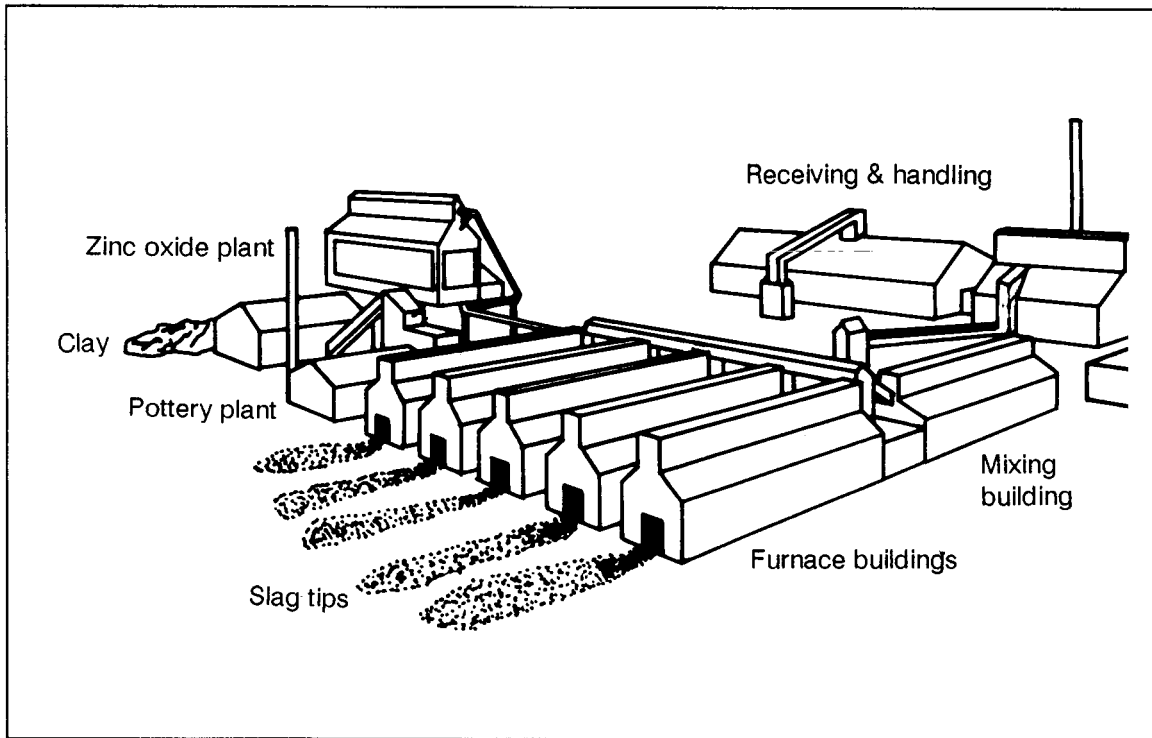


Figure 4-26. Example of construction/building
(ore processing - reduction - horizontal retort smelter)

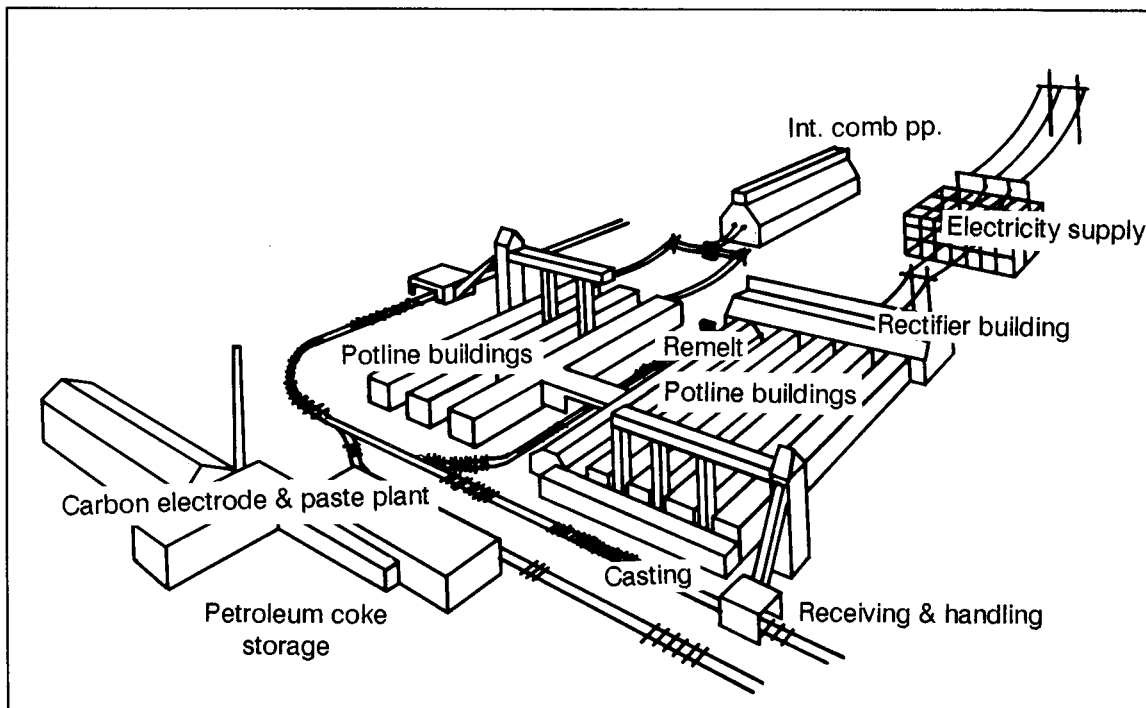


Figure 4-27. Example of construction/building
(ore processing - reduction - horizontal retort smelter)

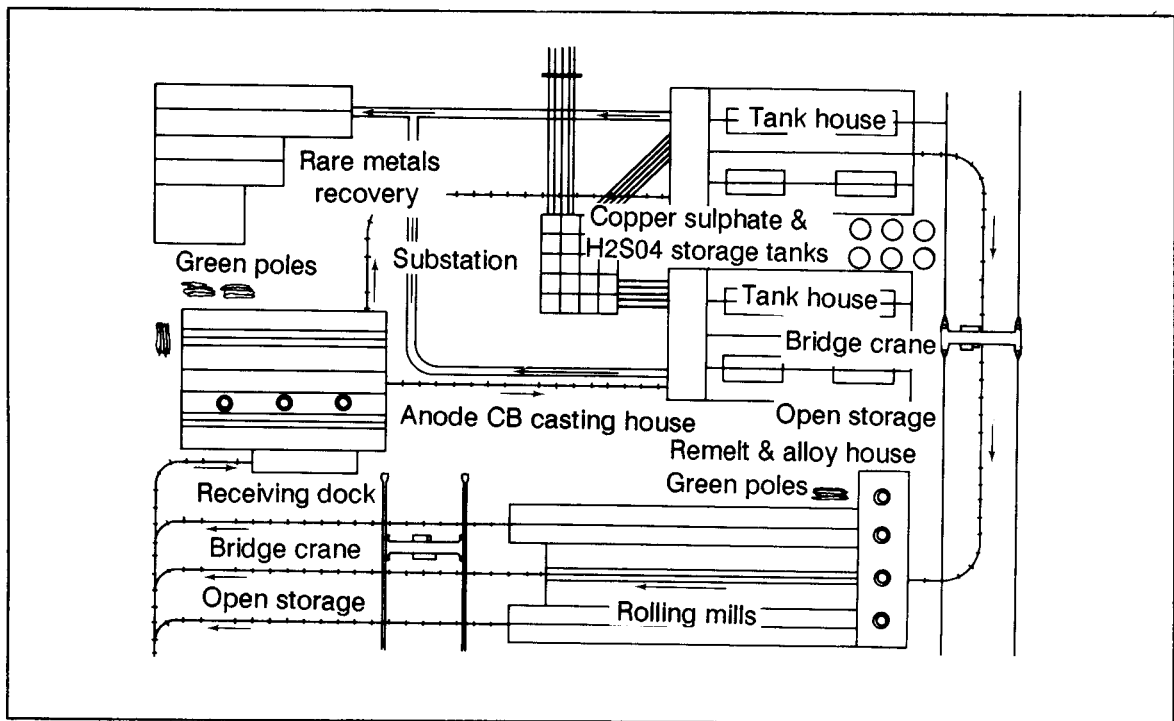


Figure 4-28. Example of construction/building type
(electrolite recovery)

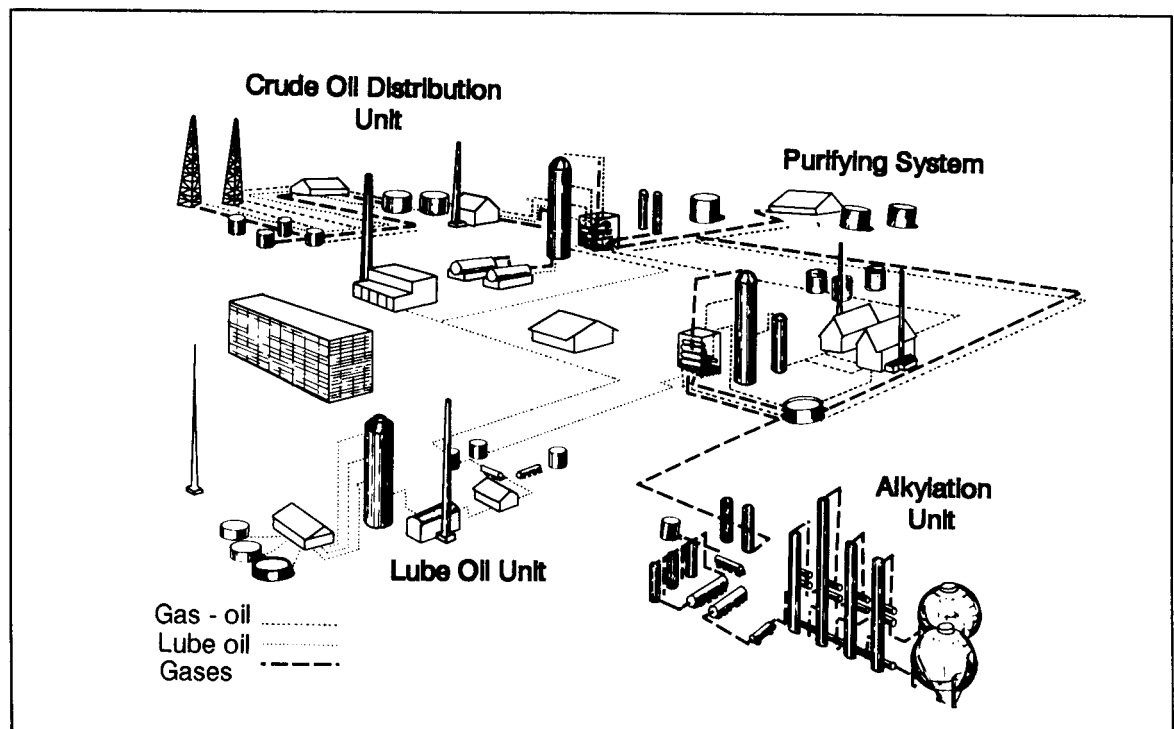


Figure 4-29. Example of construction/building type
(master flowchart of the petroleum industry)

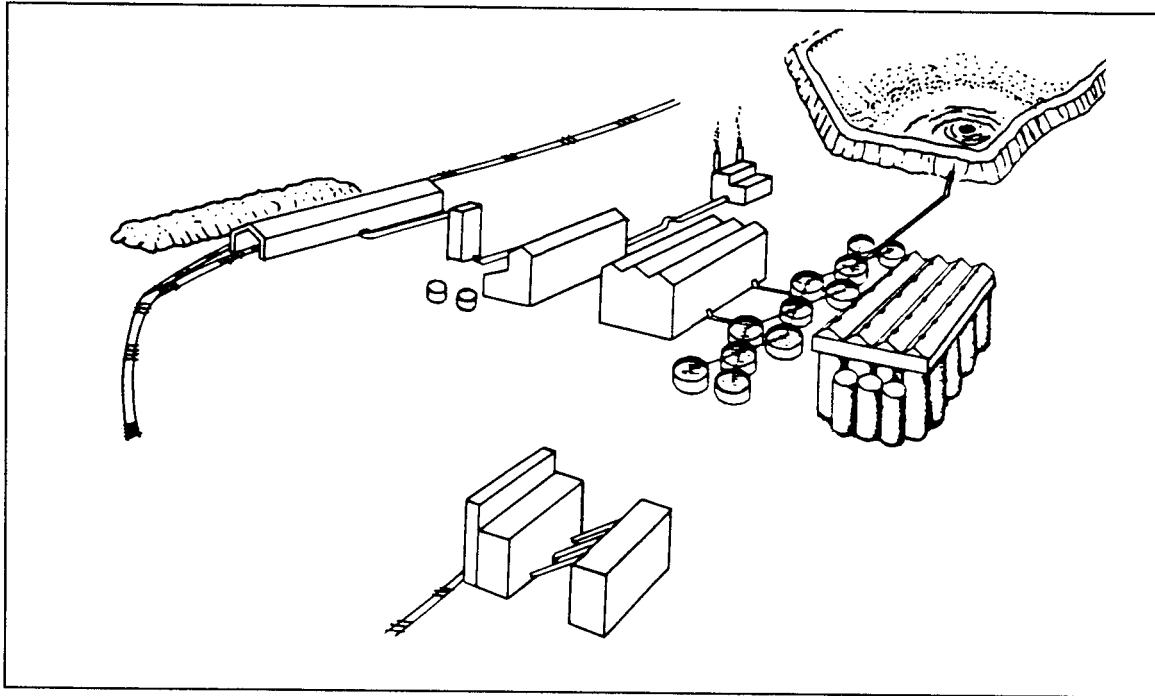


Figure 4-30. Example of construction/building type
(ore processing - bayer alumina)

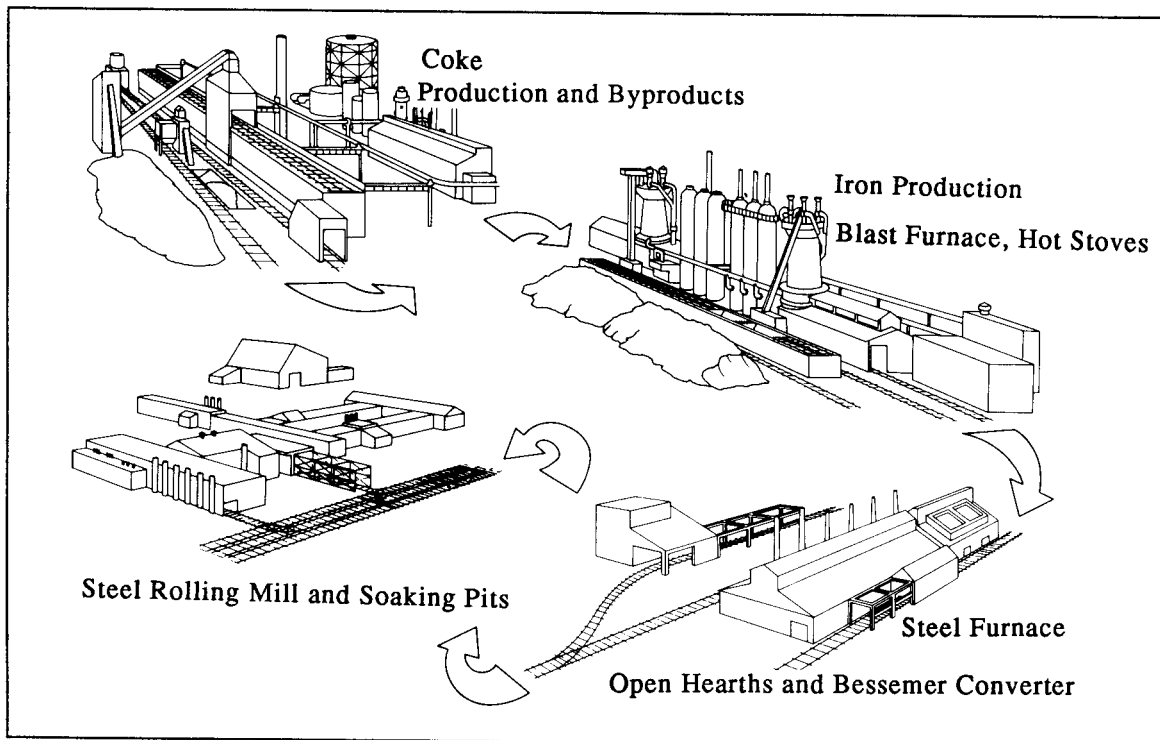
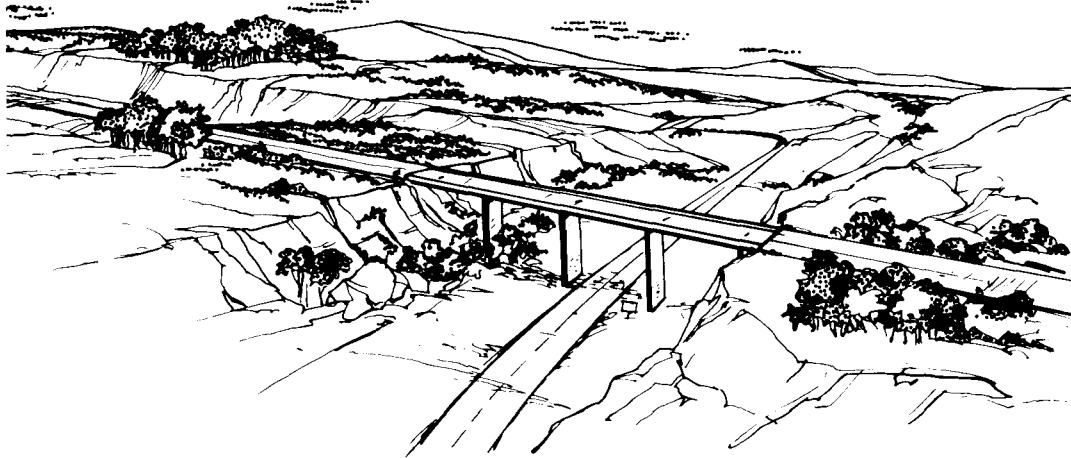


Figure 4-31. Example of construction/building type (integrated iron and steel plant)



LINE OF COMMUNICATION, COVER AND CONCEALMENT

Chapter 5

LINE OF COMMUNICATION

Lines of communication (LOC) are all the routes (land, water, and air) that connect an operating military force with a base of operations and along which supplies and reinforcements move. An LOC map is especially important to transportation corps and logistics personnel. It is also important for planning the interruption of enemy supplies. This map differs from the CCM map in that it shows routes over which supplies rather than deployed forces will move, so it depends more heavily on existing roads, railroads, and airfields.

Roads

Step 1. Study the requirements from corps and division before preparing specifications for synthesizing LOC roads.

Step 2. Examine the base map and become familiar with the LOC study area road net.

Step 3. Examine the transportation factor overlay, to select the major and secondary roads, the on-route fords, ferries, tunnels, galleries, and snowsheds for the LOC study. Identify major road categories to be used in the LOC study, such as all-weather hard surface and fair-weather loose surface.

Step 4. Examine the data tables to select the essential data elements listed on Table 1. See Figure 5-1.

Step 5. Obtain aerial photos for the area of interest to verify and update information.

ROADS	BRIDGES AND OVER-PASSES	**FORDS	**FERRIES	*TUNNELS, GALLERIES AND SNOW-SHEDS	AIRFIELDS	RAILROADS
Identification Number	*Length	Length	Crossing length	*Length and width	Identification	*Electrified
Category (highway, routes, autobahns, etc.)	*Width	Width	Vessel characteristics	Construction Details	*Runway orientation	*Abandoned
Segments	Load class construction type	Depth	Approaches	Overburden	Type	Routes
*Type	*Clearances	Bottom conditions	Load class	Clearances	*Surface material	*Yards/ terminals
*Width	*Bypass potential	Approaches			Parking facilities	Rolling stock
Surface materials and conditions					Hangars	Junctions/ crossings
Shoulders					POL	*Track(s)
Medians					Ammo/bomb storage	*Gage(s)
Obstacles					Quarters	Bridges
Culverts					*Elevation	
Cuts and fills					*Length/ width	
Turn-outs, emergency drive-offs and parking areas						
Level crossings						
Constrictions						
Grades						
Sharp curves						
Road or bridge under construction						
* Data elements deemed essential for LOC synthesis						
** Names and locations only						

Figure 5-1. Major data elements for LOC products

Step 6. Prepare an informal layout from alternate photos. Examine the road network, correlating the roads selected for the LOC study with the photos. Also examine the tunnels, galleries, snowsheds, ferries, and on-route fords.

Step 7. Stereoscopically examine the selected roads, tunnels, galleries, snowsheds, ferries and on-route fords to ensure that there are no changes or errors in the data-base parameter information. Revise and record any changes.

Step 8. Recheck all gathered information on roads, tunnels, galleries, snowsheds, ferries, and on-route fords to ensure that the selected roads meet with the user's request.

Step 9. Compile all pertinent data and draft it onto a clean overlay. Make sure the data pertains to the LOC, since not all data on factor overlays is necessary for an LOC overlay. See Figure 5-2.

See Figure 5-2 for typical roads and related structures found on a factor overlay. The data is derived from an analysis of maps, literature, and photos, and the details for the data elements are recorded on a roads factor overlay data table, which shows more than you need for a study. After examining the map area and identifying the LOC relevant data elements, check the available aerial photography of the area.

Bridges and Overpasses

Step 1. Study the requirements from corps and division before preparing specifications for synthesizing the LOC.

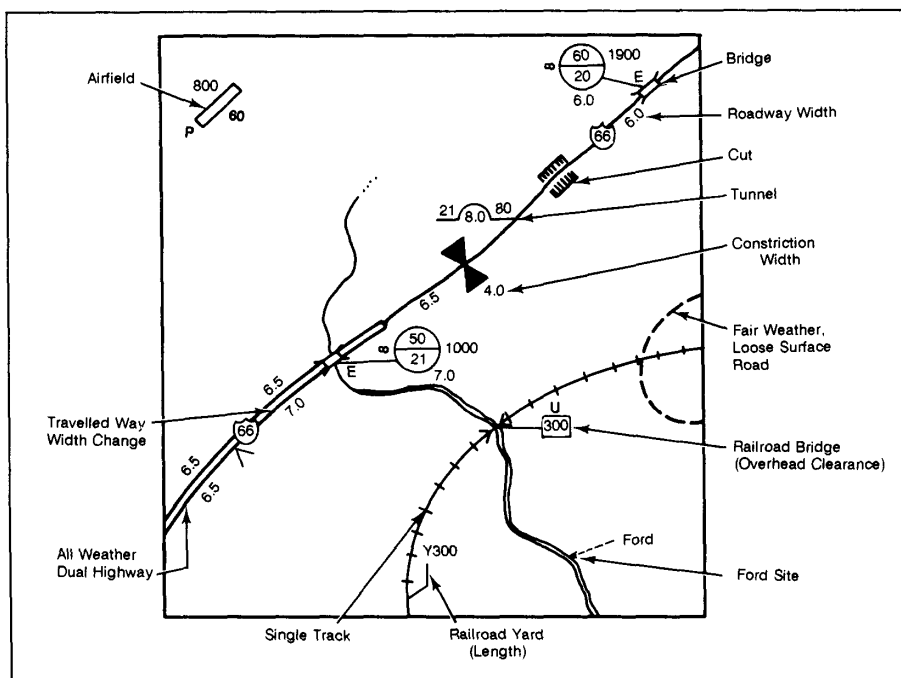


Figure 5-2. Sample annotated LOC overlay

Step 2. Examine the base topographic map to become familiar with the LOC study area.

Step 3. Examine the bridge section of the transportation factor overlay to select pertinent information.

Step 4. Examine the bridge data table to select the data elements listed on Table 1 for each relevant LOC.

Step 5. Obtain aerial photos for the area of interest to verify and update information.

Step 6. Prepare an informal layout from alternate photos. Examine the road network and locate the bridges selected for the LOC study area.

Step 7. Stereoscopically examine the selected bridges for any changes or errors in data-base parameter information. Revise and record any changes.

Step 8. Recheck all gathered bridge information to ensure the selected bridges meet with the user's request. You must show all bridges greater than or equal to 18 meters.

Step 9. Record only the pertinent information on the draft LOC. See Figure 5-2.

Railroads

Step 1. Study requirements from corps and division before preparing specifications for synthesizing the LOC railroads.

Step 2. Examine the base topographic map to become familiar with LOC study area railroads.

Step 3. Examine the transportation factor overlay to select LOC areas of interest.

Step 4. Examine the railroad data table to select the essential data element information as listed in Figure 5-3.

Step 5. Obtain aerial photos for the area of interest to verify and update information.

Step 6. Prepare an informal layout from alternate photos. Examine the area railroads and locate the segments selected for the LOC study area.

Step 7. Stereoscopically examine the selected railroads for any changes or errors in data-base parameter information and make necessary revisions.

Step 8. Recheck all gathered information to ensure that selected railroads meet with the user's request.

Step 9. Outline all information on the draft overlay.

PARAMETER	FACTOR	CRITERIA
Good	Slope	>30%
	Canopy closure	> 50%*
	C3 C4 D3	D4 E3 E4
	Roof Covered**	>40%
Fair	Slope	10-30%
	Canopy closure	<50%
	C1 C2 D1	D2 E1 E2
	Roof Coverage**	20-40
Poor	Slope	<10%
	Non-forested	A1 B G
	Roof coverage**	<20%
* Or stem spacing 5m		
** If evaluated		

Figure 5-3. Cover from flat trajectory weapons

Note : Criteria may not be applicable to your unit.

Airfields

Step 1. Study requirements from corps and division before preparing specifications for synthesizing the LOC airfields.

Step 2. Examine the base topographic map to become familiar with the LOC study area.

Step 3. Examine the transportation factor overlay to select pertinent areas of interest.

Step 4. Examine the airfield data table to select the essential data elements information as listed in Figure 5-3.

Step 5. Obtain aerial photos for the area of interest to verify and update information.

Step 6. Prepare an informal layout from alternate photos. Examine the airfields and locate the segments selected for the LOC study area.

Step 7. Stereoscopically examine the selected airfields for any changes or errors in data-base parameters information, and make necessary revisions.

Step 8. Recheck all gathered information on airfields to ensure that selected airfields meet the user's request.

Step 9. Outline all information on the draft LOC overlay.

Remaining Factor Overlays

Step 1. Check the soils factor overlay to what effect soil conditions will have on unsurfaced routes. Consider the probable weather to see if it might cause

surfaces to be muddy, frozen, dry, or dusty and to see if the expected condition will be favorable or unfavorable to movement along the roads.

Step 2. Check the vegetation factor overlay and mark any areas where vegetation will conceal the mute. Show the percent of canopy closure at the given time of year.

Step 3. Check the drainage factor overlay to locate and mark areas where flooding might impede movement, to see if any rivers must be bridged or forded, and to see what trussing facilities exist. Figure 5-4 shows steps to be followed in the synthesis process from existing factor overlays and data tables.

COVER FROM FLAT TRAJECTORY WEAPON

Cover, or protection from enemy fire, is a vital part of military operations. Examples are rocks, river banks, vegetation, quarries, walls, and buildings.

Step 1. Study requirements from the requester.

Step 2. Obtain source materials, including the base topographic map, photography, and vegetation and slope-factor overlays.

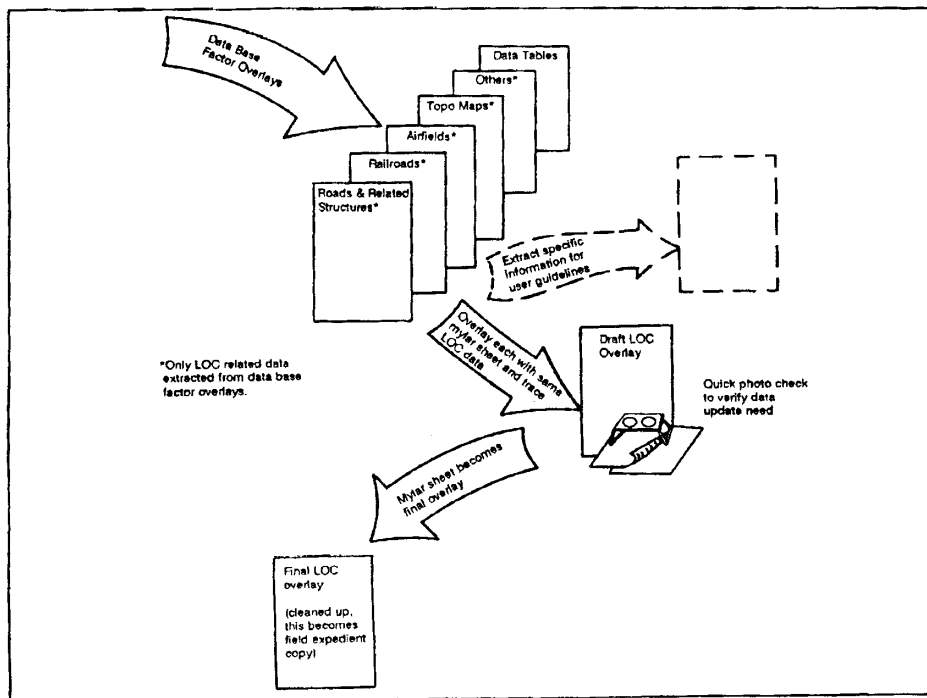


Figure 5-4. LOC synthesis process

PARAMETER	ROOF COVERAGE	VEGETATION CATEGORY		PERCENT CHANCE OF DETECTION
	Percent	Summer	Winter	
Best	>40%	C4, D4, E4, F4, I4	C4	0-25
Good	20-40	C3, D3, E3, F3, I3	C3	25-50
Fair	<20	B2, C2, E2, F2, I2, M	B2, C2, E3, E4	50-75
Poor		A1, B1, C1, D1, E1, F1, G1, G2, H, I1, J, K, L, N	A1, B1, C1, E1, E2, *D, *F, *G, H, J, K, L, N1, N2	75-100
* Or stem spacing 5m				

Figure 5-5. Concealment from aerial detection summer or wet season

Step 3. Review source materials.

Step 4. Determine what parameters each category falls into (good, fair, or poor). To construct a cover overlay, you must consider slope, vegetation, and, roof coverage (if it is evaluated).

Note: This particular criteria being used may not be applicable to your unit. It should be revised to meet your units specific needs.

Step 5. Draft the cover overlay.

CONCEALMENT FROM AERIAL DETECTION

Concealment is protection from observation. This overlay is important for judging where the enemy might be located. It is especially important in areas where guerrilla forces might be operating, because it helps the commander predict attacks. Concealment may be provided by woods, underbrush, snowdrifts, tall grass, cultivated vegetation, roof coverage, or any other feature that denies observation.

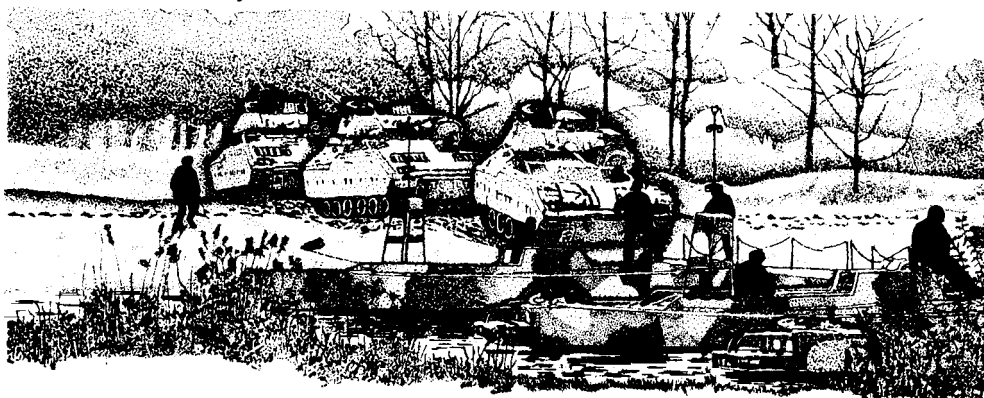
Step 1. Study the requirements and determine if concealment is for the summer (wet) season or for the winter (dry) season.

Step 2. Obtain the base map, aerial photography, and the proper seasonal vegetation factor overlay.

Step 3. Review the vegetation factor overlay with the base map and aerial photography to ensure that all vegetation categories are shown correctly. A deciduous forest with 25 to 50 percent canopy closure is a D2 vegetation code on the data-base factor overlay and is a fair area for concealment. A mixed forest with 0 to 25 percent canopy closure is an E1 vegetation code on the data-base factor overlay and is a poor area for concealment. The type of vegetation and the canopy closure are the two main factors you should check on the vegetation factor overlay.

Step 4. If evaluated, roof coverage is also used as protection from observation. You will probably look at this more in winter than summer because of the lack of vegetation during winter. Use Figure 5-5 to determine which parameter each vegetation category and roof coverage will fall into.

Step 5. Draft a concealment overlay.



CROSS-COUNTRY MOVEMENT

Chapter 6

PREPARE CCM OVERLAY

The cross-country movement (CCM) overlay is sometimes referred to as an avenue-of-approach map because it tells the best routes by which various vehicles can get to an objective when they cannot use prepared roads. It also shows parts of terrain that these vehicles cannot cross.

Step 1. Assemble source materials. These will include the base topographic map, aerial photography, slope (surface configuration), vegetation and soils (surface materials) factor overlays, and the following tables:

- Table 6-1, Vehicle characteristics.
- Table 6-2, Slope/speed characteristics.
- Table 6-3, Soils factor (dry and wet).

VEHICLE	M1	M60A1	M109	M113	M35A2	M151	T62	T72	M2	M3	M48 AVLB	M60 AVLB	MLRS
Maximum Road Speed (kph)	71	48	56	48	56	50	50	(60)	66	66	48	51	64
Maximum On-Road Gradability (°)	68.7	60	60	60	64	60	62	(62)	60	60	30	30	60
Maximum Off-Road Gradability (°)	53	45	45	45	30	28	(45)	(45)					
Vehicle Width (m)	3.65	3.63	3.10	2.69	2.43	1.69	3.37	3.38	6.2	6.2	4.3	4.3	2.97
Override Diameter at Breast Height (m)	.25	.15	(.12)	.10	.06	.04	(.15)	.18					
Vehicle Cone Index 1 Pass (VCI ₁)	25	20	25	17	26	19	21	(25)	15	15	26	22	
Vehicle Cone Index 50 Passes (VCI ₅₀)	58	48	57	40	59	44	49	(60)	35	35	60	51	
Minimum Turning Radius (m)	9.9	9.4	6.6	4.8	5.3	5.8	9.33	9.2	6.2	6.2	9.6	9.6	6.97
Vehicle Length (m)	9.9	9.4	6.6	4.8	6.7	3.35	9.33	9.2	6.2	6.2	9.6	9.6	6.97
Military Load Class	60	54	24	12	10	NA	42	45	24	24	62	63	28

Table 6-1. Vehicle characteristics

MAP UNIT	GROUND SLOPE (%)	F ₁	F ₂	F _{1/2}	NO GO
A	(0-3%) 1.5	34.80	1.00	34.80	
B	(3-10%) 6.5	30.80	.99	30.49	
C	(10-20%) 15	24.00	.98	23.52	
D	(20-30%) 25	16.00	.97	15.52	
E	(30-45%) 37.5	6.00	.96	5.76	
F	(45%)	---	---	----	XXX
G	N/A	---	---	5.76	
W	N/A	0	0	0	X

Table 6-2. Sope/speed characteristics

MAP	RCI _D	F4D	NO GO	RCI _W	F4W	NO GO
SP (063)	145	1		73	1	
SM (072)	119	1		25	.35	
SC (082)	126	1		46	1	
ML (091)	118	1		20	.13	
CL (101)	123	1		40	1	
OH (140)	107	1		1	0	XXX
	EXAMPLE	ONLY				
SM1	119					
SM2	72					
SM3	25					

Table 6-3. Soils factor (dry and wet)

- Table 6-4, Soils data.
- Table 6-5, Categories for speeds and CCM map units.

SOILS CATEGORY	TYPE	RCI VALUES		
		DRY	MOIST	WET
01 (GM)	Gravel or sandy gravel, well graded	163	123	83
02 (GP)	Gravel or sandy gravel, poorly graded	160	120	81
03 (GM)	Gravel, silty	120	76	32
04 (GC)	Gravel or sand gravel, clayed	130	91	52
05 (SW)	Sand, well graded	155	116	78
06 (SP)	Sand, poorly graded	145	109	73
07 (SM)	Sand, silty	119	72	25
08 (SC)	Sand, clayey	126	86	46
09 (ML)	Silts	118	69	20
10 (CL)	Clays	123	81	40
11 (OL)	Organic silts	111	57	3
12 (MH)	Inorganic elastic silts	114	61	8
13 (CH)	Fat clays	136	99	62
14 (OH)	Fat organic clays	107	54	1
15 (PT)	High organic soils or peat	106	52	0
20 (R)	Rock outcrops	165	165	165
30 (NE)	Not evaluated	-	-	-
W (W)	Open water	0	0	0

Table 6-4. Soils data

SPEEDS (kph)	BASIC DESCRIPTOR	CCM MAP UNIT
> 30	GO	1
>15 ≤30	RESTRICTED	2
>5 ≤15	SLOW	3
>1.5 ≤5	VERY SLOW	4
≤ 1.5	NO GO	5
---	NO GO (OPEN WATER)	6
---	NOT EVALUATED (Built up area)	7

Table 6-5. Categories for speeds and CCM map units

- Table 6-6, Vegetation factor data.
- Table 6-7, Speed Prediction tabulation sheet.

MAP UNIT	STEM DIAMETER (m)	STEM SPACING (m)	VEGETATION ROUGHNESS (VR)	SPACING FACTOR (V1)	OVERRIDE FACTOR (V2)	VEGETATION FACTOR (F3)	NO GO
C34	.15	2.6	1	0	0	0	XXX
C35	.20	3.7	1	.03	0	.03	
C45	.20	2.8	1	0	0	0	XXX
D13	.09	4.0	1	.06	.19	.19	
D24	.21	4.0	1	.05	0	.05	
E24	.185	4.0	1	0	0	0	XXX
E34	.175	2.6	1	0	0	0	XXX
EXAMPLE ONLY							
G1			.9			.9	

Table 6-6. Vegetation factor data

Step 2. Determine the vehicle to be used and whether the CCM product will be prepared for dry or wet conditions or both.

Step 3. Procure the surface configuration factor overlay and Tables 6-1 and 6-2.

Step 4. Compute the F1 speed / slope factor. This calculation determines the extent that any slope will deteriorate the speed of the vehicle without consideration for any other physical factor.

Using Table 6-1, determine the maximum off-road gradability (kph), maximum on-road gradability (%), and maximum road speed (kph). Record this information in the appropriate column of Table 6-2.

AREA	SURFACE CONFIGURATION/ SIF		VEGETATION		SURFACE MATERIALS			SURFACE ROUGHNESS	SPEED (KPH)		CCM _D MAP UNIT	CCM _W MAP UNIT
	MAP UNIT	F _{1/2}	MAP UNIT	F ₃	MAP UNIT	F _{4D}	F _{4W}	F ₅	D	W		
1	B	30.49	D24	.05	SM2	1	.35	.9	1.37	.48	5	5
2	C	23.52	D24	.05	SM2	1	.35	.9	1.06	.37	5	5
3	C	23.52	D24	.05	CL1	1	1	1	1.18	1.18	5	5
4	B	30.49	D24	.05	CL1	1	1	1	1.52	1.52	4	4
5	A	34.80	D24	.05	CL1	1	1	1	1.74	1.74	4	4
6	B	30.49	D24	.05	CL1	1	1	1	1.52	1.52	4	4
7	B	30.49	D24	.05	ML1	1	.13	1	1.52	.20	4	5
8	C	23.52	D24	.05	ML1	1	.13	1	1.18	.15	5	5
9	B	30.49	D13	.19	CL1	1	1	1	5.79	5.79	3	3
10	B	30.49	D13	.19	ML1	1	.13	1	5.79	.75	3	5
11	C	23.52	D13	.19	ML1	1	.13	1	4.47	.58	4	5
12	A	34.80	D13	.19	ML1	1	.13	1	6.61	.86	3	5
13	A	34.80	D13	.19	CL1	1	1	1	6.61	6.61	3	3
14	D	15.52	C35	.03	SP3	1	1	.8	.38	.38	5	5
15	A	34.80	C35	.03	SP3	1	1	.8	.83	.83	5	5
16	A	34.80	C35	.03	SC2	1	1	.9	.94	.94	5	5
17	C	23.52	C35	.03	CL1	1	1	1	.71	.71	5	5
18	C	23.52	C35	.03	SP3	1	1	.8	.57	.57	5	5
19	B	30.49	C35	.03	SP3	1	1	.8	.73	.73	5	5
20	B	30.49	C35	.03	SC2	1	1	.9	.82	.82	5	5
21	A	34.80	D24	.05	SC2	1	1	.9	1.57	1.57	4	4
22	B	30.49	D24	.05	SP3	1	1	.8	1.22	1.22	5	5
23	B	30.49	D24	.05	SC2	1	1	.9	1.37	1.37	5	5
24	B	30.49	D24	.05	CL1	1	1	1	1.52	1.52	4	4
25	A	34.80	D24	.05	SC2	1	1	.9	1.57	1.57	4	4

Table 6-7. Speed prediction tabulation sheet

From the surface-configuration overlay, determine the percent of ground slope for slope categories A through F. Use the mid-point value of the slope category as ground slope, as shown below.

$$\text{Formula: mid-point} = \frac{\text{highest value} + \text{lowest value}}{2}$$

Example: Slope category = 10 to 20%

$$\text{Ground slope} = \frac{20 + 10}{2}$$

$$\text{Ground slope} = \frac{30}{2}$$

$$\text{Ground slope} = 15\%$$

Record values of ground slope in the appropriate columns of Table 6-2.

Calculate F₁ values for each slope category.

$$\text{Formula: } F_1 = \frac{\text{maximum off-road gradability (\%)} - \text{ground slope (\%)}}{\text{maximum on-road gradability (\%)} \text{ maximum road speed kph}}$$

a. Negative values indicate No-Go areas, use F₁ = 0.

b. Round values to nearest hundredth, then post them on Table 6-2.

Note: Rounding is critical to the final value.

c. F₁ for map unit G (naturally or culturally dissected terrain) represents an unusual case and is best represented by using the lowest F₁ value obtained that still permits movement.

Example: Calculate the slope category for the M113 (see Table 6-1).

$$\begin{aligned} \text{Maximum off-road gradability} &= 45\% \\ \text{Maximum on-road gradability} &= 60\% \\ \text{Maximum road speed} &= 48 \text{ kph} \\ \text{Ground slope} &= 15\% \text{ (midpoint of 10-20\%)} \end{aligned}$$

$$F_1 = \frac{45 - 15}{60 - 48}$$

$$F_1 = \frac{45 - 15}{1.25}$$

$$F_1 = \frac{30}{1.25}$$

$$F_1 = 24.0 \text{ kph}$$

d. Record F₁ values on Table 6-2.

Step 5. Calculate F2, slope-intercept-frequency (SIF) factor. SIF is the number of times the ground surface changes between positive and negative slopes over a one-kilometer distance. Measuring this is extremely time-consuming in the field, so use the expedient method.

a. Register the surface-configuration overlay to the appropriate topographic map. In a slope category on the overlay, lay a line equal to the length of a diagonal of a one-kilometer square (approximately 1.4 times the length of 1 kilometer on the map).

b. Count the number of times any contour line within the slope category crosses or touches the diagonal.

c. Lay out a second line at right angles and count intercepts as before.

Note: A prepared template will greatly speed this operation.

d. Repeat this procedure at least ten times for each slope map unit, then average the counts. See Figure 6-1.

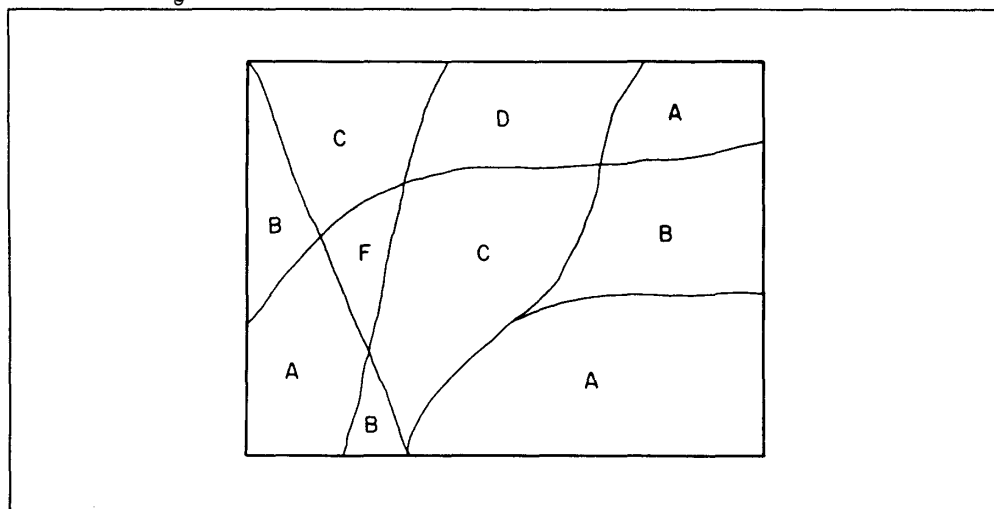


Figure 6-1. Surface configuration (slope)

e. Repeat this procedure for all slope categories A through F.

f. Adjust the average counts to the standard 1:50,000-scale map with a 20-meter contour interval.

1) Determine the adjusted count, using the formula--

$$\text{adjusted count} = \frac{\text{average count} \times \text{contour interval map used}}{\text{standard contour interval}}$$

Example:

Contour interval of map used = 10 m

$$\begin{aligned}
 \text{Average SIP count} &= 24.4 \\
 \text{Standard contour interval} &= 20 \text{ m} \\
 \text{Adjusted count} &= \frac{24.4 \times 10}{20} \\
 &= \frac{24.4}{2} \\
 &= 12.2 \text{ (Round to 12 or the nearest whole number).}
 \end{aligned}$$

2) Compute F₂ values for each slope category, using the formula--

$$F_2 = \frac{280 - \text{SIF count (adjusted)}}{280}$$

Example: SIP = 12

$$F_2 = \frac{280 - 12}{280}$$

$$F_2 = \frac{268}{280}$$

$$F_2 = .96$$

3) Round values to the nearest hundredth, and record them on Table 6-2.

4) Record the lowest F₂ value on map unit G.

Step 6. Calculate F, slope/SIF - speed calculation. This calculation gives the calculated speed based on the effects and variation of slope.

a. Compute F values using the formula

$$F = F_1 \times F_2.$$

Example: F_{1/2} = F₁ x F₂

$$F_{1/2} = 24.0 \text{ kph} \times .96$$

$$F_{1/2} = 23.04 \text{ kph}$$

b. Record F in the appropriate column of Table 6-2.

Note: The value F will tell you what effect slope will have on vehicle speed.

Step 7. Obtain F₃ vegetation factor.

a. Procure the vegetation-factor overlay and vegetation-roughness tables, Tables 1 and 6. Continuing with the previously selected vehicle, compute the F₃ vegetation factor.

b. Using Table 6-1, determine the vehicle width in meters (m), maximum override diameter (m), and minimum turning radius (m) and record them on Table 6-6.

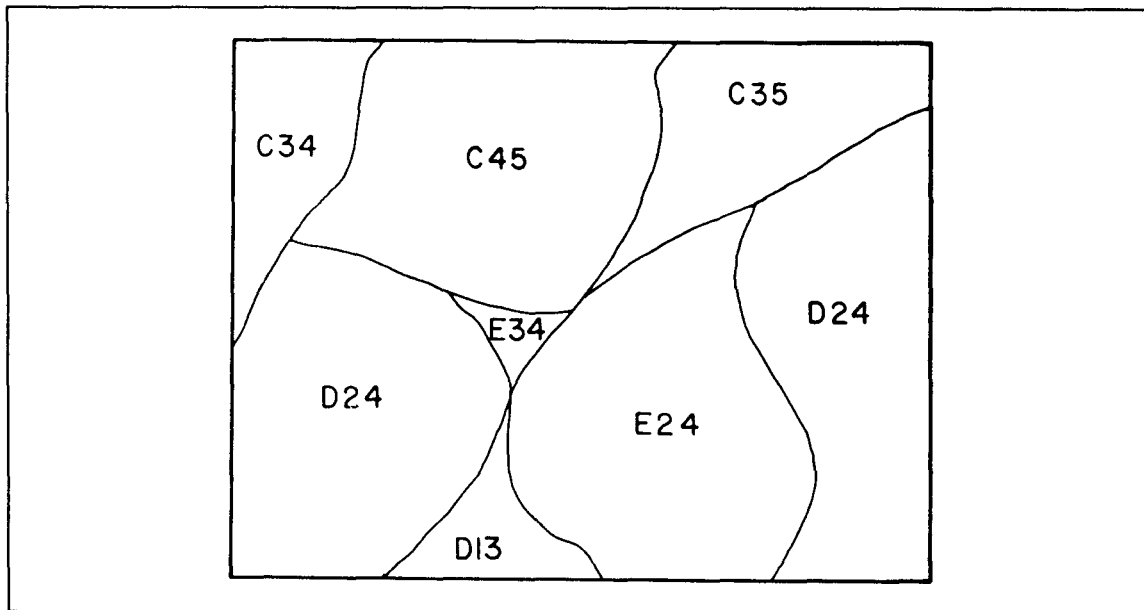


Figure 6-2. Vegetation

c. From the vegetation factor overlay, determine the forest types and list them in alphanumerical sequence on Table 6-6. List all other vegetation after the forest types. See Figure 6-2.

d. From the vegetation roughness table on the vegetation-factor overlay, determine the stem diameter (m), stem spacings (m), and vegetation-roughness factor for the appropriate forest types and record the information on Figure 6-6. See Figure 6-3.



CODE	FOREST TYPE AND CANOPY CLOSURE															
	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F1	F2	F3	F4
H E I G H T	1 2.5 1	1 2 1	1 1.5 1	1 1 1	7 2.5 1	7 2 1	7 1.2 1	7 1 1	.85 2.5 1	.85 2 1	.85 1.3 1	.85 .9 1				
	6 2.5 2	6 2 1	6 1.5 1	6 1 1	4 2.5 1	4 2 1	4 1.5 1	4 1 1	5 2.5 1	5 2.0 1	5 1.5 1	5 1.0 1				
	11 3.8 1	11 2.8 1	10 1.8 1	10 1.3 1	9 4.0 1	9 3.0 1	8 2.0 1	8 1.5 1	10 3.9 1	10 2.9 1	9 1.9 1	9 1.4 1	22 7.0 1			
	16 6.0 1	16 6.0 1	15 2.6 1	15 2.2 1	22 7.0 1	21 4.0 1	20 2.5 1	19 2 1	19 6.5 1	18.5 4.0 1	17.5 2.6 1	17 2.1 1				
	21 8.0 1	21 5.5 1	20 3.7 1	20 2.8 1	27 9.0 1	26 6.0 1	25 4.0 1	24 2.5 1	24 8.5 1	23.5 4.8 1	22.5 3.9 1	22 2.7 1				
	27 11.0 1	27 7.0 1	26 4.7 1	26 3.2 1	34 12.0 1	34 7.0 1	32 5.0 1	30 3.5 1	30.5 11.5 1	30.5 7.0 1	29 4.8 1	28 3.4 1				
	34 14 1	34 7.5 1	33 5.0 1	33 3.6 1	40 15.0 1	39 8.0 1	38 5.5 1	37 4.5 1	37 14.5 1	36.5 7.8 1	35.5 5.3 1	35 4.1 1				
								41 5.0 1								

Figure 6-3. Stem diameter(cm)-tree spacing(m)-vegetation roughness

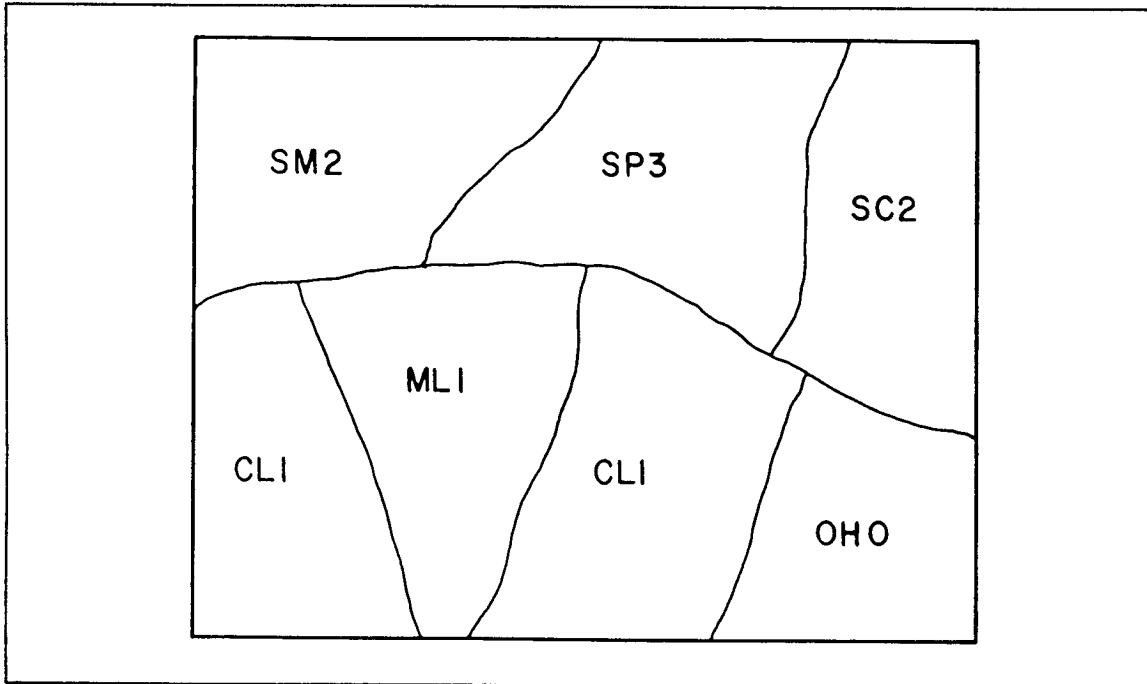


Figure 6-4. Soils

e. For nonforest types, place the vegetation roughness factor in the appropriate location on Table 6-2. For all forested areas, calculate V_1 and record it on Table 6-6. V_1 is the product of the vehicle factor (V_F) and the vehicle clearance factor (V_{1a}). V_F accounts for the response of drivers when approaching wooded areas. V_{1a} accounts for the physical ability of a vehicle to maneuver between tree stems in a wooded area.

Formula:

$$V_1 = (V_F)(V_{1a})$$

Where--

$$V_F = \frac{SS - SD - W}{W}$$

$$V_{1a} = \frac{SS - SD - W}{MTR - 4W}$$

SS = Stem Spacing (m)

SD = Stem Diameter (m)

W = Vehicle Width (m)

MTR = Minimum turning radius (m)

Notes:

1. if V_F or $V_{1a} \leq 0$, $V_{1a} = 0$
2. if $V_F \leq 1$, $V_F = 1$
3. if $V_{1a} \leq 1$, $V_{1a} = 1$.

f. Calculate V_2 for all forested areas and record it on Table 6-6. V_2 is the calculation used to determine if it would be easier for the vehicle to override the trees rather than maneuver between them. The VT portion of the formula is used to calculate the minimum number of trees a vehicle can hit at one time.

Formula:

$$V_2 = 1 - \left(VT \left(\frac{SD^2}{OD^2} \right) \right)$$

$$VT = \frac{W + SD}{SS}$$

Notes:

1. if $SD > OD$, $V_2 = 0$.
 2. if $V_2 \leq 0$, $V_2 = 0$.
 3. if $VT \leq 1$, $VT = 1$.
- g. Calculate F_3 = Select the larger value between V_1 and V_2 .

Formula: $F_3 = (VR)(V_1 \text{ or } V_2)$

VR = vegetation roughness factor (obtain from the vegetation overlay)

Notes:

1. If $F_3 > 1.0$, $F_3 = 1.0$
2. If $F_3 > 0$, $F_3 = 0$ (No-Go)

h. Record F_3 values on Table 6-5.

Step 8. Procure the soil factor overlay and Tables 1, 3, and 4. Continuing with the previously selected vehicle, compute the F_4 soil factor. This calculation will determine if a particular soil type will support vehicular movement and to what extent the speed will decrease due to that soil type. See Figure 6-4.

a. Using Table 6-1, determine the vehicle cone index (VCI_1) for one pass and the vehicle cone index (VCI_{50}) for fifty passes. Record them on Table 6-3.

b. From the surface-materials factor overlay, extract the appropriate soils map units, such as ML1, SM2, and OH0, and post them on Table 6-3.

Note: The third digit refers to the surface-roughness code.

c. From Tables 6-1 and 6-4, determine appropriate RCI values for dry and/or wet conditions and post them on Table 6-3.

d. Calculate the dry-soil factor (F_{4D}) and/or wet-soil factor (F_{4W}) for each soil type.

Formula: $F_{4D} = \frac{RCI_D - VCI_1}{CI_{50} - VCI_1}$

$$F_{4W} = \frac{RCI_W - VCI_1}{VCI_{50} - VCI_1}$$

Notes:

1. if $F_4 \leq 0$, $F_4 = 0$ (No Go)
2. if $F_4 \geq 1$, $F_4 = 1$

e. Record F_4 values on Table 6-4.

CONSTRUCT COMPLEX FACTOR OVERLAY

Step 1. Register the overlay to the base map.

Step 2. Outline the built-up areas (color in red).

Step 3. Outline the open-water areas (color in blue).

Step 4. Using the surface-configuration overlay and the vegetation-factor data table, register complex overlay to the factor overlay and outline the slope areas (color No-Go areas in yellow).

Step 5. Using the vegetation factor overlays and Table 6-3, vegetation factor data, register the complex overlay and outline the vegetation areas (do not draw lines through areas already colored). Color No-Go areas in yellow, and disregard areas less than 250 x 250 meters at map scale (5mm for 1:50,000) or narrow areas less than 100 meters in width at map scale (2mm for 1,50:000).

Step 6. Using surface-materials factor overlay and Table 6-4, soil factor (dry and wet data), follow the procedures in Step 5.

Step 7. Beginning in the upper left corner, number the noncolored areas from 1 through 99. If you have more than 99 areas, outline the first area of 99 and label it as Sector A. Number remaining areas 1 through 99, as before, and label them as Section B. Continue numbering areas and sectors as required.

Step 8. Annotate all sector and area numbers on Table 6-5.

Step 9. Compute CCM speed.

a. Using the completed complex factor overlay and the surface-configuration factor overlay, determine the appropriate map unit for each area and post it on Table 6-5.

b. Determine the $F_{1/2}$ value for the map units from Table 6-2 and post it on Table 6-5.

c. Using the complex factor overlay, the vegetation overlay, and Table 6-3, determine the map units and F_3 values and post them on Table 6-5.

d. Using the complex factor overlay, the surface materials overlay and Table 6-4, determine the map units and F4 values and post them on Table 6-5.

e. Determine the surface roughness factor (F5) for each area from the surface materials overlay and post it on Table 6-5. See Figure 6-5.

<u>SOIL TYPE</u>	
<u>MAP UNIT (1ST TWO DIGITS)</u>	<u>DESCRIPTION</u>
GW	Well-graded gravels, gravel-sand mixtures, little or no fines.
GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.
GM	Silty gravels, gravel-sand-silt mixtures.
GC	Clayey gravels, gravel-sand-clay mixtures.
SW	Well-graded sand, gravelly sands, little or no fines.
SP	Poorly graded sands or gravelly sands, little or no fines.
SM	Silty sands, sand-silt mixtures.
SC	Clayey sands, sand-clay mixtures.
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
OL	Organic silts and organic silty clays of low plasticity.
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
CH	Inorganic clays of high plasticity, fat clays.
OH	Organic clays of medium to high plasticity, organic silts.
PT	Peat and other highly organic soils.
RK	Rock outcrops.
EV	Evaporites.
X	Not evaluated.
PS	Permanent snowfields.
W	Open water.

Figure 6-5. Surface materials legend

SURFACE ROUGHNESSESTIMATED SURFACE ROUGHNESS FACTORS *

MAP UNIT (3RD DIGIT)	DESCRIPTION	MEDIUM & LARGE TANKS	LARGE WHEELED VEHICLES	SMALL WHEELED VEHICLES	SMALL TRACKED VEHICLES	FOOT TROOPS
0	No Data	—	—	—	—	—
1	No surface roughness effect	1.00	1.00	1.00	1.00	1.00
2	Area of high landslide potential	.00	.00	.00	.00	.00
3	Stony soil with scattered surface rock	.90	.90	.80	.85	.95
4	Quarry	.05	.05	.05	.05	.75

* Surface roughness factors are indicated with 0.00 having maximum and 1.00 having least impact on CCM.

SOIL DEPTHS

———— <.5 meters

SOIL MOISTURE

----- Soil normally moist

..... Soil normally wet

Example: Map unit SC3 = Clayey sands, sand-clay mixtures, stony with scattered surface rock, normally moist, depth <.5 meters

Figure 6-5 continued. Surface materials legend

f. Calculate the final CCM dry and/or wet speeds for each area. Use Table 6-7 and the following formula:

$$\text{Speed (kph)} = F1/2 \times F3 \times F4W \times F5$$

Note: Round all interim and final calculations to the nearest hundredth. Post them on Table 6-5.

g. Determine the CCM dry and/or wet map unit for each area using the CCM legend, and post it on Table 6-5.

h. Combining areas of like CCM map units, draw the CCM product in final format.

i. Add the appropriate linear obstacle data.

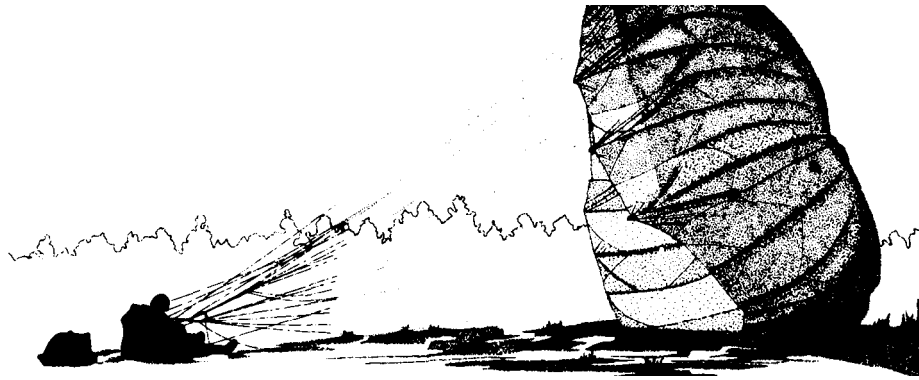
PERFORM AVENUE OF APPROACH SYNTHESIS PROCEDURE

An avenue of approach is a route that must offer some ease of movement plus provide for an adequate dispersion of a friendly or enemy force large enough to have a significant impact on a military operation. The avenue of approach product does not include the status or possible actions of an enemy force. The end results are avenues of approach suitable for friendly force configurations capable of successfully completing the mission.

Step 1. Combine and analyze previously completed terrain products such as the CCM, transportation (LOC), and linear obstacle overlays and updated aerial photography of the area of operations to produce mobility corridors.

Step 2. Incorporate the limitations imposed by the battlefield terrain on friendly and enemy doctrine.

Step 3. Forward the data gathered in Steps 1 and 2 to G2 or S2 military intelligence (MI) personnel to identify the terrain influence on the configuration of friendly and enemy forces in the area of operations. MI personnel will evaluate mobility corridors using the doctrinal template, which considers battle doctrine, the tactical situation, and possible high-value targets.



Line of Site and Zone of Entry

Chapter 7

LINE OF SITE

The line of site (LOS) is an unobstructed view from point A to point B. Requests for LOS products are becoming more frequent just as the effective ranges of our weapons, radar, and communications equipment are increasing. We can only realize the effectiveness of long-range weapons with ranges of over 4,000 meters and of current corps and division communications equipment with ranges of 50 to 60 kilometers if the equipment is emplaced properly in areas containing equivalent-distance LOSs or groups of LOSs (as in fields of fire).

The seven methods for determining LOS are--

- Ground truth (occupy positions), which is the most reliable, least likely, and least convenient method.
- Elevation layer tints, which do not consider refraction or the curvature of the earth.
- Survey intervisibility formula, which adds constants for curvature of the earth and refraction but does not consider vegetation height.
- Analytical Photogrammetric Positioning System (APPS), which is only as good as equipment accessibility, operator training, and data-base accuracy.
- Profile (topographic map) method is the old, faithful method, almost universally known, but which does not consider refraction or curvature of the earth.
- Aerial photography (the floating line method), which is better used for short distances.
- MICROFIX, which is accurate, dependent on access to digital terrain elevation data (DTED), and useful for a wide variety of product.

As a terrain analyst, you must often determine if one location can be seen from another location or if terrain is blocking the view. Intervisibility is the ability to see from one object or station to another and is important to determine LOS. It can

be a tactical means of identifying defiladed areas for maneuver units or effects of direct fire on ground forces. The best way to determine intervisibility is to physically occupy each station. Since you cannot always be in the physical area, however, you must use topographic maps and aerial photographs. You must be able to plot coordinates on stereo-paired photos and construct a profile of a topographic-map area.

Topographic Map Method

Make sure you have your photo interpretation kit. It contains a photo plot, your remote-sensed imagery (RSI), straightedge, pin vise and pin, point designation grid (PDG) template, and a mission directive that contains location instructions.

Step 1. Look at your mission directive to obtain information about the location you will profile. The directive will also tell you which points to plot on the map. Use the UTM coordinates on the map to plot the two points.

Step 2. Draw a line across the area to be profiled connecting the two points you have just plotted. This is the profile line. Figure 7-1 shows an example.

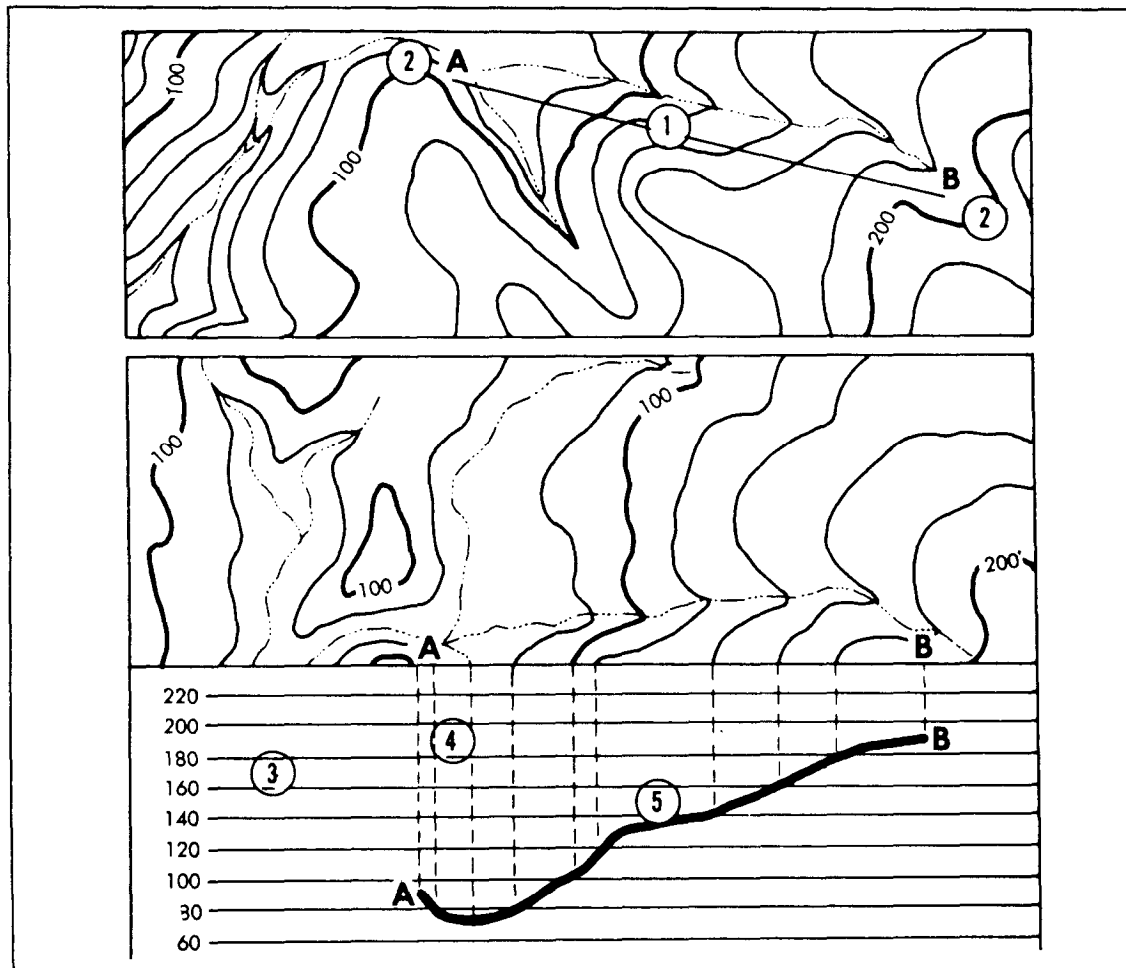


Figure 7-1. Topographic map example

Step 3. Increase the value of the highest contour line. This will become the upper-line measurement on the numbered profile lines. Start by looking at the map and identifying the highest contour line that either crosses or touches the profile line you have just drawn. Next, look at the bottom of your map and identify the contour interval; for example, it may say “contour interval 20 meters.” Increase the highest contour line by the contour interval. For example:

Highest contour line = 200 meters
Contour interval = 20 meters
 $200 + 20 = 220$ meters

Step 4. Decrease the value of the lowest contour line that touches or crosses the profile line. This will become the lowest line measurement on the numbered profile lines. Again, use the contour interval from the map. Decrease the lowest contour line by the contour interval. For example:

Lowest contour line = 80 meters
Contour interval = 20 meters
 $80 - 20 = 60$ meters

Step 5. Prepare a profile. A profile is a side view of terrain along a line between two points. On a blank sheet of paper, draw a straight line the same length as the profile line paper. Each line represents a contour value line that crosses or touches the parallel line. The highest elevation is at the top, the lowest is at the bottom. Draw two additional lines at the top and bottom so that one line is above the highest elevation and the other is below the lowest elevation. Number all lines to the right or left in sequence, with the highest value at the top. The dotted lines at 220 and 60 are the two added lines.

Next, place your lined sheet of paper against the profile line on the map. Extend dotted, vertical (perpendicular) lines from every point on the profile line to the corresponding value line. Place a tick mark where each perpendicular line crosses the profile line. This will ensure the contour value for each profile below a map. Look at the perpendicular extensions from the contour lines to the corresponding value line.

Step 6. Interpolate hill and valley lines. Interpolation is a method of determining the highest elevation of a hill and the lowest point of a valley. Since they are either higher or lower than the known elevations, determine them separately. On the profile, insert the interpolated lines between the other contour-value lines.

To estimate the height of a hill using the interpolation method, add half the contour interval to the known elevation. For example:

Known elevation = 200 meters
Contour interval = 20 meters
 $1/2$ Contour interval = 10 meters
 $200 + 10 = 210$ meters
Interpolated value = 210 meters

To estimate the bottom of a valley using the interpolation method, subtract half the contour interval from the known elevation. For example:

Known elevation = 80 meters
Contour interval = 20 meters
1/2 Contour interval = 10 meters
 $80 - 10 = 70$ meters
Interpolated value = 70 meters

Step 7. Draw interpolated perpendicular lines extending to the corresponding value lines. Notice how close they are to the highest and lowest elevation lines.

Step 8. Draw a dark line connecting the perpendicular lines. Smooth, natural lines represent hills and valleys. V- or U-shaped lines represent streams. Figure 7-1 illustrates a completed profile.

Aerial Photography Method

Step 1. Orient the aerial photos for stereo viewing. Ensure that shadows of features such as bridges, riverbanks, and low buildings appear to fall toward you, the viewer.

Step 2. Locate the PDG coordinates on each photo. PDG coordinates provide a means of locating (plotting) points that represent features, targets, and positions on an aerial photograph. Look in your mission directive to identify the PDG coordinates of two points for each photograph. Place a grid over each photo, beginning with the left one, and locate the grid square containing the point you will plot. Using the standard “read right and up,” plot each point according to its PDG coordinates. Use the standard map scale of 1:25,000, so you can use a map protractor for plotting. Plot the points in order of the first point on the left photo, first point on the right photo, second point on the left photo, and second point on the right photo. Finally, enter the coordinates in the marginal information area on each photo.

Step 3. Pinprick the points on the photos, in the same order as in step 2.

Step 4. Draw a connecting line between the points you have pin pricked and connect points 1 and 3 on the left photograph. Next, connect points 2 and 4 on the right photo. At this time, take a moment to check your work to make sure it is accurate. The points you have plotted must correspond to the location in the mission directive.

Step 5. Place the stereoscope over the aerial photographs, with the left lens placed over the left photo and the right lens over the right photo. Look through the stereoscope and adjust the photographs slightly so you will get the best possible stereo images. Features will appear to be three-dimensional if you have obtained stereovision.

Step 6. Determine intervisibility. After positioning the stereoscope over the photos, look through your stereoscope. The two lines will fuse into one line. If it appears to float above the ground, you have determined intervisibility. If the line appears to cut through the ground, you have not. By determining intervisibility between two points, you have also determined LOS between them.

ZONE OF ENTRY

Categories

A zone of entry (ZOE) is any area in which forces, supplies, or equipment can be placed within reach of an objective area. In most situations, it may also be a zone of exit. Be prepared to show good exit zones from each ZOE, as exit zones play a key role in the selection of ZOE. Types of ZOE are existing airfields, air landing zones (ALZs), helicopter landing zones (HLZs), paratroop/resupply drop zones (RDZs), ports, and amphibious landing beaches.

The three considerations of ZOE are customers, terrain, and climate. Customer consideration includes unit type and size, movement plans, and equipment type, size, and loads. Terrain consideration includes vegetation, slope, surface materials, obstacles, and surface drainage. Climatic considerations include temperature, air density, air pressure, wind, speed, and visibility. See Figure 7-2 for potential obstacles.

Airfields

POTENTIAL OBSTACLES FOR ENTRY ZONES		
Ditches	Tree stumps	Cuts and fills
Embankments	Stone walls	Hedge rows
Large rocks	Bushes	Scattered trees
Boulders	Buildings	Barbed wire fences
Wood fences	Minefields	Cemeteries
Quarries	Levees	Karst topography
Ruins	Towers	Overhead power lines
Rice paddy dikes		Overhead telephone lines

Figure 7-2. Potential obstacles for entry zones

Description

You can select existing airfields as potential ZOE if they meet the minimum size requirement dependent on the type of aircraft to be used. The easiest way to show an existing airfield on a ZOE overlay is to use the same symbol that is used on the transportation overlay, so the customer will know the runway length, width, orientation, and pavement status.

Criteria

Airfields should accommodate the maximum size aircraft, have airfield facilities, and be in correct orientation to the map scale. See Chapter 2 for information concerning the elements of an airfield. See Figures 7-3, 7-4, 7-5.

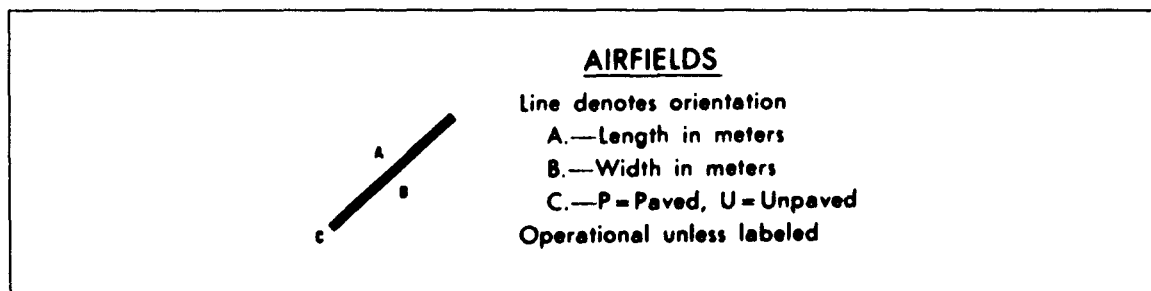


Figure 7-3. Airfield data

Aircraft	Overall dimensions (ft)			Weight (1000 lbs)		Takeoff (ft)*	
	Length	Width	Height	Basic	Maximum takeoff	Ground run	To clear 50 ft
OV-1B	41.7	48.0	13.0	10.98	15.79	1410	2185
OV-1C	41.0	42.0	13.0	10.01	14.82	1440	2230
OV-1D	41.3	48.0	12.7	15.50	17.50	1650	2280
U-8D	31.5	45.3	11.6	4.99	7.30	1455	2400
U-8F	33.3	45.9	14.2	5.49	7.70	1065	1660
U-21A	35.8	45.9	14.2	5.38	9.50	1500	2000
C12A	43.9	54.5	15.4	12.50	17.30	2200	
C12C/D	43.9	54.5	15.4	12.50	16.90	2200	

*At sea level, 59° F, no wind, hard surface

Figure 7-4. Characteristics of fixed wing Army aircraft

Airfield Type	Runway Length ft	Runway Width ft	Runway Shoulder Width ft	Total Aircraft Traffic Area* 1,000 sq ft
Battle Area				
Light Lift and Medium Lift	2,000	60	10	223
Forward Area				
Liaison	1,000	50	NA	37.5
Surveillance	2,500	60	10	337
Light Lift and Medium Lift	2,500	60	10	358
Support Area				
Liaison	1,000	50	NA	50
Surveillance	3,000	60	10	490
Light Lift and Medium Lift	3,500	60	10	753.5
Heavy Lift	6,000	100	10	1,421
Tactical	5,000	60	4	1,071
Rear Area				
Army	3,000	72	10	882
Medium Lift	6,000	72	10	2,362
Heavy Lift	10,000	156	10	3,926
Tactical	8,000	108	20	1,989

*This area includes parking, runway, taxiway, and warm-up apron

Figure 7-5. Minimum airfield requirements

Air Landing Zones

Description

ALZs are entry zones used by fixed-wing aircraft to access objective areas. They can include beaches, dry lake beds, sections of highway, and other areas that meet the criteria. Areas are classified as hasty or deliberate based on the anticipated type of missions or load requirements in a given area within the theater of operations. Hasty ALZs are unimproved surfaces good only for marginal weather operations and are unusable during prolonged periods of poor weather. Deliberate ALZs have all-weather capability and are usually permanent installations with control towers, runways, and taxiways. Deliberate classifications meet existing airfield criteria.

Figure 7-6 shows symbols for ALZ criteria. See TM 5-330 and FM 100-27 for specific information.

Criteria

- Undissected
- % Slope - per 100-foot horizontal distance
- No obstructions within glide angle of ALZ
- Oriented with prevailing winds
- Suitable Surface Materials and Surface Roughness

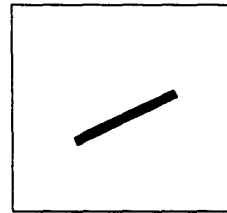


Figure 7-6. Air landing zone symbol

Procedures

Refer to FM 5-330 to determine proper values, then use the following formula to compute ALZ length:

$$\text{ALZ Length} = \text{TGR} + \text{ALT Cor} + \text{Temp Cor} \times \text{SF} + \text{Slope Cor}$$

Round Up.

Note: Round up the final ground run length to the next highest 100 foot value.

Example. ALZ length of 3,120 feet is rounded up to 3,200 feet.

Where:

TGR = Takeoff ground run at mean sea level and 59°F.

ALT Cor = Pressure altitude correction.

Add the dh value of entry zone based on FM 5-330 to the altitude of the entry zone, then increase the TGR by 10 percent for each 1,000-foot increase in altitude.

Temp Cor = Temperature correction. If the corrected ground run obtained in the previous computation is 5,000 feet or greater, increase the ground run by 7 percent for each increase in temperature above 59°F; if less than 5,000 feet, increase by 4 percent per 10° above 59°F. If the temperature is less than 59°F, no correction is required.

SF = Safety factor. Multiply the corrected ground run obtained in the previous computation by 1.5 for rear- area ALZs and 1.25 for support, forward, and battle area airfields.

Cor = Effective gradient correction. Increase the corrected ground run obtained in the previous computation by 8 percent for each 1 percent of effective gradient over 2 percent.

Round up = Round the final ground run length up to the next larger 100 feet.

Compare the final ALZ length and width to the minimum runway length and width shown in TM 5-330 and use the larger of the two lengths and widths.

Helicopter Landing Zones (HLZs)

HLZs are entry zones in which helicopters access an objective area. They are terrain and climate dependent. Even under the best weather conditions, using a vertical approach and departure, the helicopter requires flat and obstacle-free open areas and a surface material that will support the heavy loads of the aircraft. The load factor, elevation, and air temperature determine whether the helicopter can take off and land vertically. Helicopter approach and departure angles that are not vertical require longer distances to clear obstacles surrounding the edges of the entry zone.

Criteria

- Undissected
- Less than 15 percent slope (See FM 90-4)
- Minimum size should be based on METT-T (20 - 75m guide, minimum distance for a single helicopter)
- No vertical or ground obstructions greater than or equal to 18 inches
- 10:1 obstacle clearance ratio
- No dust, debris, or loose snow near LOC
- Stable soils

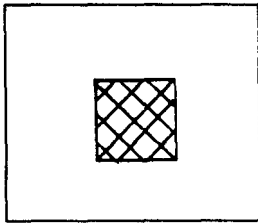


Figure 7-7.
Helicopter landing

Use the following formula to compute the size of the HLZ during daylight:

$$LS = \frac{2(RTZ + HO)}{\tan DA}$$

Where: LS = diameter of helicopter site

2 = safety factor

RTZ = radius of touch zone

HO = height of obstacle

DA = tangent of departure or approach angle in degrees, whichever is smaller

Compare the final HLZ length and width to the minimum length and width shown in FM 5-35. See Figures 7-8 and 7-9.

Use the following formula during hours of darkness:

$$LS (\text{Daylight}) \times 1.43 = LS (\text{Darkness})$$

Helicopter	Overall dimensions (ft)			Weight (1000 lbs)		Takeoff (ft)*	
	Length	Width	Height	Basic	Takeoff	Ground run	To clear 50 ft
OH-6A	30.30	26.30	8.20	1.16	2.70	0	0
OH-58A	41.00	6.60	9.65	2.76	3.00	0	0
OH-58C	42.00	6.60	9.40	2.92	3.20	0	0
UH-1D	57.01	48.00	17.16	4.92	9.50	0	0
CH-47	99.00	59.16	18.70	23.00	33.00	0	0
CH-54	88.41	72.00	25.33	19.82	42.00	0	0
AH-1	52.97	44.00	11.00			0	0

*At sea level, 59° F, no wind, hard surface

Figure 7-8. Characteristics of Army helicopters

Where: LS (Daylight)= Diameter of landing site during daylight

1.43 = Safety factor for darkness

LS (Darkness)= Diameter of landing site during darkness

Drop Zones (DZs)

Helipad or Heliport Type	Landing pad			Taxi/ Hover Lane ¹	Runway ²		
	Length ft	Width ft	Shoulder Width ft	Width ft	Length ft	Width ft	Shoulder Width ft
Forward Area							
OH-6A	12	12	NA	75	NA	NA	NA
UH-1H	20	20	NA	140	NA	NA	NA
CH-47	50	25	NA	180	NA	NA	NA
CH-54	50	50	NA	200	NA	NA	NA
Support Area							
OH-6A	12	12	10	100	NA	NA	NA
UH-1H	20	20	10	200	NA	NA	NA
CH-47	50	25	10	240	450	25	10
CH-54	50	50	10	250	450	50	10
Rear Area							
OH-6A	25	25	25	100	NA	NA	NA
UH-1H	40	40	25	200	NA	NA	NA
CH-47	100	50	25	240	450	40	25
CH-54	100	100	25	250	450	60	25

¹ Taxi/hover lane is used for takeoff and landing where provided; length is variable

² Where runway is not shown, takeoff and landing are on taxi/hover lane

Figure 7-9. Minimum helipad and heliport requirements

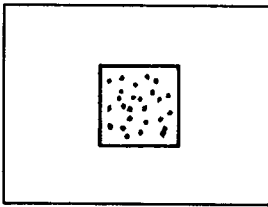


Figure 7-10. Drop zone symbol

DZs are entry zones in which troops or materials are delivered by parachute within a close proximity of an objective area. They are sometimes called resupply drop zones, when supplies are delivered to troops.

Criteria

- Undissected
- Less than 10 percent slope is preferred, 30 percent is allowable for supply drops
- Within 30km of a key city
- DZ near LOC
- No instructions within 1km
- Must have routes of entry or exit
- DZ has accessible cover and concealment
- Minimum width and length is dependent on the type, formation and speed of the aircraft, surface winds, the number of personnel or type of cargo being dropped, and visibility.
- For more information see FM 100-27.

Ports

Description

Ports may be used as entry zones when ships deliver troops and equipment close to the objective area. The selection of a port as an entry zone is based on geographic location, climatic conditions, and existing port facilities. Considerations include

PORT CATEGORIES			
Category	Vessel	Water depth	Other
Deep draft*	Naval	10 meters	
	Container	10-15 meters	
	Bulk carrier	12-18 meters	
	Tankers	10-28 meters	
Shallow draft**	Lash	2 meters	2 meters
	Seabee	3.4 meters	31 meters
	Barge	38 meters	38 meters
*Each vessel hatch requires 30 meters of wharf space, with the wharf at least 30 meters wide.			
** The wharf length must be 12 meters.			

Figure 7-11. Port categories

basin protection, bottom condition, shore area, communications, and water depth.

Port categories are deep draft, which includes ocean-going vessels, and shallow draft, which includes lighters, barges, and landing craft. See Figure 7-11.

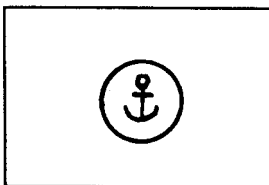


Figure 7-12. Port symbol

Criteria

- Water depth greater than 2 meters
- Minimum length 30 meters per hatch
- Exit route to Main Supply Route (MSR)
- Near LOC
- Near facilities

DMA Pub 150 lists ports worldwide. See also FM 5-35.

Amphibious Landing Beaches

Amphibious landing beaches are entry zones in which troops and equipment are involved in a transition from seaborne to a land attack force within a close proximity to the objective area. The criteria used for determining the location of an amphibious landing zone is based on geographic and climatic conditions at the entry zone. However, due to the transition from sea to land, the geographic conditions are divided into two areas: conditions of the terrain at the entry zone and hydrographic conditions at the entry zones. Additional considerations include weather, extent, depth, and bottom of the sea area, beach approach, beach gradient, and hinterland (depth, concealment and transportation net).

Criteria

- Underwater gradient 30:1
- Lack of underwater obstacles
- Firm bottom
- Trafficable soils exit
- Tide information
- Open, straight-shot of beach -no enemy salients

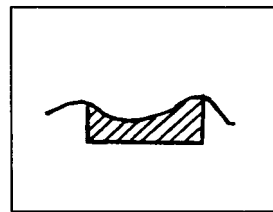


Figure 7-13.
Landing beach
symbol

SYNTHESIS PROCEDURES

Step 1. Review requirements to determine the type and criteria of the ZOE for the projected area.

Step 2. Obtain source material, including base topographic map, aerial photography, and the vegetation, surface configuration, surface materials, obstacles, surface drainage, and transportation factor overlays.

Step 3. From the vegetation-factor overlay, extinct the following No-Go area:

- All built-up areas
- Vegetation categories A2, A3, B1, B2, C1-C4, D1-D4, E1-E4, F, I, J, K, L, M
- Agriculture (A1) that includes bamboo, rice fields, and vineyards.

Step 4. From the surface-configuration-factor overlay extract the following No-Go areas:

- Any slope greater than 2 percent for ALZs
- Any slope greater than 15 percent for HLZs
- Any slope greater than 30 percent for DZs

Step 5. From the surface-materials-factor overlay extract the following nonacceptable soil types:

- Permanent snowfields
- Peat bogs

- Rock outcrops
- Permanent wet soils
- Surface roughness with a category of 3 or 4

Soil is probably not as important a factor as vegetation or slope. However, powdery, dry soil in arid climates must be considered an impediment to helicopter landing because of the reduced visibility, possible clogging of engine intakes, and revealed helicopter location due to generation of dust plume. Very wet or mucky soil may cause the helicopter wheels to settle into the soil to such an extent as to prevent the accomplishment of the mission. Thus, soil conditions can be dangerous to a helicopter and should always be considered when selecting a landing zone site.

Surface roughness affecting helicopter landing can include rocks, ridges, domes, and sandbars. Skilled terrain analysts must determine surface roughness, visualizing the landform and making decisions concerning surface irregularities. For example, some landforms of glacial origin commonly contain potential obstacles such as boulders that are not mapped topographically and may be too small to be seen on some aerial photography.

Step 6. From the obstacle-factor overlay, extract all obstacles that are within the project area.

The two types of obstacles associated with helicopter landing zone sites are vertical obstacles, which affect helicopter approach to and departure from a landing site, and ground obstacles within the landing site such as rocks, stumps, and holes. Approach and departure obstacles include power lines, transmission towers, and chimneys. These obstacles appear on standard 1:50,000-scale topographic maps from which you can compile a factor overlay. Obstacles within the landing site may not be detected easily. You must rely on ground reconnaissance, low-altitude photography, or local geographic literature.

Step 7. From the transportation-factor overlay, extract all existing airfields that meet the criteria for ZOE's.

Step 8. Evaluate all open areas and select the ZOE's needed for the projected area. If available, evaluate the areas against the CCMs and LOCs of the area.

The criteria for minimum-size requirements depends on a number of factors, including the type and number of aircraft, supplies, or troops to land in the ZOE, temperature, wind, altitude, and geographic location. Therefore, use the criteria listed for minimum areas as a guide and revise it as needed.

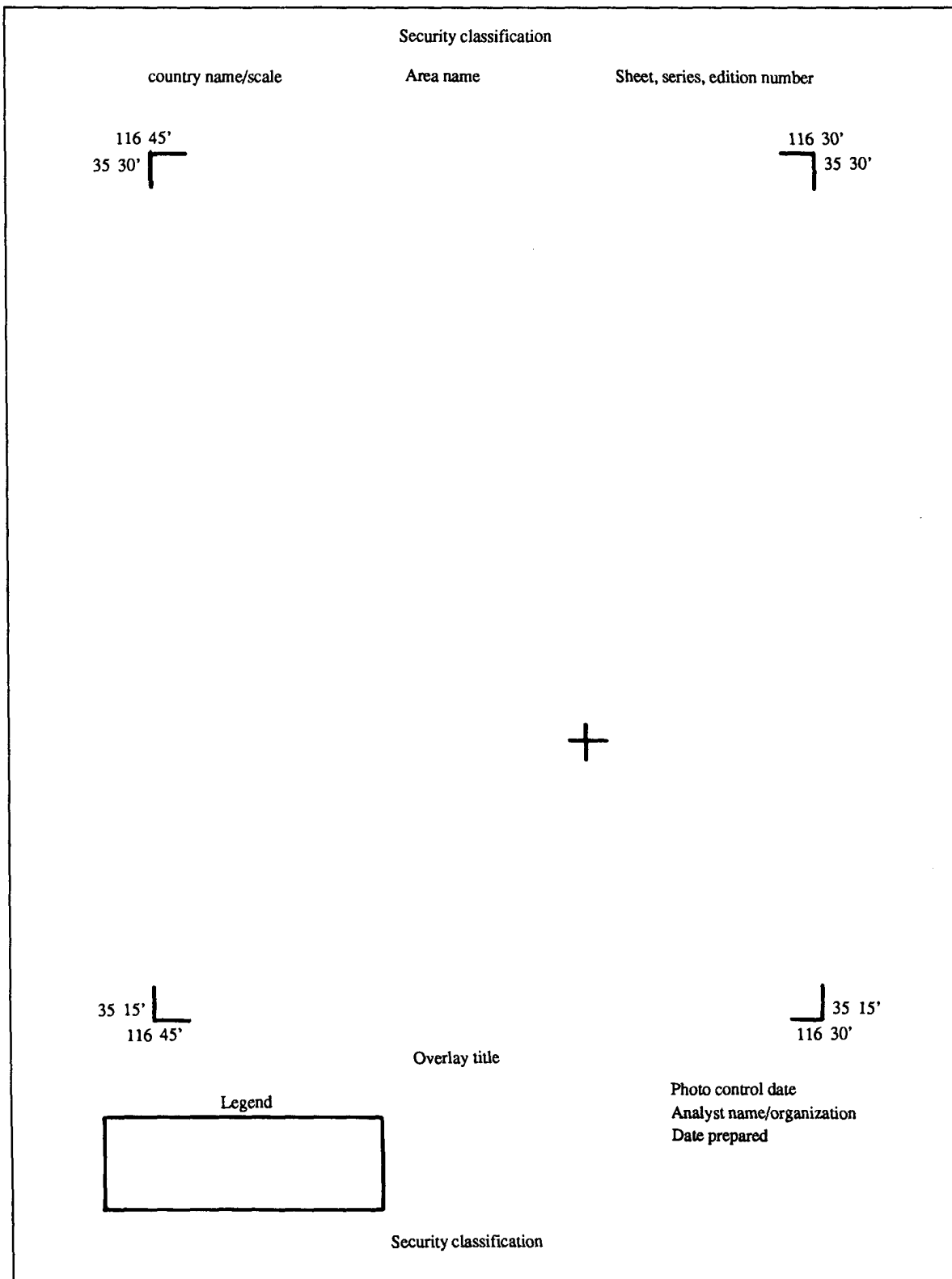
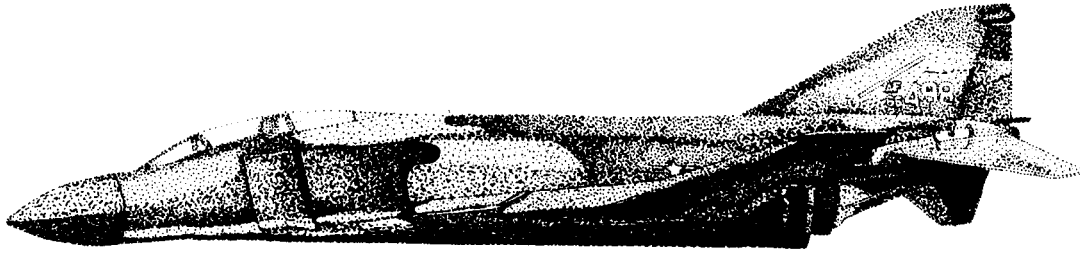


Figure 8-1. Example for map overlay



Vertical Photography

Chapter 9

Vertical photography is the process and the product of aerial photography taken with the axis of the camera held in a truly vertical position. If the vertical photography is taken over flat terrain, measured distances and directions may approach the accuracy of a line on a map. Procedures for determining measurements for vertical photography follow.

SCALE DETERMINATION

The linear scale is the relationship between distance on a map or photo and the actual ground distance. Scale is expressed as a representative fraction (RF). RF may be determined by one of three basic formulas:

$$RF = \frac{f}{H} \text{ or } \frac{f}{H-h} \quad RF = \frac{PD}{GD} \quad RF = \frac{P}{MD \times MSR}$$

Where--

- RF= The representative fraction or the scale of the imagery
- f = The focal length of the camera
- H= Height of aircraft above sea level
- h = average terrain height above sea level
- PD = Photo distance on picture
- GD = Actual ground distance
- MD= Distance on map
- MSR = Map scale reciprocal

Example: Find the RF of a photo where f equals 6 inches and H equals 5,000 feet.

$$RF = \frac{f}{H}$$

$$RF = \frac{6 \text{ in}}{5,000 \text{ ft}}$$

$$RF = 1: 10,000$$

GROUND DISTANCE DETERMINATION

You must know the photo representative fraction (PRF) or the map representative fraction (MRF) to use the MSR or the PSR ground distance determination. To

determine the actual distance or size of an object on an aerial photograph or map, use one of two formulas:

$$GD = PD \times PSR \text{ or } GD = MD \times MSR$$

Where--

GD = Ground distance
 PD = Photo distance
 MD = Map distance
 PSR = Photo scale reciprocal
 MSR = Map scale reciprocal

Example Find the GD covered by a photo where the PD = 0.026 feet and PRF = 1:8800.

$$\begin{aligned} GD &= PD \times PSR \\ GD &= 0.026 \text{ feet} \times 8800 \text{ feet} \\ GD &= 228.8 \text{ feet} \end{aligned}$$

PLOTTING TEMPLATE ADJUSTMENT

The plotting template is an adjustable instrument used for plotting vertical aerial photographs. The four sides of the template are graduated in inches and five hundredths of inches and may readjusted to any combination of lengths and widths from 0.05 inches by 0.05 inches to 5.0 inches by 5.0 inches. You can adjust the template during inspection or with the formula--

Where--

TS = Template setting in inches
 PS = Photo side (in inches)
 PSR = Photo scale reciprocal
 MSR = Map scale reciprocals

Example Find the TS of a photo where PS equals 9 inches by 9 inches, PRF equals 1:5000, and MRF equals 1:25,000.

$$\begin{aligned} TS &= \frac{PS \text{ (inches)} \times PSR}{MSR} \\ TS &= \frac{9 \text{ inches} \times 5,000}{25,000} \\ TS &= 1.8 \text{ inches} \times 1.8 \text{ inches} \end{aligned}$$

PROPORTIONAL DIVIDERS USE

The proportional divider is an adjustable, compass-like instrument designed especially for enlarging or proportionally reducing drawings and sketches. Use the formula---

$$\text{scale ratio} = \frac{MSR}{PSR} \text{ or } \frac{PSR}{MSR}$$

Where--

scale ratio = Proportional divider setting
 MSR = Map scale reciprocal
 PSR = Photo scale reciprocal

Example Find the scale ratio when MRF equals 1:25,000 and PRF equals 1:5,000.

$$\begin{aligned} \text{scale ratio} &= \frac{MSR}{PSR} \\ \text{scale ratio} &= \frac{25,000}{5,000} \\ \text{scale ratio} &= 5:1 \end{aligned}$$

PHOTO COVERAGE

Photo coverage is the ground area captured on any photo. It may be expressed in square feet, square yards, or square miles. You can determine photo coverage by using the formula--

$$PSC = PSR \times PS$$

Where--

PSC = Photo side coverage on the ground
 PSR = Photo scale reciprocal
 PS = Photo side

Example Find the ground distance covered by each side of a photo with RF equals 1:10,000 and photo format equals 9 inches by 9 inches.

$$\begin{aligned} PSC &= PSR \times PS \\ PSC &= 10,000 \times 9 \text{ inches} \\ PSC &= 10,000 \times 0.75 \text{ feet} \\ PSC &= 7,500 \text{ feet} \end{aligned}$$

The total ground area covered by this photo is 7,500 feet by 7,500 feet or 56,250,000 square feet.

PHOTO COVERAGE FOR A SPECIFIC AREA

The photo coverage for a specific area refers to the number of photos required to cover a predetermined area at a desired scale and format size. You must know--

- The desired scale of the photography.
- The photo format.
- The size of the area to be covered.
- The percentage of forward overlap between photos.
- The percentage of side lap between flight lines.

Example Determine the number of photos required to cover an area 36,000 feet by 30,000 feet.

Where--
 Photo format = 9 inches by 9 inches
 Desired scale = 1:5,000
 Forward overlap = 60 percent
 Sidelap = 40 percent

Step 1. Determine the ground-area coverage of a single photo.

$$\begin{aligned} \text{Area coverage} &= \text{format} \times PSR \\ \text{Area coverage} &= .75 \text{ feet} \times 5,000 \\ \text{Area coverage} &= 3,750 \text{ feet} \times 3,750 \text{ feet} \end{aligned}$$

Step 2. Determine the amount of ground gained forward (Ggf).

$$\begin{aligned} \text{Ggf} &= \text{Total area coverage minus forward overlap percentage} \\ \text{Ggf} &= 3,750 \text{ feet} \times 40\% \\ \text{Ggf} &= 1,500 \text{ feet} \end{aligned}$$

Step 3. Determine the amount of ground gained sideways (Ggs).

$$\begin{aligned} \text{Ggs} &= \text{Total area coverage minus sidelap} \\ &\quad \text{percentage} \\ \text{Ggs} &= 3,750 \text{ feet} \times 60\% \\ \text{Ggs} &= 2,250 \text{ feet} \end{aligned}$$

Step 4. Determine the minimum number of photos per flight line.

$$\begin{aligned} \text{Photo per flight line} &= \frac{\text{length of area}}{\text{Ggf}} \\ \text{Photo per flight line} &= \frac{36,000\text{ft}}{1,500\text{ft}} \\ \text{Photo per flight line} &= 34 \end{aligned}$$

Step 5. Round off photos per flight line to the next higher number when an uneven number exists. Add two photos to each end of the flight line to ensure complete stereo coverage.

Step 6. Determine the number of flight lines.

$$\begin{aligned} \text{Flight lines} &= \frac{\text{Area width}}{\text{Ggs}} \\ \text{Flight lines} &= \frac{30,000}{2,250} \\ \text{Flight lines} &= 13 + \end{aligned}$$

Step 7. Round off the number of flight lines to next higher number when an uneven number exists.

$$13+ = 14 \text{ flight lines}$$

Step 8. Multiply the number of photos per flight line by the number of flight lines to get the total number of photos required to complete the mission.

$$14 \times 38 = 532 \text{ Photos required}$$

HEIGHT DETERMINATION

Parallax Method

When you photograph a tall object from the air in two successive exposures, the position of the point between the two photos appears to change. This displacement is called parallax, which you can measure to determine the height of an object or the elevation of a point, using two overlapping vertical photos and taking measurements in a prescribed manner. This is the most accurate method of measuring height.

Step 1. Attach the parallax bar to the cross member of the stereoscope legs with the gage to the right. Push the ends of the bar down to engage the spring clips. Slide the bar as close to you as the stereoscope legs will permit. This will place the dots directly below the stereoscope lens. (See Figure 9-1.)

Step 2. The stereometer is a stereoscope with special measuring attachments. Under each lens is a glass plate that rests on its respective photograph of a stereoscopic pair. On the bottom of each glass plate is a small dot. The dot under the left lens remains in a fixed position. You can move the dot under the right lens by an adjusting knob along the eye base of the stereometer. The movement of the

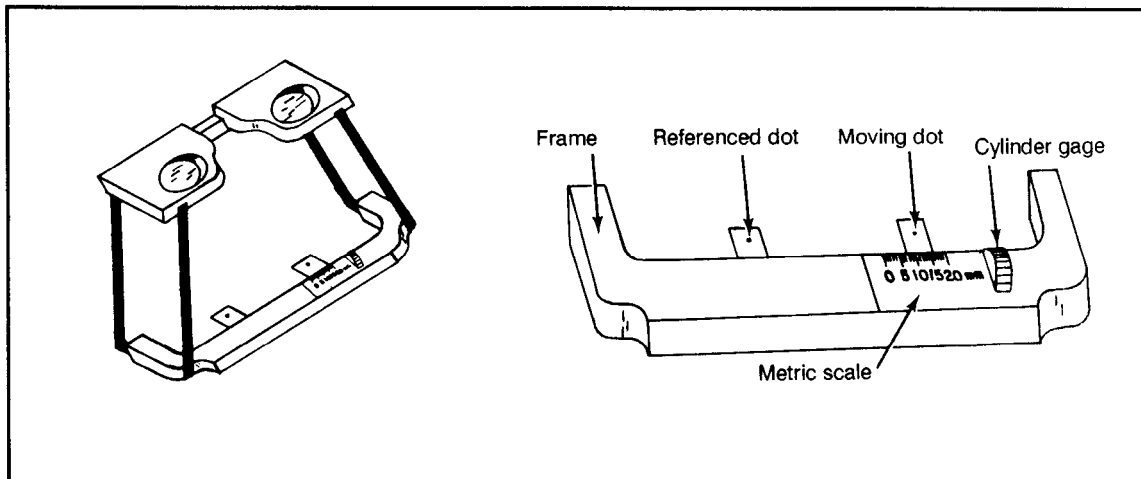


Figure 9-1 Stereoscope

right dot is measured by a micrometer dial. The range of distance between the dots is significant. For example, when you turn the adjusting knob on a stereometer so that the dots are at minimum separation, they may be 60 millimeters apart. When you turn the adjusting knob so that the dots are at a maximum separation, they may be 70 millimeters apart.

Corresponding points on two photographs must be between 60 and 70 millimeters apart when the photographs are properly oriented for stereoscopic vision. Relative to the graduation of the instrument the numbers may increase or decrease in magnitude when the dots converge. For example, if there is a range of 10 millimeters between minimum and maximum separation of the dots, the readings may be 0 at minimum and 10 at maximum or 0 at maximum and 10 at minimum, depending on the type of stereometer.

Step 3. Use fiducial marks to locate and mark principal points of both stereo paired photographs. Both photos have their own principal points but also contain the principal point of the adjacent photo in the aircraft flight line. To locate these points, transfer them from one adjacent photo to another with a stereoscope. Orient the photos for stereo viewing, locate the marked principal point, and mark the same point on the adjacent photograph. Repeat this procedure with the other photo. Each photo now has a principal point and a transferred principal point (see Figure 9-2).

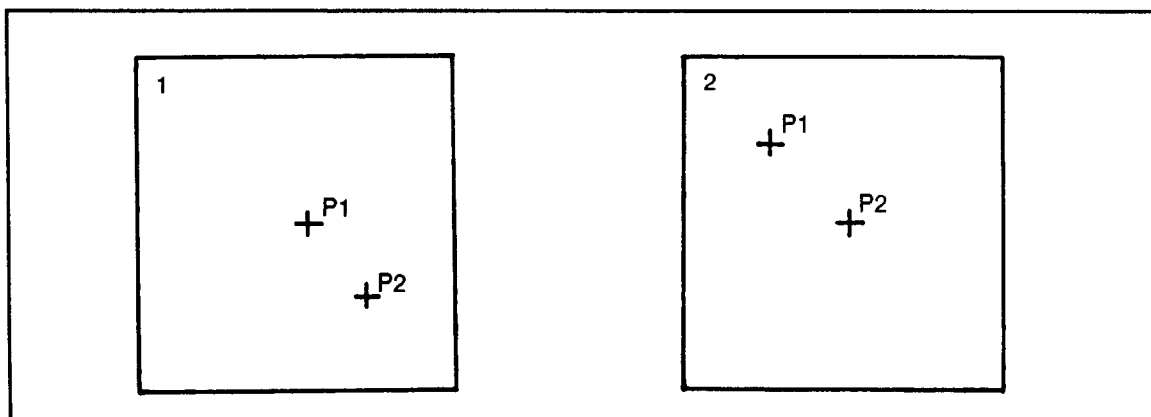


Figure 9-2 Point Transfer

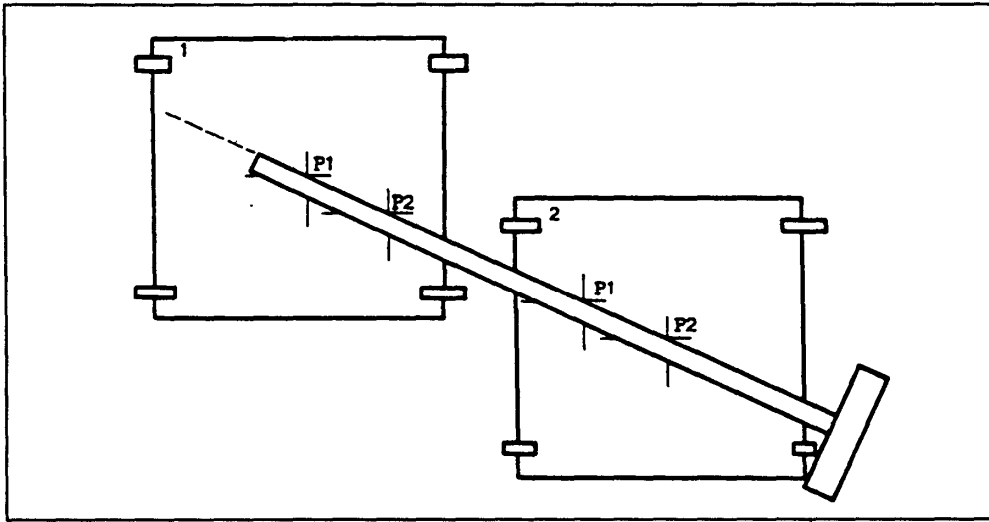


Figure 9-3 Flight Line

Now you can establish the flight line by drawing a line from the principal point to the transferred principal point on each photograph (see Figure 9-3). Measure the distance from the principal point to the transferred principal point (see Figure 9-4). Average these measurements using the formula--

$$b_m = \frac{b_1 + b_2}{2}$$

Where--

b_m = base means
 b_1 = measurement from the principal point to the transferred principal point on photo #1
 b_2 = measurement from the principal point to the transferred principal point on photo #2

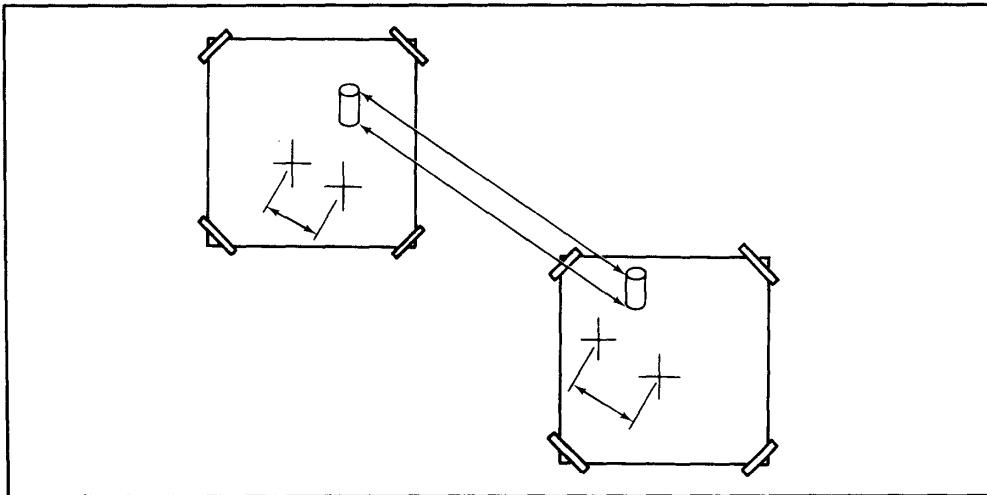


Figure 9-4 Point Measurement

Step 4. Locate the feature that you will measure using the stereoscope and stereometer. Measure the top of the feature first to obtain the first parallax measurement p_1 . Then measure the bottom of the feature to obtain the second parallax measurement, p_2 . To obtain a parallax measurement, you must place the photos so you can see them in stereo. With the stereometer attached to the stereoscope, you can see a left and right dot through the eyepieces. Place the left dot on the point to be measured, then rotate the micrometer knob until the right dot fuses with the left dot. Record the micrometer reading as shown on the scale.

After you have taken both parallax measurements (p_1 and p_2), find the differential parallax (Δp) to help determine the height of the feature, using the equation below. You can use p , as a function of the elevation of the feature being measured, to calculate the height of any natural or manmade object.

$$\Delta p = p_1 - p_2$$

Step 5. Since all elevations are relative to each other, you must establish a reference elevation to measure height differences. This reference elevation is the average terrain elevation above mean sea level, the horizontal plane above which an aircraft photographs. You can reference the terrain elevation of certain objects shown on aerial photography from topographic maps of the same area. This data can be used to provide an estimation of the average terrain elevation (h). For parallax height determination, you must also know the altitude of the aircraft, which you can determine from the marginal information on the aerial photograph. The altitude shown on the photo is the aircraft height above mean sea level (H).

Step 6. Once you have taken all measurements from the stereo-paired photographs, you can use the parallax equation to solve height determination, as follows:

Example:

a. Determine the base means.

$$b_m = \frac{b_1 + b_2}{2}$$

$$b_m = \frac{.305' + .313'}{2}$$

$$b_m = \frac{.618'}{2}$$

$$b_m = .309'$$

b. Determine the differential parallax.

$$\Delta p = p_1 - p_2$$

$$\Delta p = .0435 \text{ feet} - .0410 \text{ feet} = .0025 \text{ feet}$$

c. Determine height.

$$\text{Height} = \frac{(H - h) \times \Delta p}{b_m + \Delta p}$$

$$\text{Height} = \frac{(5,990 \text{ ft} - 640 \text{ ft}) \times .0025 \text{ ft}}{.309 \text{ ft} + .0025 \text{ ft}}$$

$$\text{Height} = \frac{(5,350 \text{ ft}) \times .0025 \text{ ft}}{.3115 \text{ ft}}$$

$$\text{Height} = \frac{13.38 \text{ ft}^2}{.3115 \text{ ft}}$$

$$\text{Height} = 43 \text{ feet}$$

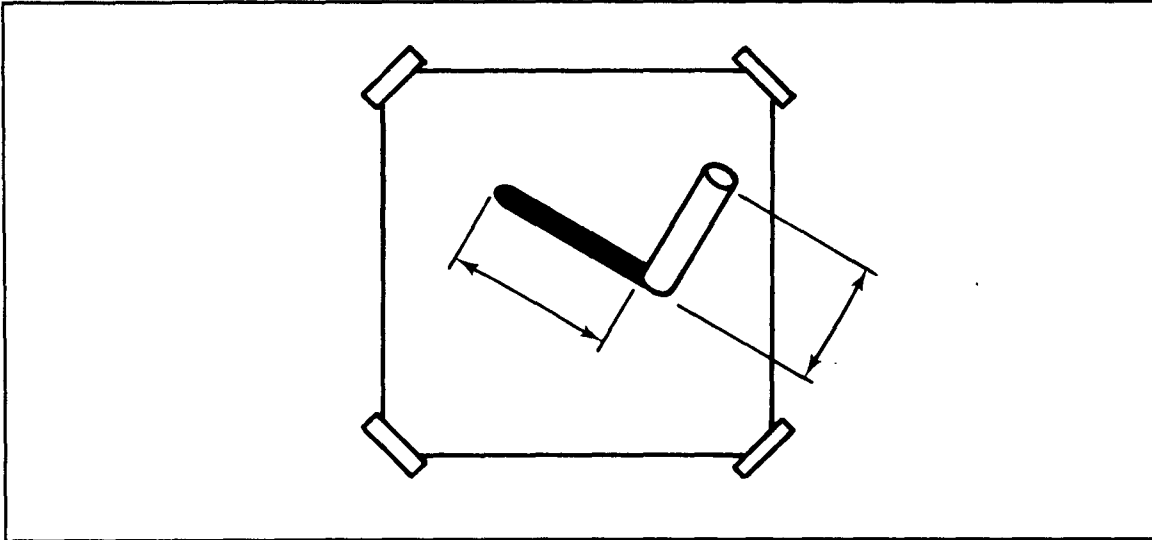


Figure 9-5 Shadow Measurement

Shadow Method

The shadow method is the least accurate of the three methods. You must have an object with a known height, and the unknown object must cast a shadow onto flat ground (see Figure 9-5). If the ground is uneven, the answer will be inaccurate. For any relatively small area of level ground, shadow length is directly proportional to object height. For example, a 40-foot tower casts a shadow twice as long as a 20-foot tower. If the shadow lengths are in a certain ratio, their photo images will be in the same ratio. To determine the height of an unknown object, measure its shadow length and multiply it by the ratio of height to shadow length established from the known object. Using the microcomparator or the photo interpreter's scale, measure the height of the unknown object and its shadow length. Place those measurements into the equation and determine the height using the following formula

Example:

$$h_k = 123 \text{ feet}$$

$$s_k = .027 \text{ feet}$$

$$s_u = .012 \text{ feet}$$

$$h_u = \frac{h_k \times s_u}{s_k}$$

$$h_u = \frac{123 \times .012'}{.027'}$$

$$h_u = 55 \text{ feet}$$

Where--

h_u = height of unknown object
 k = height of known object
 S_u = shadow length of unknown object
 S_k = shadow length of known object

Relief Displacement Method

The determination of height from relief displacement employs a single, vertical aerial photograph where both the base and the top of a vertical object are measurable. This method is particularly effective on large-scale imagery. For it to work, the displacement of the image must be visible. The formula for determining the height of an object based on its relief displacement is--

$$Hgt = \frac{\text{displacement} \times \text{flying height}}{\text{radial distance}}$$

$$Hgt = \frac{d \times (H - h)}{r}$$

Hgt = Height of the object above the average terrain elevation

H = Altitude of the aircraft above mean sea level

h = Average terrain height above mean sea level

H-h = Altitude above ground level

d = Image distance representing vertical side of the object

r = Distance between principal point and top of the object scaled from the photograph

You will first need to use a straightedge and mark the center of the photograph with fiducial marks. Always measure r from the top of the object to the center of the photograph, which you must determine by the intersection of the lines connecting the opposite fiducial marks. Measure d between the same point on the top and on the bottom of the object. The top of the object is always farther away from the center of the photograph than the bottom (see Figure 9-6). Using the photo-interpreter's scale, measure the distances and place the numbers into the equation, using procedures discussed earlier.

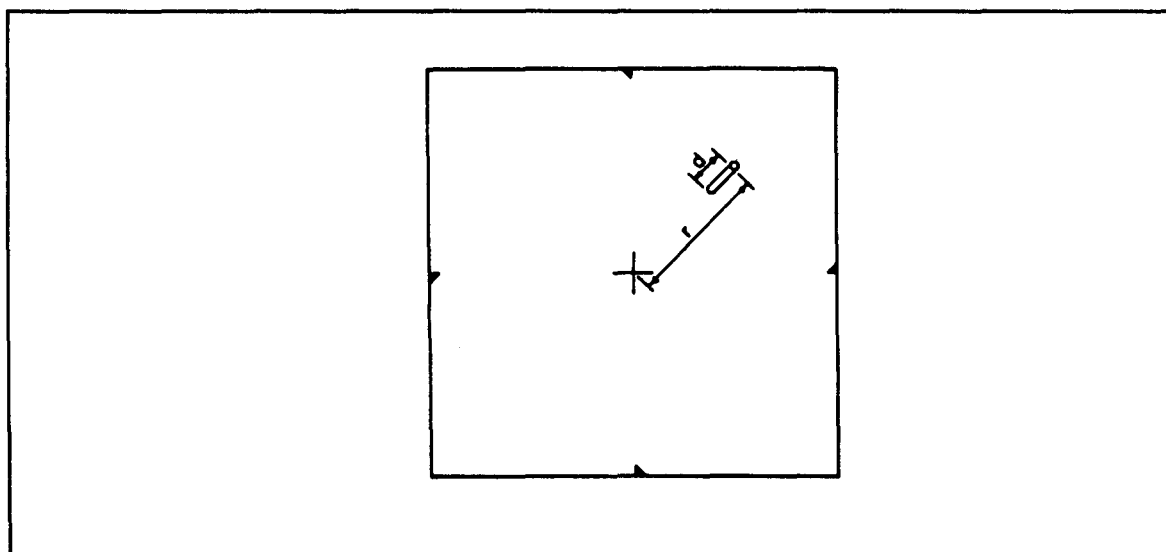


Figure 9-6 Displacement Measurement

Example

$$Hgt = \frac{dx(H-h)}{r}$$

$$Hgt = \frac{.017 ft \times 4,750 ft}{.261 ft} = 309 ft$$

AREA MEASUREMENT

You can use the dot grid template to measure area. Randomly place it on the lake or area to be measured. Count the dots that fall within the lake and those that fall on the line. Record the number, repeat the procedure at least three times, and determine the mean number of dots by adding the numbers together and dividing by the number of counts.

Example

First count	= 13
Second count	= 12
Third count	= 12
13+12+12	= 37
37/3	= 12.3
Mean number of dots	= 12.3

Step 1. Calculate the area in cm using the formula:

$$cm^2 = \frac{MEAN\ NUMBER\ OF\ DOTS}{25}$$

Example:

$$cm^2 = \frac{12.3}{25}$$

$$cm^2 = .49 cm^2$$

Note: Dots per cm² in this example are 25. Other dot grids are available, so check in each case to determine the dots per cm².

Step 2. Calculate the ground area using the formula--

$$Area = object\ area\ in\ cm^2 \times DRF^2$$

Example:

$$DRF = 24,000$$

$$DRF^2 = 5.76 \times 10^8$$

$$Area = (.49 cm^2 \times 5.76 \times 10^8)$$

$$Area = 2.8224 \times 10^8 cm^2$$

Where-- DRF = the denominator of the map or photo RF

Step 3. Convert the answer you obtained in Step 2 to square meters, using the formula--

$$m^2 = cm^2 \times .0001$$

$$m^2 = (2.8224 \times 10^8 cm^2) \times (.0001)$$

$$m^2 = 28,224$$

Examples:

- a. Calculate the volume of a lake which is 3 meters deep and has a surface of $28,800\text{m}^2$.

$$\text{Volume} = 28,800\text{m}^2 \times 3\text{m}$$

$$\text{Volume} = 86,400\text{m}^3$$

- b. Calculate the lake volume in gallons.

$$1\text{ m}^3 = 264.7\text{ gallons of water}$$

$$\text{Number of gallons} = (264.7\text{ gallons}/\text{m}^3) \times (86,400\text{m}^3)$$

$$\text{Number of gallons} = 22,870,080$$

QPS AREA MEASUREMENT

The QPS computes measurements automatically, greatly helping analysts find surface areas and volumes (see Figure 9-7).

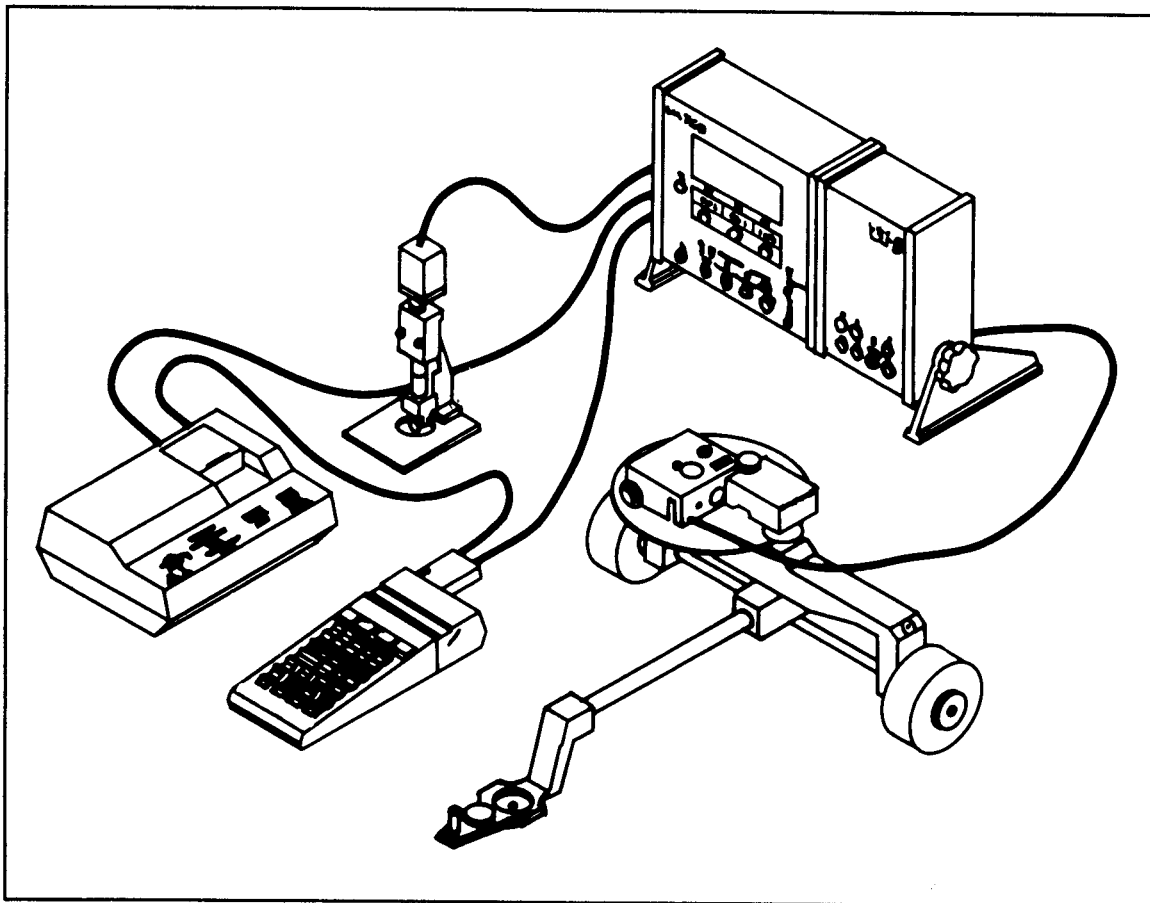


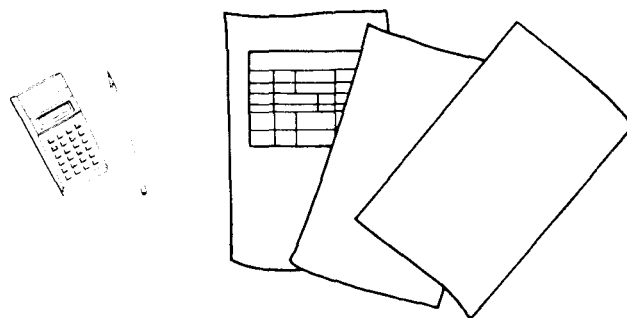
Figure 9-7 QPS

When the operator moves the QPS, it measures length, area, or volume. All measurements are displayed in the proper scale and units, and analysts can print a

hard copy of the measurement results on command or automatically. The QPS is not affected by any detrimental physical condition of a map or photograph that is to be measured, such as tears, wrinkles, or folds. QPS components include--

- A calculator, which is capable of data storage and manipulation.
- A point counter, which enables automatic determination of the count total for specific features or items located on drawings, maps, and so forth.
- A planimeter, which estimates surface areas and volumes.
- A linear measuring probe, which measures lines and distances.

See TM 5-6675-324-14, TM 5-6675-325-14, and TM 5-6675-326-14 for more information on the QPS system. See Appendix C for sources of aerial and ground imagery.



Mathematical Techniques

Chapter 10

GEOMETRIC FUNCTIONS

The result of any operation performed by terrain analysts will only be as accurate as the measurements used. An interpretation and detailed analysis often requires terrain analysts to use basic geometric functions. In addition, approximation of volume, extent of stock piles, and capacity of floor space require geometric formulas. Therefore, analysts must have a sound background in the fundamentals of basic imagery math. This section serves as a guide to a unique and comprehensive collection of current geometric formulas that are basic to all types of imagery interpretation.

Determination of Area

	1. Rectangles Where-- A = Area l = Length W = Width	FORMULA: $A = l \times W$
	2. Circles Where-- A = Area d = Diameter r = Radius $\pi = 3.142$	FORMULA: $A = 2\pi r \times r$ or $\pi \times d \times r$
	3. Triangles Where-- A = Area b = Base of the triangle h = Height of the triangle	FORMULA: $A = \frac{b \times h}{2}$
	4. General quadrilaterals Where-- A = Area h ₁ = Height no. 1 h ₂ = Height no. 2 b = Base common to two triangles formed by the diagonal	FORMULA: $A = \frac{1}{2} b (h_1 + h_2)$ or $A = \frac{b (h_1 + h_2)}{2}$

Table 10-1 Area Formulas

5. Ellipses	FORMULA: $A = \pi \times a \times b$
Where--	A = Area π = 3.142 a = Semi-axis b = Semi-axis

Table 10-1 Area Formulas - continued

Determination of Volume

1. Rectangular solids	FORMULA: $V = l \times w \times h$
Where--	V = Volume l = Length w = Width h = Height
2. Cylinders	FORMULA: $V = \pi \times r^2 \times h$
Where--	V = Volume π = 3.142 r = Radius h = Height
3. Spheres	FORMULA: $V = \frac{4}{3} \pi r^3$
Where--	V = Volume π = 3.142 r = Radius 3 = Constant
4. Cones	FORMULA: $V = \frac{\pi \times r^2 \times h}{3}$
Where--	V = Volume π = 3.142 r = Radius h = Height of cone 3 = Constant
5. Triangular solids	FORMULA: $V = \frac{l \times w \times h}{2}$
Where--	V = Volume l = Length w = Width h = Height 2 = Constant

Table 10-2 Volume Formulas

6. Trapezoidal solids	FORMULA: $V = \frac{(l + l') h (w + w')}{2}$
Where--	V = Volume l = Length of base l' = Length of top w = Width of base w' = Width of top h = Height 2 = Constant
7. Irregular triangular solids	FORMULA: $V = \frac{w x h x (2a + c)}{6}$
Where--	V = Volume w = Width h = Height a = Length of base c = Length of peak 6 = Constant

Table 10-2 Volume Formulas - continued

Angle of Repose

The angle of repose of any material is the angle at which material will stand when piled. Moisture content is often the controlling factor. The percent of fine material in the mass has a decided influence on the angle, as the fine carries the bulk of the moisture. Screened material has an angle of repose of 35 to 40 degrees.

Table 10-1 gives the average angle of repose and the average weight per cubic foot of various materials of interest to the terrain analyst.



MATERIAL	ANGLE OF REPOSE (Degrees)	TAN	WEIGHT PER CUBIC FT.
sand, dry	27	0.50952	100 lbs
sand, wet	30	0.57735	115 lbs
gravel	39	0.80978	117 lbs
earth, dry	35	0.70021	90 lbs
coal, anthracite	27	0.50952	52 lbs
coal, bituminous	32	0.62487	47 lbs
coke, industrial	40	0.83910	28 lbs
iron ore, crushed	37	0.75355	145 lbs
copper ore, crushed	37	0.75355	262 lbs
limestone, crushed	37	0.75355	165 lbs

Table 10-3. Angle of Repose

Thus, knowing the angle of repose of a specific material, we can solve for height, using the horizontal dimensions.

Example: Find the height (h) of a pile of limestone.

Formula: $h = \tan A \left(\frac{1}{2}b \right)$
 $h = 0.75355 \times 20 \text{ ft.}$
 $h = 15.071 \text{ ft.}$

Where-- $b = 40 \text{ feet}$
 Angle A = 37° degrees
 $\tan 37^\circ = 0.75355$ (from Table 10-1)

TRIGONOMETRIC FUNCTIONS

Oblique photos and thermal and SLAR imagery are often used to supplement or take the place of vertical photographs. In order to ensure maximum use of this imagery, the interpreter must be familiar with certain concepts, formulas, and principles concerning their accurate interpretation. This section gives the terrain analyst a basic understanding of trigonometric functions necessary for solving problems dealing with these special types of imagery, as well as a table of trigonometric conversions.



Six Functions

To define the six trigonometric functions upon which trigonometry is based, consider the angle, initial side AQ, and terminal side AS.

Choose any point B, different from A on the terminal side AS, and drop a perpendicular BC to the initial side AQ. From the three sides (BC, AC, and AB) associated with point B, six ratios are formed which are called the six trigonometric functions of Q.

$$\frac{CB}{AB}, \frac{AC}{AB}, \frac{CB}{AC}, \frac{AB}{CB}, \frac{AB}{AC}, \text{ and } \frac{AC}{CB}$$

These ratios are independent of the position of the point B on the freed terminal side AS, for if we choose any other point B1 on AS and drop the perpendicular B1C1 to the initial side AQ, the two right triangles ABC and AB1C1 are similar. Therefore, their corresponding sides have the same ratios.

If the angle is placed in standard position on a coordinate system, and the distance AB is designated by c, the six trigonometric functions may be defined as follows:

$$\begin{aligned}\sin \text{ angle} &= \frac{CB}{AB} = \frac{\text{Opp Side}}{\text{Hyp}} = \frac{\text{Side } a}{\text{Side } b} \\ \cos \text{ angle} &= \frac{AC}{AB} = \frac{\text{Adj Side}}{\text{Hyp}} = \frac{\text{Side } b}{\text{Side } c} \\ \tan \text{ angle} &= \frac{CB}{AC} = \frac{\text{Opp Side}}{\text{Adj Side}} = \frac{\text{Side } a}{\text{Side } b} \\ \cot \text{ angle} &= \frac{AC}{CB} = \frac{\text{Adj Side}}{\text{Opp Side}} = \frac{\text{Side } b}{\text{Side } a} \\ \sec \text{ angle} &= \frac{AB}{AC} = \frac{\text{Hyp}}{\text{Adj Side}} = \frac{\text{Side } c}{\text{Side } b} \\ \csc \text{ angle} &= \frac{AB}{CB} = \frac{\text{Hyp}}{\text{Opp Side}} = \frac{\text{Side } c}{\text{Side } a}\end{aligned}$$

To define trigonometric functions of the sides of right triangles, one will often find it convenient to use the functions of an acute angle. Thus, functions of the acute angle B may be written as follows:

$$\begin{aligned}\sin \text{ angle B} &= \frac{AC}{AB} = \frac{\text{Opp Side}}{\text{Hyp}} = \frac{\text{Side } b}{\text{Side } c} \\ \cos \text{ angle B} &= \frac{BC}{AB} = \frac{\text{Adj Side}}{\text{Hyp}} = \frac{\text{Side } a}{\text{Side } c} \\ \tan \text{ angle B} &= \frac{AC}{BC} = \frac{\text{Opp Side}}{\text{Adj Side}} = \frac{\text{Side } b}{\text{Side } a} \\ \cot \text{ angle B} &= \frac{BC}{AC} = \frac{\text{Adj Side}}{\text{Opp Side}} = \frac{\text{Side } a}{\text{Side } b} \\ \sec \text{ angle B} &= \frac{AB}{BC} = \frac{\text{Hyp}}{\text{Adj Side}} = \frac{\text{Side } c}{\text{Side } a} \\ \csc \text{ angle B} &= \frac{AB}{AC} = \frac{\text{Hyp}}{\text{Opp Side}} = \frac{\text{Side } c}{\text{Side } b}\end{aligned}$$

By comparing the values of the functions of angle A and angle B, we find the following equations:

$$\begin{array}{lll}\sin A = \cos B & \tan A = \cot B & \sec A = \csc B \\ \cos A = \sin B & \cot A = \tan B & \csc A = \sec B\end{array}$$

Since angles A and B are complementary, the cosine, cotangent, and cosecant are called cofunctions of the sine, tangent and secant respectively. Conversely, we may state the following theorem: Any trigonometric function of an acute angle is equal to the corresponding cofunction of its complementary angle.

We can use this theorem to express any function of an angle greater than 45 degrees in terms of a function of an angle less than 45 degrees. For this reason, tables of values of the trigonometric functions need be computed only for angles from 0 to 45 degrees instead of from 0 to 90 degrees.

Illustrations: (a) $\sin 76^\circ 43' = \cos 90^\circ - 76^\circ 43' = \cos 13^\circ 17'$
(b) $\cot 51^\circ 28' 9'' = \tan 90^\circ - 51^\circ 28' 9'' = \tan 38^\circ 31' 51''$

Right Triangles

Terrain analysts will use the functions of the right triangle most often for interpretation purposes. In any triangle, the sum of the interior angles is 180 degrees. If the triangle to be solved is a right triangle, one of the known parts in any case is the angle C; that is, $C = 90$ degrees, and $A + B = 90$ degrees. To solve a right triangle, therefore, we must find two sides or one side and an acute angle, using the formulas--

$$A + B = 90 \text{ degrees}$$

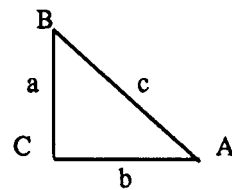
$$\begin{aligned}\sin \text{ angle A} &= \frac{\text{Opp Side}}{\text{Hyp}} = \frac{a}{c} \\ \cos \text{ angle A} &= \frac{\text{Adj Side}}{\text{Hyp}} = \frac{b}{c} \\ \tan \text{ angle A} &= \frac{\text{Opp Side}}{\text{Adj Side}} = \frac{a}{b}\end{aligned}$$

If two sides are given, we can find the sin of angle A from the above formulas involving the two given sides. We may then use another formula to find the remaining side, and then find angle B by subtracting angle A from 90 degrees.

If one side of an acute angle is given, we begin by finding the other acute angle. Then we select one of the trigonometric formulas containing an unknown side and solve for it.

Pythagorean Theorem

The Pythagorean theorem provides a method for finding the lengths of the sides of a right triangle and checking the trigonometric method, with the statement: The square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides. Related to a right triangle labeled A, B, and C, as shown previously and reproduced here for convenience, the theorem may be stated as the formula



$$a^2 + b^2 = c^2$$

or

$$c^2 = a^2 + b^2$$

Note: In order to solve the formula, we must understand the solution to the square root function. The square root of a number is the result of a number multiplied by itself. For example, $2 \times 2 = 4$, so the square root of 4 is 2.

Degrees	Sines							Cosines
	0'	10'	20'	30'	40'	50'	60'	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03299	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67778	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
Sines	60'	50'	40'	30'	20'	10'	0'	Degrees
Cosines								

Degrees	Cosines							Sines
	0'	10'	20'	30'	40'	50'	60'	
0	1.00000	1.00000	0.99998	0.99996	0.99993	0.99989	0.99985	89
1	0.99985	0.99979	0.99973	0.99966	0.99958	0.99949	0.99939	88
2	0.99939	0.99929	0.99917	0.99905	0.99892	0.99878	0.99863	87
3	0.99863	0.99847	0.99831	0.99813	0.99795	0.99776	0.99756	86
4	0.99756	0.99736	0.99714	0.99692	0.99668	0.99644	0.99619	85
5	0.99619	0.99594	0.99567	0.99540	0.99511	0.99482	0.99452	84
6	0.99452	0.99421	0.99390	0.99357	0.99324	0.99290	0.99255	83
7	0.99255	0.99219	0.99182	0.99144	0.99106	0.99067	0.99027	82
8	0.99027	0.98986	0.98944	0.98902	0.98858	0.98814	0.98769	81
9	0.98769	0.98723	0.98676	0.98629	0.98580	0.98531	0.98481	80
10	0.98481	0.98430	0.98378	0.98325	0.98272	0.98218	0.98163	79
11	0.98163	0.98107	0.98050	0.97992	0.97934	0.97875	0.97815	78
12	0.97815	0.97754	0.97692	0.97630	0.97566	0.97502	0.97437	77
13	0.97437	0.97371	0.97304	0.97237	0.97169	0.97100	0.97030	76
14	0.97030	0.96959	0.96887	0.96815	0.96742	0.96667	0.96593	75
15	0.96593	0.96517	0.96440	0.96363	0.96285	0.96206	0.96126	74
16	0.96126	0.96046	0.95964	0.95882	0.95799	0.95715	0.95630	73
17	0.95630	0.95545	0.95459	0.95372	0.95284	0.95195	0.95106	72
18	0.95106	0.95015	0.94924	0.94832	0.94740	0.94646	0.94552	71
19	0.94552	0.94457	0.94361	0.94264	0.94167	0.94068	0.93969	70
20	0.93969	0.93869	0.93769	0.93667	0.93565	0.93462	0.93358	69
21	0.93358	0.93253	0.93148	0.93042	0.92935	0.92827	0.92718	68
22	0.92718	0.92609	0.92499	0.92388	0.92276	0.92164	0.92050	67
23	0.92050	0.91936	0.91822	0.91706	0.91590	0.91472	0.91355	66
24	0.91355	0.91236	0.91116	0.90996	0.90875	0.90753	0.90631	65
25	0.90631	0.90507	0.90383	0.90259	0.90133	0.90007	0.89879	64
26	0.89879	0.89752	0.89623	0.89493	0.89363	0.89232	0.89101	63
27	0.89101	0.88968	0.88835	0.88701	0.88566	0.88431	0.88295	62
28	0.88295	0.88158	0.88020	0.87882	0.87743	0.87603	0.87462	61
29	0.87462	0.87321	0.87178	0.87036	0.86892	0.86748	0.86603	60
30	0.86603	0.86457	0.86310	0.86163	0.86015	0.85866	0.85717	59
31	0.85717	0.85567	0.85416	0.85264	0.85112	0.84959	0.84805	58
32	0.84805	0.84650	0.84495	0.84339	0.84182	0.84025	0.83867	57
33	0.83867	0.83708	0.83549	0.83389	0.83228	0.83066	0.82904	56
34	0.82904	0.82741	0.82577	0.82413	0.82248	0.82082	0.81915	55
35	0.81915	0.81748	0.81580	0.81412	0.81242	0.81072	0.80902	54
36	0.80902	0.80730	0.80558	0.80386	0.80212	0.80038	0.79864	53
37	0.79864	0.79688	0.79512	0.79335	0.79158	0.78980	0.78801	52
38	0.78801	0.78622	0.78442	0.78261	0.78079	0.77897	0.77715	51
39	0.77715	0.77531	0.77347	0.77162	0.76977	0.76791	0.76604	50
40	0.76604	0.76417	0.76229	0.76041	0.75851	0.75661	0.75471	49
41	0.75471	0.75280	0.75088	0.74896	0.74703	0.74509	0.74314	48
42	0.74314	0.74120	0.73924	0.73728	0.73531	0.73333	0.73135	47
43	0.73135	0.72937	0.72737	0.72537	0.72337	0.72136	0.71934	46
44	0.71934	0.71732	0.71529	0.71325	0.71121	0.70916	0.70711	45
Cosines	60'	50'	40'	30'	20'	10'	0'	Degrees
Sines								

Table 10-4 Natural Trigonometric Functions

Degrees	Tangents							Cotangents
	0°	10°	20°	30°	40°	50°	60°	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85
5	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75
15	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70
20	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54674	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60
30	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55
35	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50
40	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
Tangents	60°	50°	40°	30°	20°	10°	0°	Degrees
	Cotangents							

Degrees	Cotangents							Tangents
	0°	10°	20°	30°	40°	50°	60°	
0	∞	343.77371	171.88540	114.58865	85.93979	68.75009	57.28996	89
1	57.28996	49.10388	42.96408	38.18846	34.36777	31.24158	28.63625	88
2	28.63625	26.43160	24.54176	22.90377	21.47040	20.20555	19.08114	87
3	19.08114	18.07498	17.16934	16.34986	15.60479	14.92442	14.30067	86
4	14.30067	13.72674	13.19637	12.70621	12.25051	11.82617	11.43005	85
5	11.43005	11.05943	10.71191	10.38540	10.07803	9.78817	9.51436	84
6	9.51436	9.25530	9.00983	8.77689	8.55555	8.34496	8.14435	83
7	8.14435	7.95302	7.77035	7.59575	7.42871	7.26873	7.11537	82
8	7.11537	6.96823	6.82694	6.69116	6.56055	6.43484	6.31375	81
9	6.31375	6.19703	6.08444	5.97576	5.87080	5.76937	5.67128	80
10	5.67128	5.57638	5.48451	5.39552	5.30928	5.22566	5.14455	79
11	5.14455	5.06584	4.98940	4.91516	4.84300	4.77286	4.70463	78
12	4.70463	4.63825	4.57363	4.51071	4.44942	4.38969	4.33148	77
13	4.33148	4.27471	4.21933	4.16530	4.11256	4.06107	4.01078	76
14	4.01078	3.96165	3.91364	3.86671	3.82083	3.77595	3.73205	75
15	3.73205	3.68909	3.64705	3.60588	3.56557	3.52609	3.48741	74
16	3.48741	3.44951	3.41236	3.37594	3.34023	3.30521	3.27085	73
17	3.27085	3.23714	3.20406	3.17159	3.13972	3.10842	3.07768	72
18	3.07768	3.04749	3.01783	2.98869	2.96004	2.93189	2.90421	71
19	2.90421	2.87700	2.85023	2.82391	2.79802	2.77254	2.74748	70
20	2.74748	2.72281	2.69853	2.67462	2.65109	2.62791	2.60509	69
21	2.60509	2.58261	2.56046	2.53865	2.51715	2.49597	2.47509	68
22	2.47509	2.45451	2.43422	2.41421	2.39449	2.37504	2.35585	67
23	2.35585	2.33696	2.31826	2.29984	2.28167	2.26374	2.24604	66
24	2.24604	2.22857	2.21132	2.19430	2.17749	2.16090	2.14451	65
25	2.14451	2.12832	2.11233	2.09654	2.08094	2.06553	2.05030	64
26	2.05030	2.03526	2.02039	2.00569	1.99116	1.97680	1.96261	63
27	1.96261	1.94858	1.93470	1.92089	1.90741	1.89400	1.88073	62
28	1.88073	1.86760	1.85462	1.84177	1.82907	1.81649	1.80405	61
29	1.80405	1.79174	1.77955	1.76749	1.75556	1.74375	1.73205	60
30	1.73205	1.72047	1.70901	1.69766	1.68643	1.67530	1.66428	59
31	1.66428	1.65337	1.64256	1.63185	1.62125	1.61074	1.60033	58
32	1.60033	1.59002	1.57981	1.56969	1.55966	1.54972	1.53987	57
33	1.53987	1.53010	1.52043	1.51084	1.50133	1.49190	1.48256	56
34	1.48256	1.47330	1.46411	1.45501	1.44598	1.43703	1.42815	55
35	1.42815	1.41934	1.41061	1.40195	1.39336	1.38484	1.37638	54
36	1.37638	1.36800	1.35968	1.35142	1.34323	1.33511	1.32704	53
37	1.32704	1.31904	1.31110	1.30323	1.29541	1.28764	1.27994	52
38	1.27994	1.27230	1.26471	1.25717	1.24969	1.24227	1.23490	51
39	1.23490	1.22758	1.22031	1.21310	1.20593	1.19882	1.19175	50
40	1.19175	1.18474	1.17777	1.17085	1.16398	1.15715	1.15037	49
41	1.15037	1.14363	1.13694	1.13029	1.12369	1.11713	1.11061	48
42	1.11061	1.10414	1.09770	1.09131	1.08496	1.07864	1.07237	47
43	1.07237	1.06613	1.05994	1.05378	1.04766	1.04158	1.03553	46
44	1.03553	1.02952	1.02355	1.01761	1.01170	1.00583	1.00000	45
Cotangents	60°	50°	40°	30°	20°	10°	0°	Degrees
	Tangents							

Table 10-4 Natural Trigonometric Functions

Mensural Conversions

Appendix A

Multiply	By	To Obtain	Multiply	By	To Obtain
Acres	40.47	Ares	Feet	30.48	Centimeters
Acres	4,047	Centares	Feet	0.1667	Fathoms
Acres	10	Square chains	Feet	0.3048	Meters
Acres	43,560	Square Feet	Feet per Minute	0.01136	Miles per Hour
Acres	4,840	Square Yards	Feet per Second	0.5921	Knots
Ares	0.02471	Acres	Feet per Second	18.288	Meters per Minute
Ares	100	Centares	Feet per Second	0.6818	Miles per Hour
Ares	1,076	Square Feet	Furlongs	10	Chains
Ares	119.6	Square Yards	Furlongs	660	Feet
Barrels (U.S., dry)	3.281	Bushels	Furlongs	40	Rods
Barrels (U.S., liquid)	4.21	Cubic Feet	Furlongs	220	Yards
Barrels (U.S., liquid)	31.5	Gallons	Gallons (British)	4,546.1	Cubic Centimeters
Board Feet (1' x 1' x 1')	144	Cubic inches	Gallons (British)	0.1605	Cubic Feet
Cable lengths (U.S.)	120	Fathoms	Gallons (British)	277.274	Cubic Inches
Cable lengths (U.S.)	720	Feet	Gallons (British)	1.2009	Gallons (U.S.)
Cable lengths (U.S.)	240	Yards	Gallons (British)	4.546	Liters
Centares	10.76	Square feet	Gallons (British)	4	Quarts (British)
Centares	1.196	Square Yards	Gallons (U.S.)	0.03175	Barrels (liquid, U.S.)
Centimeters	0.3937	Inches	Gallons (U.S.)	3,785.4	Cubic Centimeters
Cubic Centimeters	0.06102	Cubic Inches	Gallons (U.S.)	0.13368	Cubic Feet
Chains	66	Feet	Gallons (U.S.)	231	Cubic Inches
Chains	100	Links	Gallons (U.S.)	0.8327	Gallons (British)
Chains	4	Rods	Gallons (U.S.)	3.785	Liters
Cubic Feet	1,728	Cubic Inches	Gallons (U.S.)	4	Quarts (U.S.)
Cubic Feet	0.02832	Cubic Meters	Grams	15.43	Grains
Cubic Feet	0.03704	Cubic Yards	Grams	0.001	Kilograms
Cubic Feet	6.229	Gallons (British)	Grams	1,000	Milligrams
Cubic Feet	7.481	Gallons (U.S.)	Grams	0.03527	Ounces (avoir-dupois)
Cubic Feet	28.316	Liters	Hands	10.16	Centimeters
Cubic Inches	16.39	Cubic Centimeters	Hands	4	Inches
Cubic Inches	0.0005787	Cubic Feet	Hectares	2.471	Acres
Cubic Inches	0.003606	Gallons (British)	Hectares	100	Ares
Cubic Inches	0.004329	Gallons (U.S.)	Hectoliters	0.1	Cubic Meters
Cubic Inches	0.01639	Liters	Hectoliters	26.417	Gallons (U.S.)
Cubic Meters	35.31	Cubic Feet	Hectoliters	100	Liters
Cubic Meters	1.308	Cubic Yards	Hogsheads	2	Barrels (Liquid, U.S.)
Cubic Yards	27	Cubic Feet	Hogsheads (U.S.)	63	Gallons (U.S.)
Cubic Yards	0.7646	Cubic Meters	Hundredweights	0.508	Quintals (metric)
Cubic Yards	764.6	Liters	Inches	72	Points
Degrees (C.) + 17.8	1.8	Degrees (F.)	Inches	6	Picas
Degrees (F.) - 32	0.5556	Degrees (C.)	Inches	6	Ems
Degrees	0.01745	Radians	Inches	12	Ens
Fathoms	0.00833	Cable Lengths (U.S.)	Inches	2.54	Centimeters
Fathoms	6	Feet			
Fathoms	1.8288	Meters			

Multiply	By	To Obtain	Multiply	By	To Obtain
Inches	0.0833	Feet	Miles, Nautical	6,076.1	Feet
Inches	1,000	Mils	Miles, Nautical	72,963	Inches
Inches	0.0277	Yards	Miles, Nautical	1.8532	Kilometers
Inches of Mercury	0.49131	Pounds per Square Inch	Miles, Nautical	1,853.2	Meters
Kilograms	1,000	Grams	Miles, Nautical	1.1508	Miles, Statute
Kilograms	2.2046	Pounds (Avoirdupois)	Miles, Nautical	1	Minutes of Latitude
Kiloliters	1	Cubic Meters	Miles, Nautical	2,026.8	Yards
Kiloliters	1.308	Cubic Yards	Miles per Hour (Statute)	88	Feet per Minute
Kiloliters	264.18	Gallons (U.S.)	Miles per Hour (Statute)	1.467	Feet per Second
Kiloliters	1,000	Liters	Miles per Hour (Statute)	0.8684	Knots
Kilometers	4.557	Cable Lengths	Miles, Statute	7.33	Cable Lengths
Kilometers	3,280.8	Feet	Miles, Statute	5,280	Feet
Kilometers	39,370	Inches	Miles, Statute	8	Furlongs
Kilometers	1,000	Meters	Miles, Statute	63,360	Inches
Kilometers	0.5396	Miles, Nautical	Miles, Statute	1.6093	Kilometers
Kilometers	0.62137	Miles, Statute	Miles, Statute	1,609.3	Meters
Kilometers	1,093.6	Yards	Miles, Statute	0.8689	Miles, Nautical
Knots	1.1516	Statute Miles per Hour	Miles, Statute	1,760	Yards
Knots	1.688	Feet per Second	Millier (See Tons - Metric)		
Leagues, Nautical	25.33	Cable Lengths	Milliradians	206.265	Seconds of Arc
Leagues, Nautical	5.5597	Kilometers	Mils	0.001	Inches
Leagues, Nautical	3	Miles, Nautical	Myriameters	10	Kilometers
Leagues, Statute	4.8280	Kilometers	Ounces (avoirdupois)	28.3495	Grams
Leagues, Statute	3	Miles, Statute	Pint (Liquid, U.S.)	4	Gills (U.S.)
Links	7.92	Inches	Pint (Liquid, Br.)	4	Gills (British)
Liters	1,000	Cubic Centimeters	Pint (Liquid, Br.)	0.56825	Liters
Liters	61.025	Cubic Inches	Pint (Liquid, U.S.)	0.4732	Liters
Liters	0.21998	Gallons (British)	Pounds (avoirdupois)	7,000	Grains
Liters	0.26418	Gallons (U.S.)	Pounds (avoirdupois)	453.59	Grams
Liters	0.8799	Quarts (British)	Pounds (avoirdupois)	0.4536	Kilograms
Liters	0.908	Quarts (U.S., dry)	Pounds (avoirdupois)	16	Ounces
Liters	1.0567	Quarts (Liquid, U.S.)	Pounds (avoirdupois)	1.2153	Pounds (troy)
Meters	100	Centimeters	Pounds (troy)	0.8229	Pounds (avoirdupois)
Meters	0.001	Kilometers	Pounds per Square Inch	2.03537	Inches of Mercury
Meters	1.0936	Yards	Quart (British)	1.1365	Liters
Meters	3.281	Feet	Quart (British)	2	Pints (British)
Meters	39.37	Inches	Quart (Liquid, U.S.)	0.9463	Liters
Meters	1,000	Millimeters	Quart (U.S.)	2	Pints (U.S.)
Meters	1.0936	Yards	Quintals (Metric)	1.97	Hundredweights
Meters per Minute	0.0547	Feet per Second	Quintals (Metric)	100	Kilograms
Meters per Second	2.237	Miles per Hour			
Microns	0.001	Millimeters			
Miles, Nautical	8.44	Cable Lengths			

Multiply	By	To Obtain	Multiply	By	To Obtain
Radians	57.30	Degrees	Square Miles, Statute	259	Hectares
Rods	16.3	Feet	Square Miles, Statute	2.59	Square Kilometers
Rods	25	Links	Square Yards	0.8362	Centares
Square Centimeters	0.1550	Square Inches	Square Yards	9	Square Feet
Square Feet	0.0929	Centares	Square Yards	1,296	Square Inches
Square Feet	929	Square Centimeters	Tons (Long)	1.016	Metric Tons
Square Feet	144	Square Inches	Tons (Long)	2,240	Pounds (Avoir- dupois)
Square Feet	0.1111	Square Yards	Tons (Metric)	1,000	Kilograms
Square Inches	6.452	Square Centimeters	(Millier)		
Square Inches	0.006944	Square Feet	Tons (Metric)	2,204.6	Pounds (Avoir- dupois)
Square Kilometers	100	Hectares	(Millier)		
Square Kilometers	0.3861	Square Miles (Statute)	Tons (Short)	0.9072	Metric Tons
Square Meters (See Centares)			Tons (Short)	2,000	Pounds (Avoir- dupois)
Square Miles, Statute	640	Acres	Yards	91.44	Centimeters
Square Miles, Statute	25,900	Ares	Yards	0.9144	Meters

To understand the interactions between weather and terrain and to work effectively with the staff weather officer (SWO), the terrain analyst must have a basic knowledge of weather phenomena and weather support procedures. This appendix discusses weather and weather-related factors that may affect military operations.

In addition to terrain, the battlefield environment includes atmosphere (weather), battle-induced contaminants (man-made weather), background signatures, and illumination (both natural and man-made). The terrain analyst, intelligence analyst, and United States Air Force weather personnel work together to integrate these environmental factors with terrain to determine their net effects on mobility and weapons usage. While weather effects on personnel and tactics are specifically an intelligence function, the same environmental phenomena also affect topographic engineer concerns. Therefore, analysis of factors should be a joint effort between topographic engineer, intelligence, and USAF weather personnel. The analyst should have a general knowledge of weather phenomena and its interaction with terrain. The analyst should also know how to get and use weather information. Since equipment and procedures change frequently, analysts should get specific information from the unit involved about effects of the weather on unit equipment and operations.

TYPES OF WEATHER INFORMATION

The three groups of weather information are observations, forecasts, and climatology. Units use observations and forecasts in support of current operations, while they use climatology for long-range planning.

Weather Observations

Weather observations are reports of actual weather conditions existing at a specific location at a given time. Observations are determined visually, with instruments, or both. Terrain analysts will base much of their analysis on current weather observations, since weather information can change very quickly. For this reason, units must also keep observations current. The SWO generally receives weather observations in codes comprised of abbreviations, numbers, letters, and symbols. Codes are used to simplify and speed transmission, not because of classification. The USAF weather personnel can explain the codes used in a given area.

The SWO can obtain observations taken by USAF weather observers, Army personnel in the Forward Area Limited Observation Program (FALOP), artillery meteorology (ARTYMET), and domestic and foreign weather services.

Unfortunately, weather observations are not always available, nor do they always contain the weather parameters of interest. However, the weather forecaster can forecast the present weather at a given location for which observations are not available. This forecast is called a "nowcast"; the complexity of the meteorological situation and the forecaster's knowledge of past conditions at that location determine its accuracy.

Weather Forecasts

SWOs usually base weather support to current operations on observed current weather and on weather forecasts. Weather forecasts are predictions of future weather for a specific period at a specific location or area. Forecast accuracy depends on the time range being forecast, the complexity of the meteorological situation, and the amount and quality of data available. Forecasts for longer time ranges are more general in nature and less accurate than those for 24 hours or less. Forecasts longer than a week are rarely very accurate because of our limited knowledge of how the weather operates. Thus, forecasters usually base long-range forecasts on climatology, a statistical summary of usual weather conditions for a given location and time of the year.

When possible, analysts should present observed weather along with forecast weather information. This lends credence to the forecast and gives the commander a sense of the reliability of the forecast. Weather forecasting is not an exact science, and not all forecasts will be accurate. The SWO will be more confident in the forecast in some situations than in others. Analysts should keep in contact with the SWO in case the forecast changes and should check the progress of the weather observations for their area of operations.

Climatology

Climate refers to the characteristic weather for a given place or area over a specified time. It is usually represented by statistics of weather conditions such as mean values, extreme values, and probability distributions. Commanders use climatology for planning upcoming operations. The SWO should have climatological information for the unit area. If not, he can get it from higher USAF channels. If the unit does not have an SWO, analysts can order climatology data directly from the Air Force under procedures in AR 115-1. Response time depends on whether the data exists and whether it exists in the format needed. Often it will be better to change the request so it can be filled with immediately available data than to demand specific computer-formulated data, which could take more time to get.

Often information from standard climatological summaries will be satisfactory, and units can get it quickly. Examples of such information include normal daily maximum and minimum surface temperatures and normal monthly rainfall amounts. If the supported unit has specific weather sensitivities not covered in standard climatological summaries, USAFETAC can formulate statistics to meet those needs. For example, if a unit has a weapon system that is limited by surface winds of 20 knots or more, the analyst can request statistics on the monthly frequencies of such winds and statistics indicating how often particular hours of the day have winds of 20 knots or more.

Two problems arise from using climatology. First, the specific information may not be available. Observations at that location may never have been taken, or the available observations may not include the specific parameter. Consequently, there is no data base upon which to formulate statistics. Units can usually overcome this shortage by the SWO or USAFETAC estimating weather conditions from nearby stations for which data is available.

Second, too much data is sometimes available. This can create a difficult situation, in which the analyst must be careful not to swamp a commander with useless statistics and unnecessary

detail. Thus, the analyst must know which weather conditions will affect the unit's operations and work with the SWO to present a concise summary of pertinent climatology.

WEATHER ELEMENTS

This section describes the application of the more common weather elements to terrain analysis. It contains the basic knowledge needed to work effectively with WETM and intelligence personnel. The information here is not complete; specific information about weather effects on the equipment used by the supported unit must come from that unit itself. Weather effects on terrain can be complex; unfortunately, few tactical decision aids are available. Until further procedures are available, much of the application of weather information will depend on the combined judgement and experience of the terrain analyst, SWO, and intelligence analyst.

Temperature

Temperature, alone or in combination with other weather elements, impacts on many activities. Extremes of temperature are a discomfort to personnel and can affect equipment and weapons systems. The difference between the temperature of a target and its background is critical to weapons using infrared sighting devices. This section outlines some factors to remember in using temperature information.

Surface temperatures in North America are generally measured in degrees Fahrenheit (°F); elsewhere they are reported in degrees Celsius (°C). Analysts always report upper air temperatures in degrees Celsius. Conversion between the two temperature scales is by the following formulas:

$$F = (9/5 \times C) + 32$$

$$C = 5/9 \times (F - 32)$$

Temperature is normally measured at about 5 feet above a grassy surface, with the thermometer shielded from direct sunlight and precipitation. This temperature is not necessarily the same as the temperature just above the surface of the ground. The temperature at grass level can be several degrees higher during the day and several degrees cooler at night. Temperature is dependent on topography, with higher elevations generally being cooler. However, since cold air is denser than warm air, cold air tends to flow into lower areas on nights with light winds.

Analysts must remember that objects are not necessarily the same temperature as the air. Metal objects exposed to sunlight, for example, tend to be hotter than air temperature, due to their absorption of solar radiation. At night they tend to be cooler than the air, because they lose their heat more rapidly by radiation. This can be very important to infrared sensing devices.

Windchill equivalent temperature (WCET), often simply called wind chill, is an approximation of the combined effect of temperature and wind on the exposed human body. Analysts must remember that the air movement causing windchill comes not only from wind but from any movement of the body relative to the air. Riding in an open truck moving at 20 mph in a 10-mph headwind gives a windchill equivalent to a 30 miles per hour wind. Windchill does not apply to equipment. For example, with a -10° F temperature, a battery will perform the same in calm conditions as in a 20-mph wind.

Frozen ground can be critical to trafficability. Frost depth depends on soil type, soil moisture content, type of ground cover, and recent temperature history at the site. Given the same soil and weather conditions, increased soil moisture (up to near the point of saturation)

will cause frost to penetrate deeper and faster. Bare soil will normally also freeze faster and deeper than sod-covered areas. Snow cover is an excellent insulator and can cause depth of frost to be shallower than in areas without snow cover. Usually, few observations of frost depth will be available. Furthermore, frost depth cannot be forecast now. Analysts will probably have to depend on their own observations of frost depth.

Temperature climatology information is usually readily available. It is important not to be misled by mean temperature information; extreme temperatures are most important. While there can be no set format for presenting temperature climatology, analysts and SWOs should consider the following example, which gives monthly data on mean daily maximums, mean daily minimums, monthly extremes, and an indication of frequency of some critical values by giving statistics of how many days those values are exceeded:

CATEGORIES*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Extreme maximum	45	48	60	78	92	98	104	104	92	70	60	48
Mean daily maximum	22	32	49	60	75	92	98	98	83	64	43	33
Mean daily minimum	2	11	29	40	55	72	78	80	63	44	24	11
Extreme minimum	128	-22	-2	15	28	53	55	55	26	14	-2	-13
Number of days with temperature less than or equal to 32	31	28	23	5	2	0	0	0	4	14	24	27

* All categories are in degrees fahrenheit

Table B-1. Sample temperature data

Wind

Wind direction is always recorded as the direction *from which* the wind is blowing. Direction is in the sixteen points of the compass or in tens of degrees with north being 360°; east, 90°; south, 180°; and west, 270°. Wind speed is usually in knots (nautical miles per hour, with a nautical mile being 6,076 feet), miles per hour, or meters per second. See Appendix A for conversion tables.

A gust is a rapid fluctuation in wind speed with a variation of 10 knots or more between peak and lull. For example, if the wind were blowing out of the north northeast at a mean speed of 20 knots with gusts to 40 knots, it would be recorded as 030/20G40.

Gust spread is a measurement of wind speed fluctuation normally used only for aircraft operations. The gust spread is the instantaneous difference between peak wind speed and lull wind speed. Since the lull speed is not necessarily the same as the mean speed, the gust spread in the above example could be more than 20 knots.

Wind is highly dependent on terrain and can vary considerably over a few hundred meters. When forecasting for a large area, weather forecasters try to forecast the highest wind condition over that area. Sheltered areas will naturally experience lower wind speeds.

Analysts try to identify wind patterns not only by the general weather situation but also by any influencing terrain factors. Sea coasts and mountainous regions can have unique wind regimes. Analysts and SWOs must especially be aware of narrow mountain gaps that may funnel winds and cause locally high wind speeds.

Wind can act in combination with other weather phenomena. It raises dust which in turn reduces visibility. A very light wind can make fog more dense, but higher winds will disperse fog. Wind breaks temperature inversions. It also speeds the drying of ground and can improve trafficability.

Be careful when examining climatology of wind. Prevailing wind direction is the wind direction that predominates over a given period and is a useful statistic. However, mean wind speed over a period can be very misleading. It could be very windy during daylight hours but almost calm at night and the resulting mean wind speed would be low. However, higher wind speeds during the day could adversely affect operations. Analysts must try to get information on the frequency of occurrence of winds above the critical values for their unit.

Precipitation

Precipitation is very important to trafficability. The effect depends on the type and amount of precipitation, the soil type, surface slope, type and amount of vegetation cover, and soil moisture content before the precipitation fell. Because of this complexity, exact rules are not given. Table 6-3 lists dry and wet season rating cone indices (RCIs) for various USCS soil types. However, the decision to use dry or wet values is, at present, up to the analyst's judgement. Light showers seldom affect trafficability. They may even improve it over sand. However, moderate or greater rain will degrade it.

Aerial and Ground Imagery Sources

Appendix C

AERIAL IMAGERY SOURCES

Federal Agencies

Aerial Photography Field Office
2222 West 2300 south
P.O. Box 30010
Salt Lake City, UT 84125

Agricultural Stabilization and Conservation Service
Department of Agriculture
Western Laboratory
2505 Parleys Way
Salt Lake City, UT 84109 (Source for all states)

Defense Intelligence Agency
ATTN: DIAAP-10
Washington survey photography held by DMAHTC
6500 Brooks Lane
Washington, DC 20408

Bureau of Land Management
Department of Interior
Washington, DC 20408

Cartographic Archives Division
National Archives (GSA)
Washington, DC 20408

EROS Data Center
U.S. Geological Survey
Sioux Falls, SD 57198

National Cartographic Information Center (Headquarters)
Geological Survey
Department of Interior
Reston, VA 22090

NCIC-Mid-Continent
USGS, 1400 Independence Rd
Rolla, MO 65401

NCIC-Rocky Mountain
USGS, Topographic Division
Stop 510, BOX 25046
Denver Federal Center
Denver, CO 80225

NCIC-Western
USGS, 345 Middlefield Rd.
Menlo Park, CA 94025
National Ocean Survey
Department of Commerce
Washington Science Center
Rockville, MD 20852

Soil Conservation Service
Department of Agriculture
Federal Center Building
East-West Highway and Belcrest Rd.
Hyattsville, MD 20781

Tennessee Valley Authority
Maps and Surveys Branch
210 Haney Building
Chattanooga, TN 37401

Technology Application Center
University of New Mexico, Code 11
Albuquerque, NM 87131

FOREST SERVICE PHOTOGRAPHY, EASTERN US

Chief Forest Service
US Department of Agriculture
Washington, DC 20250

FOREST SERVICE PHOTOGRAPHY, WESTERN US

Region

- 1 Federal Building, Missoula, MT 59801
- 2 Federal Center, Building 85, Denver, CO 80025
- 3 Federal Center, 517 Gold Ave. SW, Albuquerque, NM 87101
- 4 Forest Service Building, Ogden, UT 84403
- 5 630 Sansome St., San Francisco, CA 94111
- 6 P.O. Box 8623, Portland, OR 97208
- 10 Regional Forester, U.S. Forest Service, P.O. Box 1628,
Juneau, AL 99801

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

EROS Data Center
User Services Section
Sioux Falls, SD 57198
Phone (605) 594-6151
FTS 784-7151

Technology Applications Center
University of New Mexico
Albuquerque, NM 87131
Phone (505) 277-3622

Media Services Branch
Still Photography Library
NASA/Johnson Space Center
P.O. Box 58425, Mail Code AP3
Houston, TX 77258-8425
Phone (713)483-4231

US GEOLOGICAL SURVEY

Western Center
Box 25286 Federal Center, Bldg. 41
Denver, CO 80225

Mid-Continent Center
1400 Independence Road
Rolla, MO 65401

Eastern Center
United States Dept. of the Interior
Geological Survey
Reston, VA 22092

State Agencies

Arizona Highway Department
Administrative Services Division
206 South 17th Avenue
Phoenix, AZ 85007

State of Arkansas Highway Department
Surveys, 9500 New Denton Highway
P.O. Box 2261
Little Rock, AK

Illinois Department of Transportation
2300 South - 31st Street
Springfield, IL 62734

Indiana Highway Department
608 State Office Building
Indianapolis, IN 46204

Southeast Michigan
Council of Governments
1249 Washington Boulevard
Detroit, MI 49226

State of Nebraska
Department of Roads
14th & Burnham Streets
Lincoln, NE 68502

State of Ohio
Department of Highways
Columbus, OH 43216

Oregon State Highway Division
Salem, OR 97310

Virginia Department of Highways
Location and Design Engineer
1401 East Broad Street
Richmond, VA 23219

State of Washington
Department of Natural Resources
600 North Capital Way
Olympia, WA 98501

Southeastern Wisconsin Regional Planning Commission
916 North East Avenue
Waukesha, WI 53186

Wisconsin Department of Transportation
Engineering Services
4802 Sheboygan Avenue
Madison, WI 53702

NOTE: *This list is not all-inclusive. Most states have departments of transportation, departments of natural resources, or agricultural management departments. These agencies are good sources for photography. Coordination must be made with local state or county offices to aid in the procurement process.*

Commerical Firms

Aerial Data Service
10338 East 21st Street
Tulsa, OK 74129

Aero Service Corporation
4219 Van Kirk Street
Philadelphia, Pennsylvania 19135

Air Photographic Inc.
P.O. Box 786
Purcellville, VA 23132

Alster and Associates, Inc.
6135 Kansas Avenue, NE
Washington, DC 20011

Ammann International Base Map & Air Photo Library
223 Tenth Street
San Antonio, TX 78215

Burlington Northern Inc.
650 Central Building
Seattle, Washington 98104

Cartwright Aerial Surveys Inc.
Executive Airport
6151 Freeprot Boulevard
Sacramento, California 95822

Fairchild Aeromaps Inc.
14437 North 73th Street
Scottsdale, Arizona 85254

Grumman Ecosystems Corp.
Bethpage, NY 11714

Henderson Aerial Surveys Inc.
5125 West Broad Street
Columbus, Ohio 43228

H. G. Chickening, Jr.
Consulting Photogrammetrist, Inc.
P.O. Box 2767
1190 West 7th Avenue
Eugene, Oregon 97402

L. Robert Kimball
615 West Highland Avenue
Ebensburg, Pennsylvania 15931

Lockwood, Kessler & Bartlett, Inc.
One Aerial Way
Syosset, NY 11791

Mark Hurd Aerial Surveys, Inc.
345 Pennsylvania Avenue south
Minneapolis, Minnesota 55426

Merrick and Company
Consulting Engineers
2700 West Evans
Denver, CO 80219

Murry - McCormick
Aerial Surveys Inc.
6220 24th Street
Sacramento, CA 95822

Photographic Interpretation Corporation
Box 868
Hanover, New Hampshire 03755

Quinn and Associates
460 Caredean Drive
Harsham, Pennsylvania 13044

Sanborn Map Company, Inc.
P.O. Box 61
629 Fifth Avenue
Pelham, NY 10803

The Sidwell Company
Sidwell Park
28 W 240 North Avenue
West Chicago, 111 60185

Surdex Corporation
25 Mercury Boulevard
Chesterfield, MO 63017

Teledyne Geotronics
725 East Third Street
Long Beach, CA 90812

United Aerial Mapping
5411 Jackwood Drive
San Antonio, TX 78238

Walker and Associates Inc.
310 Perfontaine Building
Seattle, Washington 98104

Western Aerial Contractors, Inc.
Mahlon Sweet Airport - Route 1, Box 740
Eugene, Oregon 97401

Foreign Government Agencies

National Air Photo Library
Survey and Mapping Building
615 Booth St.
Ottawa, Canada KIA OE 9

GROUND IMAGERY SOURCES

US Army Imagery Interpretation Group
Bldg. 213, Washington Navy Yard
Washington, DC 20374

Defense Intelligence Agency
ATTN: RPP-3
Washington, DC 20301

US Army AMC Service Support Activity
Audio-Visual Presentations division
Room 1C13, Pentagon
Washington, DC 20310

Glossary

ACRONYMS AND ABBREVIATIONS

AK	Arkansas
AL	Alabama
ALZ	air landing zone
APPS	analytical photogrammetric positioning system
AR	Army regulation
ARTYMET	artillery meteorology
ATTN	attention
AWS	air weather service
AZ	Arizona
C	Celsius
C A	California
CCM	cross-country movement
CI	cone index
cm	centimeter
CO	Colorado
Cos	cosine
Cot	cotangent
Csc	cosecant
DA	Department of the Army
DBH	diameter at breast height
DC	District of Columbia
DFAD	digital features analysis data
DMA	Defense Mapping Agency

DSS	direct support system
DTED	digital terrain elevation data
DTSS	digital topographic support system
DZ	drop zone
EAC	echelon above corps
EETI	essential elements of terrain information
etc.	et cetera
F	Fahrenheit
FALOP	Forward Area Limited Observation Program
FC	field circular
FM	field manual
FRG	Federal Republic of Germany
G2	Assistant Chief of Staff, G2 (Intelligence)
Ggf	ground gained forward
Ggs	ground gained sideways
H	altitude of the aircraft above mean sea level
h	average terrain height above mean sea level
HLZ	helicopter landing zone
HO	height of obstacle
ID	identification
IL	Illinois
IN	Indiana
IPB	intelligence preparation of the battlefield
km	kilometer
kph	kilometers per hour
LOC	lines of communication
LOS	line of site
m	meters
MD	Maryland
METT-T	mission, enemy, terrain, troops, and time available
MGI	military geographic information
MI	military intelligence
MI	Michigan
MLC	military load classification
mm	millimeters

MN	Minnesota
MO	Missouri
MOUT	military operations on urbanized terrain
mph	miles per hour
MRF	map representative fraction
MSR	main supply route
MT	Montana
MTR	minimum turning radius
MY	New York
NATO	North Atlantic Treaty Organization
NCO	noncommissioned officer
N E	Nebraska
NH	New Hampshire
NM	New Mexico
NO	number
NOE	nap of the earth
OCOKA	observation and fields of fire, cover and concealment, obstacles, key terrain, and avenues of approach
OD	override diameter
OH	Ohio
OK	Oklahoma
OR	Oregon
P	paved
PA	Pennsylvania
PDG	point designation grid
PI	photo interpretation
PRF	photo representative fraction
PSR	photo scale reciprocal
PTADB	planning terrain analysis data base
QPS	quantity processing system
RCI	rating cone index
RDZ	paratroop/resupply drop zone
RF	representative fraction
RI	remolding index
RSI	remote-sensed imagery

RTZ	radius of touch zone
S2	intelligence officer (US Army)
SD	stem diameter
SD	South Dakota
Sec	secant
SF	safety factor
SIF	slope-intercept frequency
Sin	sine
SLAR	side-looking airborne radar
S s	stem spacing
Swo	staff weather officer
Tan	tangent
TC	tree count
TGR	takeoff ground run
TM	technical manual
TN	Tennessee
TOE	table(s) of organization and equipment
TTADB	tactical terrain analysis data base
TX	Texas
u	unpaved
Uc	under construction
us	United States (of America)
USAF	United States Air Force
USAFETAC	United States Air Force Environmental Technical Applications Center
USCS	Unified Soil Classification System
USGS	United States Geological Survey
USSR	Union of Soviet Socialist Republics
UT	Utah
UTM	universal transverse mercator
VA	Virginia
VCI	vehicle cone index
VF	vehicle factor
VR	vegetation roughness
VRF	vegetation roughness factor

WA	Washington
WCET	windchill equivalent temperature
WETM	weather teams
WI	Wisconsin
ZOE	zone of entry

TERMS

abutment - the support at either end of a bridge.

air base - an airfield having, in addition to operational facilities, shelter for personnel and facilities for supply and repair of aircraft.

airfield - a group of facilities designed for takeoff, landing, servicing, fueling, and parking of fixed-wing and rotary-wing aircraft.

alluvium - general term for material deposited by streams, including silt, sand, gravel, clay, or boulders derived from decomposed bedrock but deposited elsewhere.

altitude - the height above an established reference base. Altitude is usually measured as height above mean sea level.

apron, cargo - a prepared area for loading and unloading personnel and cargo.

apron, maintenance - a prepared area for parking aircraft being serviced or repaired.

apron, parking - a prepared area used in place of hardstands for the parking of aircraft. It is also referred to as a conventional apron.

apron, warmup - a stabilized or surfaced area used for the assembly or warming up of aircraft, usually located at both ends of the runway adjacent to and with the long axis parallel to the connecting taxiway.

aqueduct - a large pipe or conduit made for transporting water from a distant source.

avenue of approach - route by which a force may reach an objective.

badlands - a geographical area nearly void of vegetation. An almost impassable region due to narrow avenues, sharp crests, and pinnacles.

bank - the continuous sloping margin of a stream or other water body; on a stream, designated left or right bank as it would appear to an observer facing downstream.

bar - an accumulation of alluvial material in a stream channel, commonly emergent at low water.

basalt - common name for a group of dark, fine-grained, heavy, very hard volcanic rock.

bed - the bottom on which a body of water rests.

bog - a swamp or tract of wet land commonly covered with peat.

brush - shrubs and stands of short, scrubby tree species that do not reach sufficient size for use as timber.

canal - a channel or waterway artificially constructed or maintained for conveying water or for connecting two or more bodies of water.

canopy - uppermost closed surface or roof of the forest.

channel - the trench in which a stream normally flows; that part of a body of water deep enough to be navigable.

channel cross section - a representation of a channel as it would appear if cut through crosswise and vertically at right angles to its long axis and depicting, specifically, the area of the channel through which flow has passed or is supposed to pass.

channel roughness - roughness of the channel, including extra roughness due to local expansion or contraction and obstacles, as well as roughness of the stream bed proper, such as friction offered to the flow by the surface of the bed of the channel in contact with the water; expressed by the roughness coefficient of the velocity formulas.

classification yard - a yard in which the traffic is classified in accordance with requirements and made up into trains.

clay - soil particles having diameters less than 0.0002 millimeters.

concealment - protection from observation only,

conduit - an artificial or natural channel which carries water for supply or industrial purposes.

conifer - cone bearing - trees of the "soft-wood" group such as spruce and pine. Most but not all conifers are evergreen and needle-leaved.

coniferous forest - a forest of evergreen coniferous or cone-bearing trees carrying needle-shaped leaves. Such forests have valuable softwood timber.

contamination - impairment of the quality of water to a degree which creates an actual hazard to public health by toxic chemicals, radioactive isotopes, or pathogenic organisms.

contour density - the spacing of contour lines on a map.

cover - protection from weapons fire.

cross-country movement - movement across terrain that is not specifically improved for vehicular traffic.

crown - the entire leafy part of a tree or shrub, especially as seen from above.

current velocity - the speed, expressed in units of time and distance, at which water flows in a stream, channel, or conduit.

data base - a collection of information in any form, assembled for a particular future use.

deciduous - vegetation losing all their leaves seasonally, either in the cold or dry season.

deciduous forest - a forest consisting of trees that lose their leaves at some season of the year. Such forests have valuable hardwood timber.

dendritic - a branching tree-like pattern of tributaries of a main stream.

departure yard - a yard in which trains are placed waiting departure.

diameter breast height - the diameter of a tree at 1.4m (approximately 4.5 feet) above ground level. It is abbreviated DBH.

drainage - the process of removing surface water or ground water by artificial or natural means.

engine yards or terminals - an area containing all the tracks, buildings, structures, and facilities necessary for the maintenance, care, and storage of locomotives and for providing them with all needed supplies such as fuel, water, sand and oil.

estuary - the portion of a stream valley influenced by the tide of the body of water into which it flows.

evergreen - vegetation that retains its green foliage throughout the year.

flight line - a line drawn on a map or chart to represent the flight path which an aircraft has flown when taking a series of consecutive aerial photos.

flow - a quantity of water carried by a stream or conduit, expressed in volume per unit of time.

freight terminal - the installation and facilities for handling freight business.

fiducial marks - index marks rigidly connected with the camera lens through the camera body, which form images on the negative. These marks, when intersected by a straight line drawn between opposite fiducial marks, define the principal point of the photographic print.

fuel storage area - an accessible area, having good cover, located a safe distance from troops, aircraft, and other facilities, and used for the storage and dispensing of aviation fuels.

gradient - the longitudinal slope, obtained by dividing the difference in bed or water-surface elevations.

grasslands - regions or areas where the dominant natural vegetation consists of grass.

gravel - loose, coarse, granular material larger than sand grains, resulting from breaking down of rock.

gravity yard - a yard in which the movement of cars to different sidings for sorting is accomplished by gravity alone.

hardstand - a stabilized or surfaced area provided to support standing aircraft. Hardstands are normally dispersed at intervals along each side of a taxiway.

hectare - 10,000 square meters, or 2.47 acres.

helicopter landing pad (helipad) - a prepared area on the ground designated and used only to accommodate takeoff and landing of helicopters.

heliport - a group of facilities designed for takeoff, landing, servicing, fueling, and parking of rotary-wing aircraft.

heliport landing area - a specifically prepared surface designed for rotary-wing aircraft takeoff and landing operations. It includes the paved surface (runway or landing pad) and the areas immediately adjacent thereto that have been cleared of all above-ground obstructions.

hydrology - a science dealing with the occurrence of water on the earth; its physical and chemical properties, transformations, combinations, and movements; especially with the course of water from the time of its precipitation on land until its discharge into the sea or return to the atmosphere.

index contour - contour line shown more prominently than the adjacent ones, usually every fifth one.

inland waterways - rivers, canals, lakes, and inland seas that are used as avenues of transport.

intermittent stream - a stream that flows only seasonally; one that has not cut its valley below the water table.

key terrain - any area whose seizure or control affords a marked advantage to either opposing force.

landform - the physical expression of the land surface.

lateral safety zone - an area (transitional surface) located between the runway clear area of runway edge when no clear area is provided and the clearance lines limiting the placement of building construction and other obstacles with respect to the runway centerline. The slope of the transitional surface is 7:1 outward and upward at right angles to the runway centerline.

levee - an embankment along a stream or other water body, built for the purpose of limiting floods.

line of sight - intervisibility between two points located on the earth's surface.

lines of communication - all routes--land, water, and air--that can be used by military forces in an area of operations.

local relief - the difference in elevation of the land surface.

lock - an enclosure in a canal or river with gates at each end, used in raising or lowering boats as they pass from level to level.

marsh - a tract of spongy, wet, or water-covered treeless ground usually covered by grasses, cattails, or similar vegetation.

observation - ability of force to exercise surveillance over a given area through the use of personnel or sensors.

obstacle - any object that stops, delays, or diverts movement.

outcrop - any exposure of bedrock.

overrun - a graded and compacted portion of the clear zone, located at the extension of each end of the runway to minimize risk of accident to aircraft due to overrun on takeoff or undershooting on landing. Its length is normally equal to that of the clear zone and its width is equal to that of the runway and shoulders.

parallax - the apparent displacement of the position of a feature with respect to a reference point or system caused by a shift in the point of observation.

passenger terminal - the installation and facilities for handling waiting passengers.

permeability - a rock's capacity for transmitting fluids.

photo base - the straight-line distance between the two principal points of two consecutive serial photographs.

planimeter - an instrument for measuring the area of any plane figure by passing a tracer around the boundary line.

pollution - impairment of the quality of water by biological, chemical, physical, and radioactive substances to a degree which may not create an actual hazard to public health but which does adversely and unreasonably affect such water for some beneficial uses; almost any substance becomes a pollutant if concentrated sufficiently.

pond - a small area of still water, usually artificial.

porosity - a measure of the proportion of a material consisting of pore space or voids.

profile - the bottom or water surface elevation of a stream plotted against distance.

relief - the irregularities of a land surface.

representative fraction - the ration between map or photo distance and ground distance expressed as a fraction in the same units.

reservoir - an area of water storage often artificially created by building a dam at a suitable retaining point across a watercourse.

revetment - usually a mound or wall of earth, masonry, timber, sandbags, or other suitable material erected as a protection for aircraft against small arms or artillery fire, bomb splinters, or blast.

road, access - a two-way road, normally improved, connecting the air base or airfield with the existing road system of the vicinity.

road, service - a road connecting the access road and the bomb and fuel storage areas with all hardstands and aprons for the purposes of refueling, rearming, and servicing aircraft.

running track - a track reserved for movement through a yard. Running tracks are provided for movement in either direction to enable yard engines to pass freely from one part of the yard to another.

runoff - that portion of the precipitation that is transmitted through natural surface channels; the residual of rainfall after the deduction of losses.

runway - a stabilized or surfaced rectangular area located along the centerline of the flightstrip on which aircraft normally land and take off.

sand - individual rock or mineral particles having diameters ranging from 0.5 to 2.0 millimeters.

sandstone - a sedimentary rock composed of sand-sized grains of minerals and rock fragments cemented together.

scale - the ratio between the distance on a map or photo and the corresponding distance on the ground.

sedimentation - the process by which mineral and organic matter are deposited to make sediments.

shoulder - a graded and compacted area on either side of the runway to minimize the risk of accident to aircraft running off or landing off the runway.

shrub - a low plant (not more than 5 meters high) with woody stems branching near the base.

siding - a short track connected to the main track by a switch and used for unloading, bypassing, and so forth.

silt - individual mineral particles of soil that range in size between clay and sand (0.002 m to 0.5 millimeters in diameter).

single track - a main track upon which trains are operated in both directions.

species - a kind of plant that can be distinguished from all others on the basis of inherited characteristics.

spring - a natural flow of water from the earth's surface occurring where the water table intersects the course.

sour track - a track of indefinite length diverging from a main line or track.

stand - an aggregation of trees, standing in a definite limited area.

stand density - density of stocking expressed in number of trees per hectare.

station - a place designated by name on the timetable at which a train may stop for traffic, enter or leave the main tracks, or from which fixed signals are operated.

stereoscope - a binocular instrument used for viewing in three-dimensional expressions.

storage yard - a yard in which cars are held awaiting disposition.

stream - a general term for a body of flowing water. The term is usually applied to water flowing in a natural surface channel; but it may also be applied to water flowing in an open or closed conduit and to a jet of water issuing from an opening.

swamp - a tract of wet or water-covered ground overgrown with trees and shrubs.

switch engine - an engine assigned to yard service and working within yard limits.

synthesis - the combining of elements of diverse material into a single or unified product.

takeoff ground run - the distance traveled by an aircraft along the runway before becoming airborne.

taxiway - a prepared strip for the passage of aircraft on the ground to and from the runway and parking areas. The width of the taxiway includes a stabilized, surfaced, or paved central strip.

texture - the frequency of change and arrangement of photographic tones.

touchdown area - that portion of the beginning of the runway normally used by aircraft for primary contact of wheels on landing.

tree - a woody, perennial plant with a single main stem more than 5 meters tall,

tributary - a surface or underground stream which contributes its water, either continuously or intermittently, to another and larger stream.

turbidity - the approximate amount of suspended matter in water, expressed in parts per million.

water body - an inland body of water which may or may not have a current or single direction of flow, such as a lake, reservoir, or pond.

water table - the upper surface of the zone of saturation.

watershed - the entire region that contributes water to a river or lake. Also called a drainage basin, river basin, or catchment area.

well - a deep hole or shaft sunk into the earth to tap an underground supply of water.

yard - a system of tracks provided for making up trains, storing cars, or for maintaining or repairing cars.

zone of entry - any area in which personnel, supplies, or equipment can be placed within reach of a military objective.

References

REQUIRED PUBLICATIONS

Required publications are sources which users must read to understand or to comply with FM 5-33.

Army Regulations (ARs)

- 115-10 Meteorological Support for the US Army
- 115-12 US Army Requirements for Weather Service Support

Field Manuals (FMs)

- 5-36 Route Reconnaissance and Classification
- 5-530 Materials Testing
- 90-4 Air Assault Operators
- 90-10 Military Operations on Urbanized Terrain (MOUT)
- 100-27 US Army/US Air Force Doctrine for Joint Airborne and Tactical Airlift Operations

DA Forms

- 1249 Bridge Reconnaissance Report
- 1250 Tunnel Reconnaissance Report
- 1252 Ferry Reconnaissance Report
- 2028 Recommended Changes to Publications and Blank Forms

RELATED PUBLICATIONS

Related publications are sources of additional information. They are not required to understand FM 5-33.

Army Regulations (ARs)

115-1 Point Weather Warning Dissemination

Defense Mapping Agency (DMA) Publications

150 World Port Index

Field Manuals (FMs)

21-26 Map Reading and Land Navigation

101-5 Staff Organization and Operations

Technical Manuals (TMs)

5-312 Military Fixed Bridges

5-330 Planning and Design of Roads, Air Bases, and Heliports in the Theater of Operations

5-6675-324-14 Operator's Organizational Direct Support and General Support Maintenance Manual for Topographic Support System Information Section

5-6675-325-14 Operator's Organizational Direct Support and General Support Maintenance Manual for Topographic Support System Synthesis Section

5-6675-326-14 Operator's Organizational Direct Support and General Support Maintenance Manual for Topographic Support System Direct Support Section

PROJECTED PUBLICATIONS

Projected publications are sources of additional information that are scheduled for printing but are not yet available. Upon print, they will be distributed automatically via pinpoint distribution. They may not be obtained from the US Army AG Publications Center until indexed in DA Pamphlet 25-30.

FM 5-312 Nonstandard Fixed Bridging

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Photo Point Monitoring Handbook:

Part A—Field Procedures

Frederick C. Hall



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Photo Point Monitoring Handbook:

Part A—Field Procedures

Frederick C. Hall

Part A contains pages 1–48

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Abstract

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This handbook describes quick, effective methods for documenting change in vegetation and soil through repeat photography. It is published in two parts: field procedures in part A and concepts and office analysis in part B. Topics may be effects of logging, change in wildlife habitat, livestock grazing impacts, or stream channel reaction to land management. Land managers, foresters, ranchers, wildlife biologists, and land owners may find this monitoring system useful. Part A discusses three critical elements: (1) maps to find the sampling location and maps of the photo monitoring layout; (2) documentation of the monitoring system to include purpose, camera and film, weather, season, sampling system, and equipment; and (3) precise replication in the repeat photography.

Keywords: Monitoring, photography.

Preface

This handbook is a synopsis of repeat photography principles and photo point sampling from the publication *Ground Based Photographic Monitoring*, PNW-GTR-503, which is based on 45 years of experience in repeat photography by the author. During those years, many nuances were discovered that bear discussion and emphasis so that new users can avoid the pitfalls I ran into. The terms *should*, *must*, *do not*, and *will* are used to help users avoid problems and are not meant as rules.

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Introduction

Anyone interested in quick and effective documentation of change in vegetation or soil through repeat photography will find this handbook useful. Illustrations cover such topics as streamside changes, riparian willow response to beavers, logging, livestock use, and mountain pine beetle (*Dendroctonus ponderosa*) kill of lodgepole pine (*Pinus contorta* var. *latifolia* Englm.). People, such as foresters, ranchers, wildlife biologists, and nature enthusiasts, interested in natural resources can establish photo point monitoring (discussed here) to appraise changes (see part B) in natural resources. No special skill or training is required other than some knowledge of cameras.

There is one essential criteria if repeat photography is used to document change. Distance from camera to photo point **must** remain the same (part B). For this reason, both the camera location and photo point require permanent markers. The system recommended is use of cheap fenceposts or steel stakes, usually ½ inch (1.2 cm) diameter concrete reinforcing bar.

This field procedure handbook is divided into several parts: basic foundations for photo monitoring, with discussions on objectives, selecting an area, techniques for general photography, procedures for specific topic pictures, shrub profile monitoring, and tree cover sampling. Use of forms in part B are illustrated.

Basics

The primary consideration in photo monitoring is an objective. Ask yourself several questions: What is the topic of this photograph? Why do I want to take this picture? What am I trying to show? What appeals to me? What will the picture demonstrate? (Hedgecoe 1994, Johnson 1991).

Photo Monitoring Objectives

Consider the five basic questions for any inquiry: why, where, what, when, and how (Borman 1995, Nader and others 1995).

Why—“Why” to monitor reveals the question or questions needing to be answered. Implementation monitoring asks **if** we did what we said, effectiveness asks if it **did** what we wanted, and validation asks if it **is** meeting the objectives. The “why” question

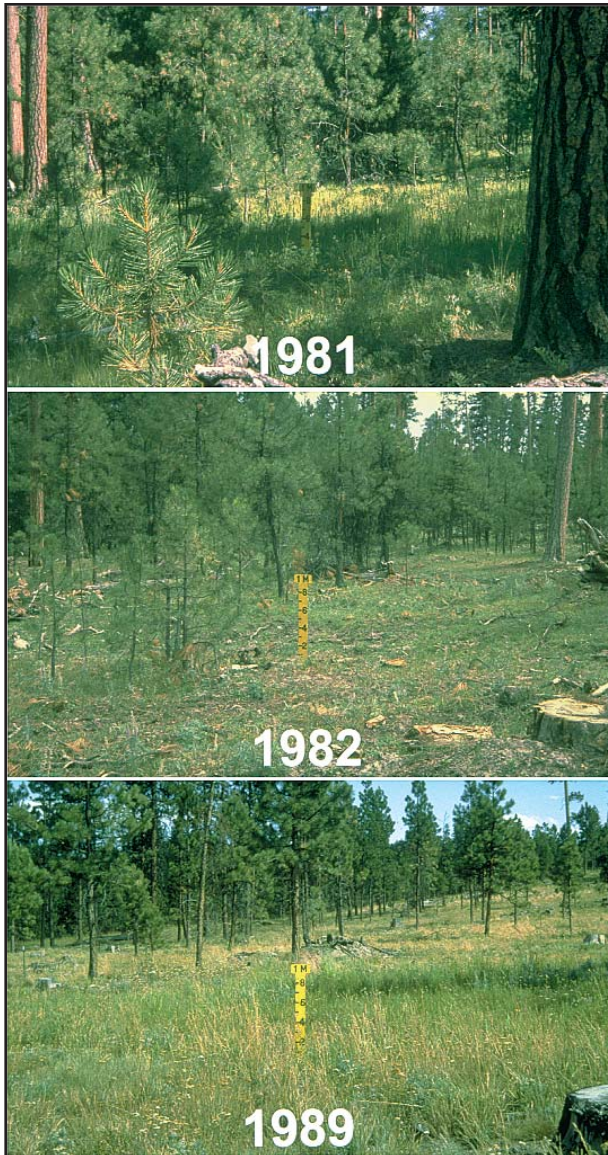


Figure 1—A ponderosa pine stand with pinegrass ground vegetation showing effects of logging: undisturbed in 1981, 1982 after the first selection cut, and in 1989 after the second selection cut and precommercial thinning. These views, with their dramatic differences, emphasize the need for permanent marking of both camera locations and photo points. Exact picture reorientation uses the “1M” of the meter board as the photographic center (also see fig. 18) and for focusing the camera for best depth of field at the meter board.

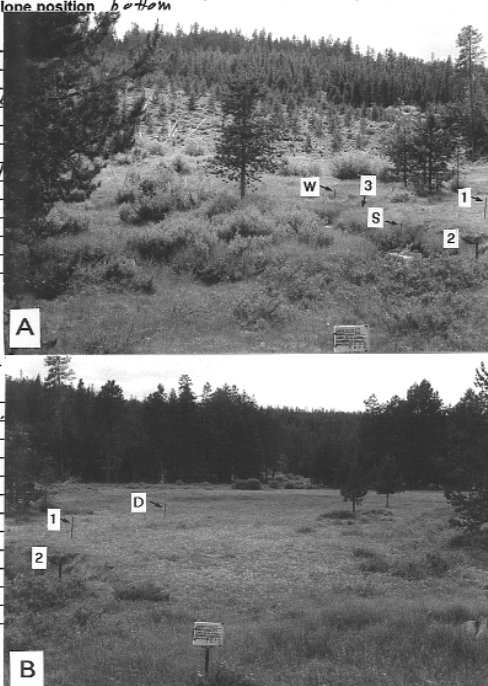
CAMERA LOCATION AND PHOTO POINTS			
Date	1997/6/17		
Area	Snow Mtn. Dist.	Camera Location	Witness Stump
Unit	Pole Camp	Number of Photo points:	2
Comments	From rd June, 43/4365, on rd 43 for 0.25 mi W. to turnout on S. side road; witness stump 22 nd LP 20 yds. S slope 1 Aspect W Slope position bottom		
Photo point A	_____		
Compass bearing:	237°M		
Distance:	_____		
Flood plain, left view of Pole Camp study site, Mt. pine beetle killed LP stand in background 1, 2, 3 are camera locations; S & W are photo points			
Photo point B: _____			
Compass bearing: 270°M			
Distance: _____			
Flood plain, right view of Pole Camp study site. 1 & 2 are camera locations, D is dry meadow photo point.			
			

Figure 2—Filing system form “Camera Location and Photo Points” showing general photographs of Pole Camp taken from the witness stump: (A) the left landscape, and (B) the right landscape diagramed in figure 6. Note repeat of fenceposts 1 and 2 in both pictures. Fenceposts identify camera locations 1, 2 and 3 and photo points “D” for the dry meadow, “W” for the wet meadow, and “S” for the streambank. Photo identification cards similar to figure 10, a form from part B, appendix A, are at the bottom of each picture. The purpose of these photographs is twofold: to illustrate the general sampling area and to show location of the photo monitoring layout. Used in conjunction with the map in figure 6, someone other than the original sampling crew could find and rephotograph this site.

sets the stage for all other discussion. Is a proposed treatment to be monitored (fig. 1)? Is animal distribution to be appraised? Are things changing as a result of management decisions (Borman 1995, Nader and others 1995)?

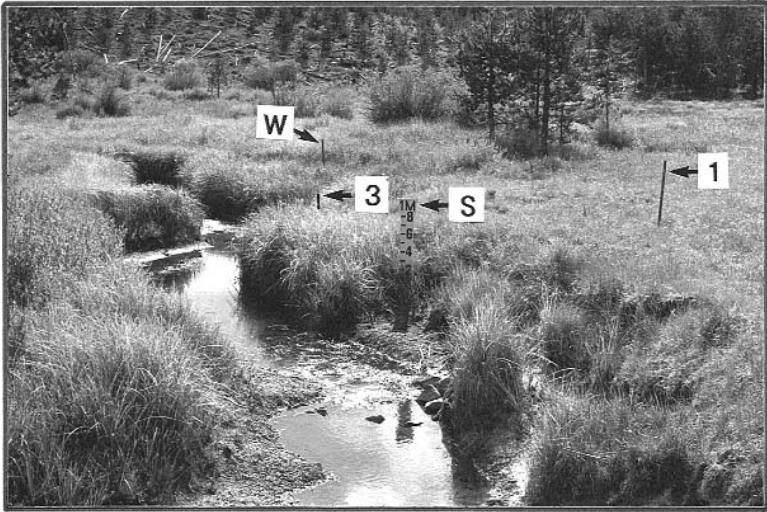


Figure 3—A general photograph taken in 1997 at Pole Camp; the topic is streambank stability. This streambank photo point is taken upstream from camera location 2 (shown in fig. 2 and on the map in fig. 6). Fencepost 1 is camera location 1, fencepost 3 is camera location 3 looking downstream at photo point “S,” “S” is the photo point for the streambank, and fencepost “W” is the photo point for the wet meadow.

Where—“Where” to monitor depends on the “why.” How does one select representative tracts, animal activity areas, treatment sites, or particular kinds of treatments? How are number, size, and location of activities, such as fire, logging, revegetation, livestock grazing or flood, selected? Ask yourself, “Where is the best location that will answer my questions (fig. 2; Borman 1995, Nader and others 1995)?” Critical documents are a map to locate the site and a site map to document all camera locations and photo points.

What—“What” to monitor means selecting specific items (topics) on the tract to support the “why” questions: vegetation, soil, streambanks (fig. 3), or animals. Ask yourself, “What are the critical few items that must be documented? What is expected to change? What will the picture demonstrate (Borman 1995, Johnson 1991, Nader and others 1995)?” The “what” dictates the sampling layout.

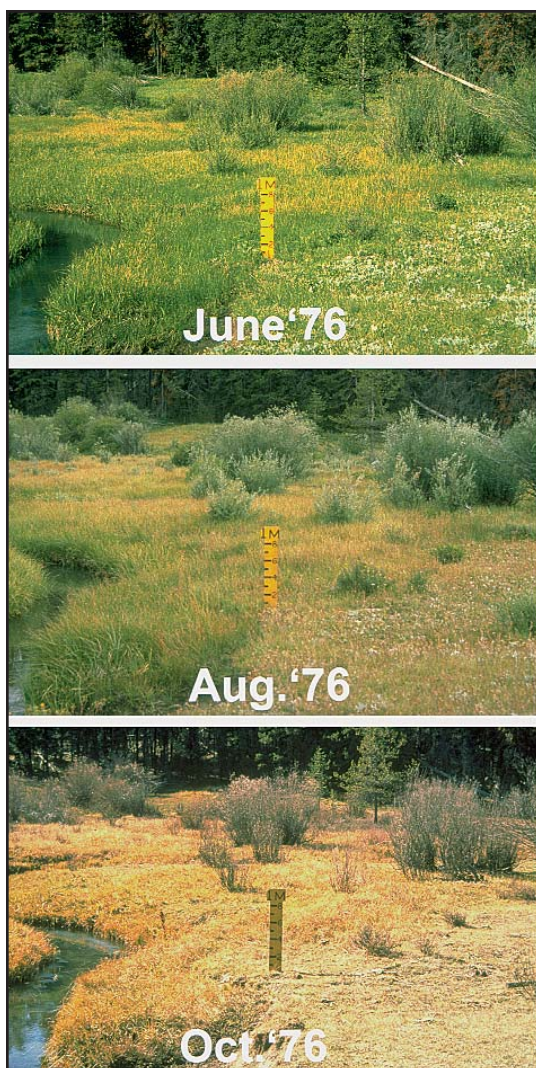


Figure 4—Pole Camp “W” (wet meadow) photo point showing three dates of the same year. June 15 is before scheduled grazing, August 1 is at change in rotation pastures, and October 1 is after grazing. This pasture was rested from June 15 to August 1. October 1 illustrates the degree of livestock use on Kentucky bluegrass at the meter board, on aquatic sedge behind the board, and on willows.

When—“When” to monitor supports the “why” and “what” questions. Does it encompass a year or years? one or more times a year (fig. 4)? specific dates? specific time(s) of day (Borman 1995, Nader and others 1995)? All are important with both animal and site monitoring. Scheduling when to photograph deals with before and after treatment and how often thereafter. Unplanned disturbances, such as fire or flood, pose special problems. A monitoring protocol may have to be developed on the spot during an event to establish photo points and define a followup schedule.

How—“How” to monitor is determined by “what” as influenced by “why” and “when.” It may encompass detailed protocols for photographic procedures, which may be to obtain either qualitative data (estimates) or quantitative data (measured in the field or measured from photographs).

A simple question might deal with effects of livestock grazing on a riparian area: (1) Are streambanks being broken down? (2) Are riparian shrubs able to grow in both height and crown spread? (3) Is there enough herbage remaining after grazing to trap sediments from flooding? (4) Is herbaceous vegetation stable, improving, or deteriorating?

These questions require selection of a sampling location, placement of enough photo points to answer each of the four questions, and establishment of camera locations to adequately photograph each photo point. Try to select camera locations that will photograph more than one photo point. Next, time or times of year to do the photography must be specified, such as just prior to animal use of the area, just after they leave, or fall vegetation conditions. Will a riparian site be monitored for high spring runoff? late season low flows? or during floods? Monitoring of stream flows vs. animal use probably will require different scheduling.

Recommendation—Write down the specific objectives and protocols for each photo monitoring project. Write them so that someone other than the installer can understand the purpose, can follow the protocols, and can become enthusiastic about the project.

Selecting an Area

Selection of a monitoring area requires a great deal of professional expertise liberally mixed with artistic finesse. The **purpose** for photographic monitoring is the most critical factor in considering where to monitor (Borman 1995, Nader and others 1995): Where in the landscape is my topic of concern, and once at the area, what kind of change do I want to document? In some cases, "where" is straight forward; for example, documentation of logging impacts requires an area being logged (fig. 1), and effects of beavers on a stream requires beaver dams. On the other hand, documentation of impacts from livestock grazing requires understanding livestock distribution plus knowing the location of areas sensitive to grazing and the most critical season of use.

Once in an area, the real decisions must be made. Determine specifically what to monitor for change. Figure 2 shows two general views of Pole Camp in northeast Oregon where some examples of photo monitoring are located. The purpose was to document effects on a riparian area from livestock grazing. Pole Camp was selected because it was preferred by livestock. Specific objectives were to evaluate grazing effects on streambanks (fig. 3); willow (*Salix* spp.) shrub utilization (fig. 3); differences in use between Kentucky bluegrass (*Poa pratensis* L.) by the fencepost on the right (1) and aquatic sedge (*Carex aquatilis* Wahlenb.) at the fencepost in the left background (W). The topic in figure 3 is streambank stability.

Figure 1 is a different situation. The purpose for photo sampling was to document effects of a two-stage overstory removal and subsequent precommercial thinning on stand structure and ground vegetation. The sale area determined the site. Stand conditions of open ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and clumped reproduction across an opening were chosen for the photo point. The opening was selected to avoid tree crown encroachment between the camera location and photo point and to appraise logging effects on livestock forage. It was photographed before and after each entry to log.

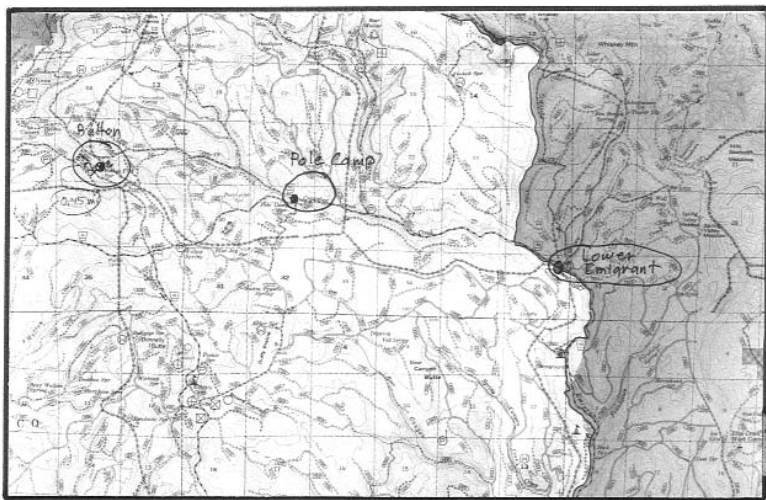


Figure 5—USDA Forest Service ranger district map showing location of the Button Meadow, Pole Camp, and Lower Emigrant riparian study sites. Road numbers, mileage from road junctions, and directions to the witness sites are given on the filing system form “Photographic Site Description and Location” (fig. 6).

After appraising the area, establish the photo monitoring system as discussed below in “General Photography” and “Topic Photography.” The sampling layout must be mapped as described next.

Locating the Monitoring System

Assume that the person installing the monitoring program will **not** be the one to find and rephotograph the area. Provide maps and instructions accordingly. A local map showing roads and the site locates Pole Camp, one of three locations for the Emigrant Creek riparian study (fig. 5).

After laying out the photography system, select a witness site to mark the area. Identify it with a permanent marker, such as an orange aluminum tag, and determine direction and measured distance to camera locations, photo points, or both. Inscribe these on the identification tag. Next map the camera locations and photo points with directions and measured distances on the filing system form “Photographic Site Description and Location” (fig. 6), found in part B, appendix A. Note whether the direction

PHOTOGRAPHIC SITE DESCRIPTION AND LOCATION

Date 1974/10/5 Area Snow Mtn. Dist
 Unit Pole Camp Observer: F. C. Hall
 No. of Camera locations: 5 No. of Photo points: 4
 Plant community Dry & wet meadow; willows
 Location: T.19S R.27E Sec. 29 SW of NE
 Location description: 5 of rd 43; 0.25 mi. W of junc. 43 & 4365 rds
off of turnout at E end of meadow
 Photo purpose: Document effects of change from season-long cattle
use to 3-pasture rest. rotation
 Discussion: Three photo points established in Oct 1974 documented
dry meadow (D), wet meadow with willows (W) and a falling block of
rock at the stream edge (S) (1997) Flood at 2/96, washed out beaver
dams & created a new channel. Shrub sampling initiated 6/97.

MAP

Use back of sheet for additional details.

Figure 6—Filing system form "Photographic Site Description and Location" showing the monitoring layout for Pole Camp. In the lower left corner is a reference to the junction of roads 43 and 4365 at 0.25 mile (0.4 km). Immediately opposite the road turnout is a lodgepole pine witness stump 28 inches (71 cm) in diameter. An aluminum tag, orange for visibility, is attached to the stump with directions and distances to camera locations. An additional map, noted by the square labeled "See detail attached," is shown in figure 17. It documents triangulation of the streambank photo point "S." Another note, "Shrub transect - see attached," refers to an installation in 1997, which is shown in figures 22, 23, and 25 dealing with shrub profile photo monitoring.

is taken in magnetic or true degrees by indicating either "M" or "T." A 21-degree deviation in the Pacific Northwest must be accounted for. Measure distances between the witness site, camera locations, and photo points on the ground. Do not attempt conversion to horizontal distance.

Fenceposts or stakes—Monitoring, by definition, means repeated observation; therefore, all camera locations and photo points must be permanently marked. The recommended method is stamped metal fenceposts shown in figures 2 and 3. In 2000, these cost about \$2.75 each for a 5-foot (1.5-m) post. Stamped metal has several advantages over strong T-bar posts: they are flimsy and will bend if driven over by a vehicle or run into by an animal; they will bend flat and remain in the ground to mark the spot; they resist theft because they are just as difficult to pull out as a good fencepost but are not worth the trouble; and they are easy to carry and pound. The primary advantage of flimsy fenceposts is their visibility, as seen in figures 2 and 3. If visibility is not desired, steel rebar stakes are a choice but require a metal detector for relocation (White's Electronics, Inc. 1996).

Steel stakes, preferably concrete reinforcing bar (rebar) have been used and may be required for shallow soils, areas that will be disturbed, or locations where fenceposts may be obtrusive. If disturbance or shallow soils prevents the use of fenceposts, stakes should be driven flush with the ground. If left a few inches above the ground, stakes will damage tires, hooves, or feet. They are always difficult to find. When driven flush with the ground, they require a metal detector for relocation (White's Electronics, Inc. 1996), but even then, the stakes must be of some mass for detection with a simple, \$250 machine. Angle iron should be 1 inch (2.5 cm) on the angle and at least 12 inches (30 cm) long. Cement reinforcing bar should be at least $\frac{3}{8}$ inch (1 cm) in diameter and at least 12 inches (30 cm) long. Shorter lengths may be needed for shallow soils.

Distance from camera to photo point—One overriding consideration in photo monitoring is to use the same distance between the camera location and photo point for all subsequent photography of that sample. Any analysis of change depicted in the photographs can be made **only** when the distance remains the same (part B). Therefore, always **measure** the distance from camera location to photo point and mark with steel fenceposts or stakes.

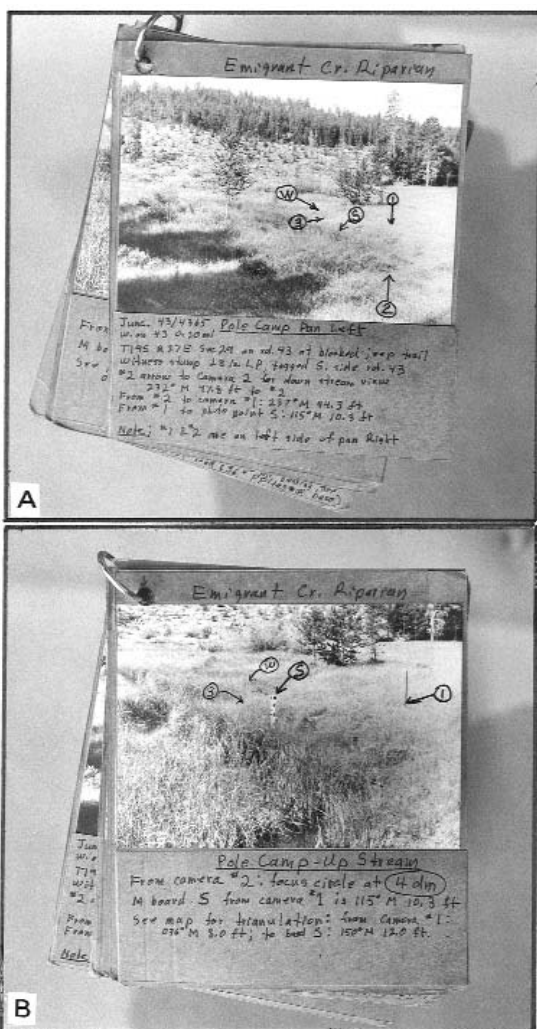


Figure 7—A site locator fieldbook is my system for finding camera locations and photo points. It is a pocket-sized set of photographs and directions mounted on cardboard (file separator thickness). (A) The left landscape view of the sampling area at Pole Camp shown in figure 2. (A) also locates camera locations 1, 2, and 3. Camera location 1 has two photo points: "D" is Pole Camp dry meadow and "W" is Pole Camp wet meadow (figs. 2 and 6). (B) The upstream photo point taken from camera location (2) to "S" (illustrated in fig. 3). A map of this area is shown in figure 6.

A fixed distance for all photo monitoring is not required. It may differ from one photo point to another. Camera format also may change, such as first pictures with a 50mm lens and next pictures with a 35mm lens, but distance must remain the same. It can remain the same in repeat photography only if permanently marked.

Site locator fieldbook—A photo monitoring fieldbook is recommended for carrying the original photos and some intervening photographs into the field (fig. 7). If previous photographs were done by different people, you may discover some disorientation of subsequent views. For that reason, a copy of the original photograph is very important. Rephotograph from the original and not from any misoriented intervening views.

My system for Pole Camp is depicted in figure 7. Figure 7A is a landscape view of the Pole Camp flood plain from the witness site that identifies camera locations and some photo points. It locates the left of two flood-plain scenes, both shown in figure 2 (and mapped in fig. 6). Figure 7B is a view from camera location 2 to photo point “S” on the streambank, the scene in figure 3.

The pocket-size booklet has a picture from each witness site to each camera location and photo point and includes directions from the witness site to camera location and orientation of the photo point.

Once at the area, review the photographs for changes in vegetation. Next, note the number of years since the last photograph, particularly if it was taken more than 3 years previous. The purpose is to evaluate change in the vegetation that might make previous photographs difficult to interpret (fig.1).

Relocating Photo Points

If camera locations and photo points were not marked, they may be approximated by the following triangulation procedure. Align items in the original photograph as shown in figure 8A. Start in the center of the photograph to orient the direction of the picture and draw line 1 on the photo, the photo point direction. Then, for

Text continues on page 15.

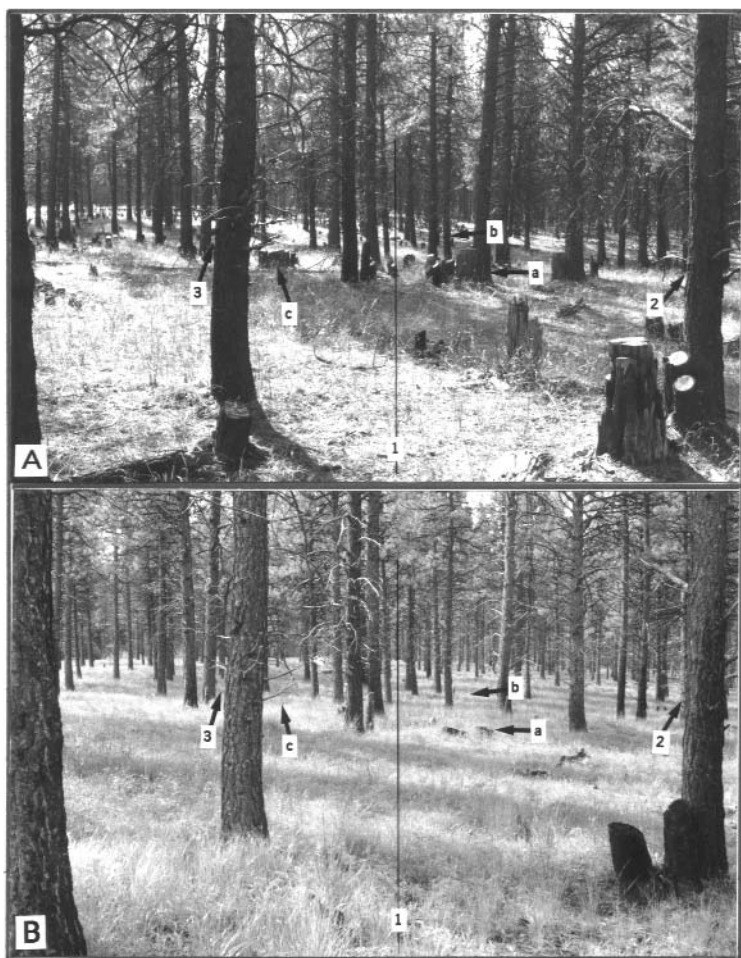


Figure 8—Photograph reorientation uses a black-and-white photo on which a triangulation system is diagrammed. A center line (1) is established on the original photograph (A) for direction. The center line is identified by position of trees in the background and framing the picture with trees in the foreground. Then positions of items 2 and 3 at the sides of the picture are used to triangulate the camera location. Looking to the right, note the position of trees at arrow 2 while also looking left for tree positions at arrow 3. For (B), the photographer moves forward and backward along the center line until items at arrow 2 and arrow 3 are aligned. Try to include some unusual object in the photograph, such as the pair of stumps in the lower right corner. Photograph (A) is preunderburn condition and (B) is postburn and salvage of killed trees. In (B), note the missing trees at arrows “a” and “b,” and a burned-out stump at arrow “c.”

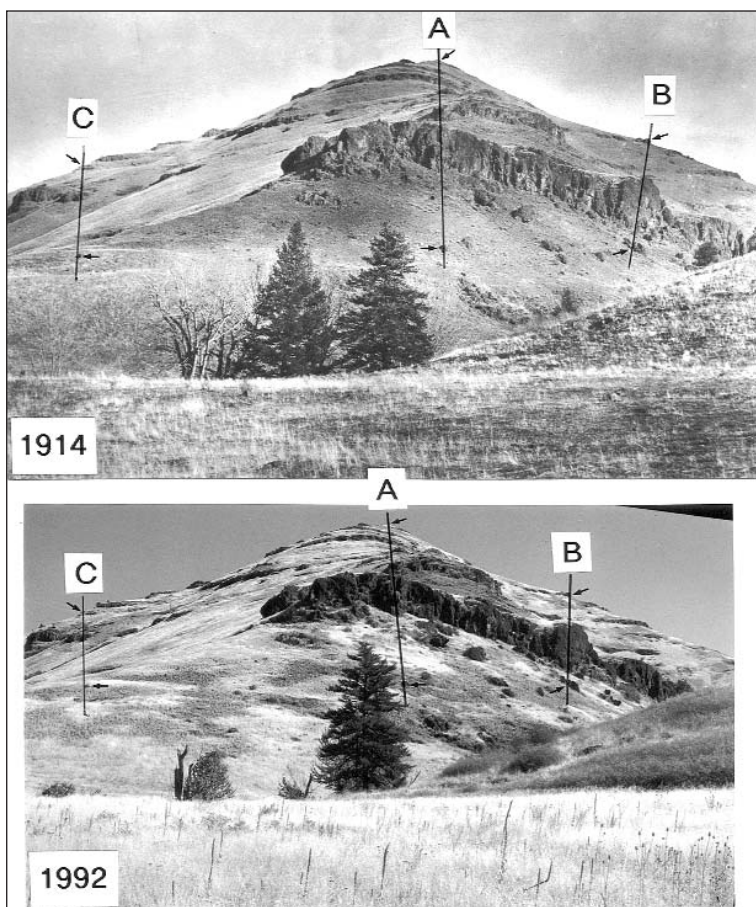


Figure 9—Relocation of a historical photograph taken in 1914 of Branson Creek, Wallowa County, Oregon. Skovlin and Thomas (1995, p. 22-23) took the bottom view in 1992. On a copy of the original (1914) photo, mark orientation lines. "A" identifies the centerline orientation. Then choose objects on the edges of the picture, such as "B" and "C," to triangulate location of the original camera. Once centered on the original photograph, move forward or backward until the angles of B and C are similar to the original photograph. Slight differences in orientation lines between 1914 and 1992 suggest that in 1992, the camera was a few yards left of the original location. The usefulness of black-and-white photographs is illustrated here by being able to draw triangulation lines directly on a copy of the 1914 picture.

the camera location, find items on the sides of the picture, shown by arrows 2 and 3, to triangulate the location. The items are distances between trees. Move forward or backward along line 1 (fig. 8B) to repeat the distances shown at 2 and 3. This is the camera location and photo point direction. Mark the camera location with a fencepost and add a meter board (photo point) location 25 to 35 feet (8 to 10 m) distant.

Figure 9 applies this triangulation concept to relocation of landscape photographs.

If major vegetation manipulation has occurred as shown in figure 1, relocation may be very difficult.

When to Photograph

When to photograph is usually determined by the activity being monitored. Pole Camp, for example, is part of a study evaluating effects of cattle grazing on a riparian area. Figure 3 illustrates one topic of concern, streambank stability. Photographs have been taken three times per year to correspond with livestock activity: June 15 just before grazing, August 1 as cattle change pastures, and October 1 after animals leave the allotment (fig. 4). This three-season monitoring is repeated every year.

Figure 1 illustrates a very different monitoring schedule. Photographs were planned for the first week in August as an index to appraise vegetation development. They were taken just before logging and in each of the two seasons after cutting to document rapid changes in ground vegetation. Then a 5-year rephotography cycle was established to follow slower changes in both stand structure and ground vegetation. The routine was repeated with the second logging and the precommercial thinning.

If vegetation is a primary topic, consider establishing a fixed date or dates for rephotography. Established dates have several advantages: (1) they set a consistent reference point to evaluate seasonal differences in plant phenological development, (2) they provide a consistent reference for comparing change over several years, and (3) they establish a consistent time interval over which change is documented.

Text continues on page 18.

DATE _____

AREA _____

UNIT _____

CAMERA: 1 2 3 4 5

PHOTO: A B C D

E F G H I J

Figure 10—An example of a photograph identification card to be placed in the camera view (fig. 2). This has been reduced to 60 percent of its original size. Part B, appendix A has blank forms that can be reproduced onto dark blue paper. The best paper colors are Hammermill Brite Hue Blue or Georgia Pacific Papers Hots Blue. Light colored paper, common in the office environment, bleaches out under direct sun and should not be used.

PHOTO POINTS AND CLOSE PHOTOS	
Date <u>7/7/66</u> Camera <u>Plot 226 (669)</u>	
Area <u>Snow Mtn. Dist.</u>	
Unit <u>Green Butte</u>	
Photo point: <u>A</u>	
Observer <u>E. C. Hall</u>	
Remarks <u>15 yr setback</u> <u>of ecology plot just</u> <u>prior to partial cut.</u> <u>Good range condition;</u> <u>benchmark for range</u> <u>condition guides. See</u> <u>plot 226 (669) for data.</u>	
Photo point A: Left of meter board	
Species/covers:	
<u>CAGE 60%</u> <u>PONE 15%</u> <u>CARO 5%</u>	
Comments: <u>Very good</u> <u>range condition; tight</u> <u>soil.</u>	
Photo point A: Right of meter board	
Species/covers:	
<u>CAGE 50%</u> <u>PONE 25%</u> <u>CARO 8%</u> <u>FRVI 2%</u>	
Comments: <u>Very good</u> <u>condition</u>	

Figure 11—Filing system form “Photo Points and Close Photos” documenting a ponderosa pine/elk sedge community. This area had not been previously logged and had only sporadic sheep use because water was 1.5 miles (2.4 km) distant. The general view is followed by pictures to the left and right of the meter board. The concept is to show both a general view and a pair of closeups to document change. Figure 18 illustrates what happened in this view after logging and 18 years later. Species noted are: CAGE (*Carex geyeri* Boot.), PONE (*Poa nervosa* (Hook.) Vasey), CARO (*Carex rossii* Boot.), and FRVI (*Fragaria virginiana* Duchesne).

Photograph Identification

Each photograph should be identified by site name, photograph number, and date. Figure 10 is an example for use with general or topic photographs (fig. 2). A critical factor is identifying **negatives** for color or black-and-white pictures or digital images. The borders of slides can be written on, but there is no similar place to identify negatives or digital memory card images. Placing a photo identification card in each picture assures a permanent record on the negative or image. This—negative identification—has been one of my biggest problems. Part B, appendix A, contains blank photo identification forms (“Camera-Photo” and “Shrub Photo Sampling”), which can be copied onto medium blue colored paper.

Paper color is the next consideration. Plain white or light colors, common in the office environment, are not suitable because they are too light in color and will bleach out when photographed. The recommended paper color is either Hammermill Brite Hue Blue or Georgia Pacific Papers Hots Blue (part B, app. A). Tests have shown these darker blue hues to be superior to other intense colors such as green and yellow.

Describing the Topic

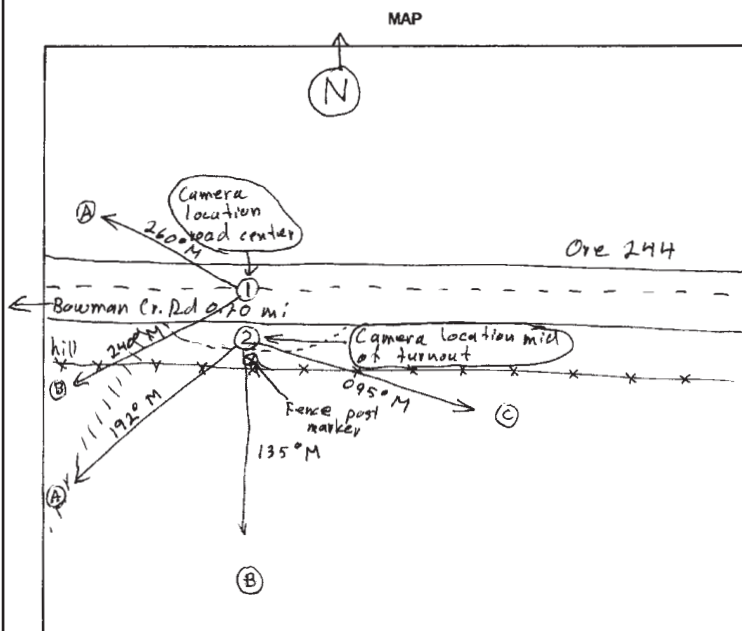
Describe what is in the photographed scene. Include plant species, ground conditions, disturbances, or any other pertinent item. Part B, appendix A, contains forms having provision for recording these notes. For example, the filing system form “Camera Location and Photo Points” is shown in figure 2 with two views of Pole Camp and brief comments about each photo. And figure 11 is the “Photo Points and Close Photos” form for a general view and two closeup photographs of a ponderosa pine/elk sedge (*Carex geyeri* Boot.) plant community in undisturbed condition. Canopy cover estimates of dominant species are recorded in each closeup photo. Other topic description forms are discussed below in “Shrub Profile Photo Monitoring” and “Tree Cover Sampling.” The forms are available in part B, appendix A.

General Photography

General photographs document a scene rather than a specific topic marked by a meter board. They are similar to landscape pictures in that they may not contain a size control board (meter

PHOTOGRAPHIC SITE DESCRIPTION AND LOCATION

Date Aug 1976 Area Camas Cr. Meadows
 Unit Ukiah District Observer: F.C. Hall
 Number of photo points 5 Plant community: lodgepole pine
 Location: T. 45 R. 33 E. Sec. 35 9W of 5W
 Location description On Ore. highway 244 between mile posts 15
8.16 & 0.20 mi. east of junc. with Bowman Cr. Rd.
 Photo purpose: Document effects of Mt. pine beetle
attack on bottomland climax lodgepole pine
 Discussion Some beetles noticed in 1975; this year major
kill (70%) of dominant lodgepole - needles red. Follow
for each year for 3 yrs, then about 5 yr. intervals.



Use back of sheet for additional details.

Figure 12—Filing system form "Photographic Site Description and Location" with a map to locate camera locations and photo points to document the affects of mountain pine beetle on lodgepole pine. Two camera locations are shown. Figures 13 to 15 are from camera location 1 and show photo points 1A and 1B.

board) on which to focus the camera and orient subsequent photographs. A photo usually covers an area of 2 to 20 acres (0.8 to 8 ha) and distances of 50 to 200 yards (40 to 180 m) (figs. 12 to 15).

CAMERA LOCATION AND PHOTO POINTS	
Date <u>7/7/82</u>	Camera Location <u>Orc 244, Series 1</u>
Area <u>Camas Cr. Meadow</u>	Number of Photo points: <u>5</u>
Unit <u>Ukr. Dist</u>	Observer <u>JEV</u>
Comments <u>LD 70% with white needles, many shed; 20% red needles. 5 stands 90% dead - all larger trees; mtn. pine beetle</u>	
Slope <u>10</u>	Aspect <u>E</u> Slope position <u>Top</u>
Photo point A: Compass bearing: <u>260°M</u> Distance: <u>—</u> <u>Camera located on</u> <u>Orc 244 centerline</u> <u>massive lodgepole</u> <u>kill</u>	
	
Photo point B: Compass bearing: <u>240°M</u> Distance: <u>—</u> <u>Camera on Orc 244</u> <u>centerline</u>	
	

Figure 13—Filing system form “Camera Location and Photo Points” documenting stand conditions in 1977, one year after mountain pine beetle attack on lodgepole pine. The needle color on trees killed in the first year changed from green to dark red (not visible here). Compare to figures 14 and 15. Photo orientation used the road center line.

Concept

In many cases, general photographs document a scene in which a meter board cannot be placed to orient and focus the camera. One use of general photographs is shown in figure 2. Filing system form “Camera Location and Photo Points” is used in two pictures of Pole Camp where fenceposts marking camera locations and photo points may be identified. Another use is illustrated in figures 13 to 15, which document effects of mountain pine beetle attacks on lodgepole pine.

CAMERA LOCATION AND PHOTO POINTS			
Area	Camas Cr. meadow	Date	7/8/87
Unit	Utah Dist.	Camera Location	Ore 244, Series 1
Comments	Longleaf needles gray & shed; few green trees are mostly less than 3" dbh.	Number of Photo points:	5
Slope	10	Aspect	E
		Slope position	Top
Photo point A: Compass bearing: 260°M Distance: — 90% of dominant & codominant trees with gray or shed needles			
			
Photo point B: Compass bearing: 240°M Distance: — Salvage logged units of '77-78. Screen of dead trees retained			
			

Figure 14—Stand conditions in 1978, 2 years after beetle attack in 1976. Photo point "A" has 90 percent kill and massive standing dead fuel. Photo point "B" was salvaged the winter of 1977-78.

Equipment

The following equipment is needed:

1. Camera or cameras for different film, or digital camera.
2. Photograph identification form "Camera-Photo" from part B, appendix A (fig. 10).
3. Clipboard and its support for holding the photo identification sheets (part B, app. B).
4. Compass and 100-foot (30-m) measuring tape.
5. Previous photographs for orientation of the camera.

CAMERA LOCATION AND PHOTO POINTS			
Date	9/18/5	Camera Location	Ore 244 Series 1
Area	Camas Cr. meadow	Number of Photo points:	5
Unit	Ukiah Dist	Observer	et al
Comments Lodgepole regeneration growing well.			
Slope	10	Aspect	5
Slope position		Top	
Photo point A:			
Compass bearing: 260°M			
Distance: —			
70% of lodgepole			
down by 5th year			
after beetle kill			
A			
Photo point B:			
Compass bearing: 240°M			
Distance: —			
70% of trees in			
screen down after			
5 yrs. salvaged area			
well stocked (not			
planted) and growing			
well			
B			

Figure 15—Stand conditions in 1991, 14 years after beetle attack and 13 growing seasons since figure 13. Photo point "A" shows most dominant trees are down, which creates severe burn conditions at ground level. Photo point "B" illustrates natural regeneration height growth. Orientation of repeat general photography without a meter board requires skill and a set of orientation pictures similar to those in figure 7.

- Filing system forms "Photographic Site Description and Location" (figs. 6 and 12) and "Camera Location and Photo Points" (figs. 2 and 13-15) from part B, appendix A.
- Fenceposts and steel stakes sufficient for the number of camera locations desired. Include a pounder.
- A tripod to use for camera reorientation.

Technique

Select a scene that will meet your monitoring objectives. Describe it, including plant species, ground cover items, disturbance, or whatever the topic of the photograph is by using the filing system form “Camera Location and Photo Points.”

Photograph the scene.

Make maps of the location and layout of the scene on the filing system form “Photographic Site Description and Location” (figs. 6 and 12). In figure 6, the two photos from figure 2 are labeled “Pan Left” and “Pan Right.”

Reorientation—Reorientation of subsequent pictures is a major concern due to lack of a meter board. Identification of key items in each view will be needed. In figure 6, for example, the tall tree in the right background of picture (A) is the same tree as in the left background of picture (B). Panoramic views, such as figure 6, always should include about 10 percent overlap between photographs.

Systems used for landscape photo reorientation (discussion at fig. 8) are of major help. On a black-and-white copy of the scene, mark reorientation items as shown in figures 8 and 9. With the camera mounted on a tripod, compare the picture in hand with the scene through the camera. Orient the camera accordingly.

Figure 7 illustrates a site locator fieldbook for rephotographing general views. It has 3- by 5-inch (7.5- by 12.5-cm) photographs mounted on 5- by 5-inch (12.5- by 12.5-cm) cardboard. Instructions are given under each picture for its location and orientation. These fit into a vest pocket for use in the field. Figure 3 is a recent picture of figure 7B.

Example—Figures 13 to 15 illustrate general photography documenting effects of mountain pine beetle on lodgepole pine along highway 244 in the Blue Mountains of eastern Oregon. Figure 12 is filing system form “Photographic Site Description and Location” mapping two camera locations. Camera location 1 has two photo points (figs. 13 to 15) and camera location 2 has three photo points. Monitoring started in 1976 when beetles first attacked the stands.

Figures 13 to 15 show the use of filing system form “Camera Location and Photo Points” to document beetle effects over a 14-year period. Figure 13 depicts second-year effects of beetle attack where trees killed the first year have started to drop their needles. Figure 14 is the third year after attack and shows massive standing fuel (14A) and salvage (14B). Figure 15, 14 years after initial attack and 13 growing seasons after figure 13, illustrates tree fall (15A) and growth of natural regeneration (15B).

Topic Photography

Topic photography narrows the subject from a general view to a specific item of interest. It adds a meter board, or other size control object, to identify the photographic topic (figs. 1, 3, 4, and 11).

Concept

We will assume monitoring objectives have been established as discussed in “Basics.” A meter board, or other size control board, is placed at the selected topic for several reasons: to (1) identify the item being monitored for change; (2) establish a camera orientation reference point for subsequent photography; (3) set up a constant size-reference by which change can be documented, for example by grid analysis; and (4) provide a point on which to focus the camera for optimum depth of field.

Figure 3 illustrates identification of a very specific topic, stream-bank stability. Figure 1 deals with a general view limited to area around the meter board; the topic is effect of logging and pre-commercial thinning on stand structure and ground vegetation. Purpose of topic monitoring is the primary factor in selecting a monitoring layout.

The effect of distance from the camera to the meter board to emphasize a topic is shown in figure 16. The topic in 16A is a transect for nested frequency, in 16B it is density of grass and big sagebrush (*Artemisia tridentata* Nutt.), and in 16C it is species density and use (none in this case). Select a camera-to-photo-point distance that best depicts what you want to emphasize. Remember that once the distance is established, it **must** remain fixed.

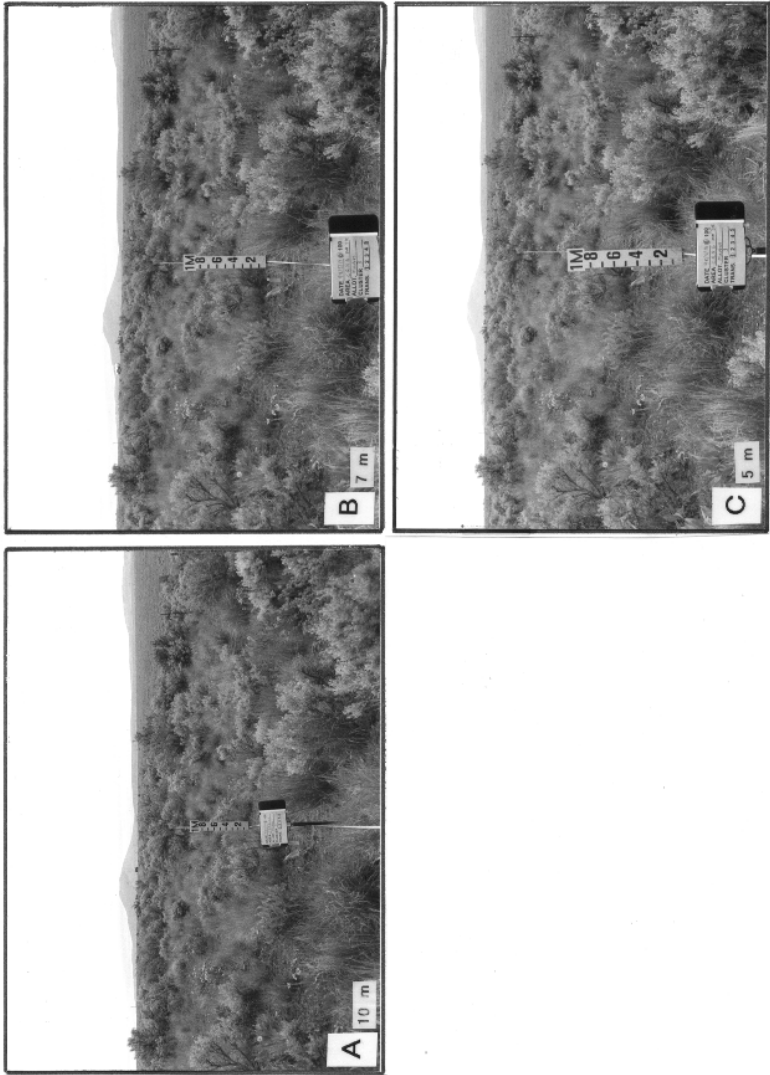


Figure 16—Evaluation of a 35mm lens on a 35mm camera for placement of a meter board to emphasize a topic. This is a transect on the Crooked River National Grassland in eastern Oregon. (A) Placement of the meter board 33 feet (10 m) from the camera. It is essentially the same as 46 feet (14 m) distance with a 50mm lens. (B) Distance of 23 feet (7 m), essentially similar to 33 feet using a 50mm lens (fig. 31, part B). (C) Sixteen feet (5 m) distant, equivalent to 23 feet with a 50mm lens. A consistent distance between camera location and photo point for all photographs is not required. Choose a distance that best documents what you want to show. But, after your choose it, it must remain the same.

Equipment

The following equipment is required for topic photography:

1. Camera or cameras with both color and black and white film or a digital camera.
2. Form "Camera-Photo" from part B, appendix A, printed on medium blue paper.
3. Forms for site identification and photo points from part B, appendix A: "Photographic Site Description and Location" and "Camera Location and Photo Points"
4. Meter board (part B, app. B).
5. Clipboard with its support to hold the photo identification forms (part B, appendix B).
6. Fenceposts and steel stakes sufficient for the number of camera locations and photo points desired. Include a pounder.
7. Compass and 100-foot (30 m) tape for measuring distance.
8. Metal detector for locating stakes.

Technique

Several steps are needed to establish topic photo monitoring. Pole Camp (fig. 2) is used as an example.

Define the topics of interest. At Pole Camp, primary topics were effects of livestock grazing on streambank stability, differential utilization on dry and wet meadows, and impacts on willow shrubs.

Next, define what coverage is desired in the monitoring area. How many streambank sites are desired? How many dry and wet meadows and where? How many shrubs should be monitored and where are they located (see "Shrub Profile Photo Monitoring")? Notice the distribution of willow shrubs in figure 2A and the pattern of dry to moist to wet meadow in 2B.

Photo points and camera locations—Based on the desired objectives, locate photo points (meter boards) to best document change. Then establish camera locations for optimum coverage of the photo point topic. Coverage might require multiple photo

points from the same camera location or multiple camera locations focusing on the same photo point. Figure 6 maps two photo points (“D” and “W”—dry and wet meadow) from camera location 1 and two camera locations (2 and 3) focusing on photo point “S” (streambank). Figure 2 shows these camera locations and photo points. Advantages are twofold: First, relocation tends to be easier when only one point must be located that will serve two or more views, and second, one point showing several views tends to tie the sampling area together.

Riparian considerations—Riverine riparian settings have two unique photo monitoring characteristics not found in dryland situations: floods and beavers. These characteristics require some special considerations in locating both camera locations and photo points.

Camera locations should not be placed at the stream edge because they cannot be relocated if the edge erodes. Place them 3 to 5 feet (1 to 1.5 m) away from the edge and, if deemed necessary, triangulate their location (fig. 17). They should not be placed in the stream unless exact relocation for both height above the original streambed and position in the stream is assured. At times, camera locations documenting photo points in or at a stream edge may be difficult to establish.

Photo points at the stream edge may be highly desirable (figs. 3 and 17). Consider the following: (1) Use a fencepost to mark the meter board and pound it down to exactly the meter board height. This will help document erosion or deposition (fig. 3) at the base of the fencepost. When the meter board is placed for a repeat photo, measure the distance from the top of the fencepost to the top of the meter board to document the amount of change. (2) Triangulate location of the streambank fencepost (fig. 17) to assure its exact relocation should a flood remove it. If it is removed, replace the fencepost to the current meter board height. Amount of change in the meter board can be documented from an unchanged camera location only by comparing the meter board with adjacent items, such as the streambank.

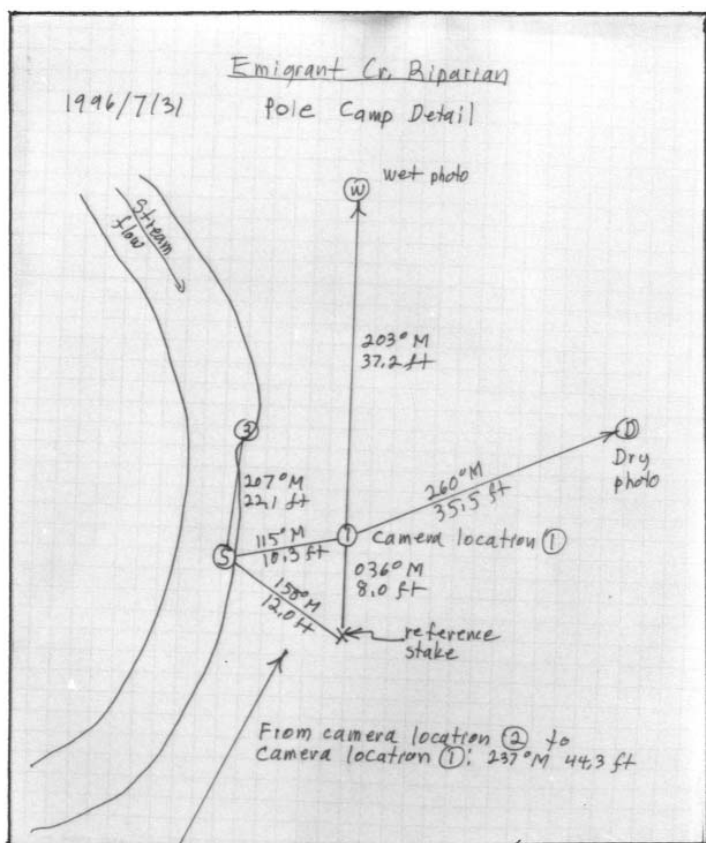


Figure 17—Triangulation location of the meter board in figure 3 to document streambank erosion at Pole Camp. This map is the boxed area shown in figure 6. Any photo point or camera location in a tenuous spot should be referenced by two or more locator stakes.

Camera orientation and focus—Consistent repeat photography requires a reference point to orient subsequent views. The objective is to have the view remain constant as items within the view change. A meter board serves this purpose. Figure 18 shows three repeat photographs of a ponderosa pine/elk sedge community that was selectively cut. Figure 18A illustrates how the camera focus ring is placed over the “1M,” which accomplishes two things: (1) it provides a common orientation point for the first and subsequent photographs, and (2) it provides a

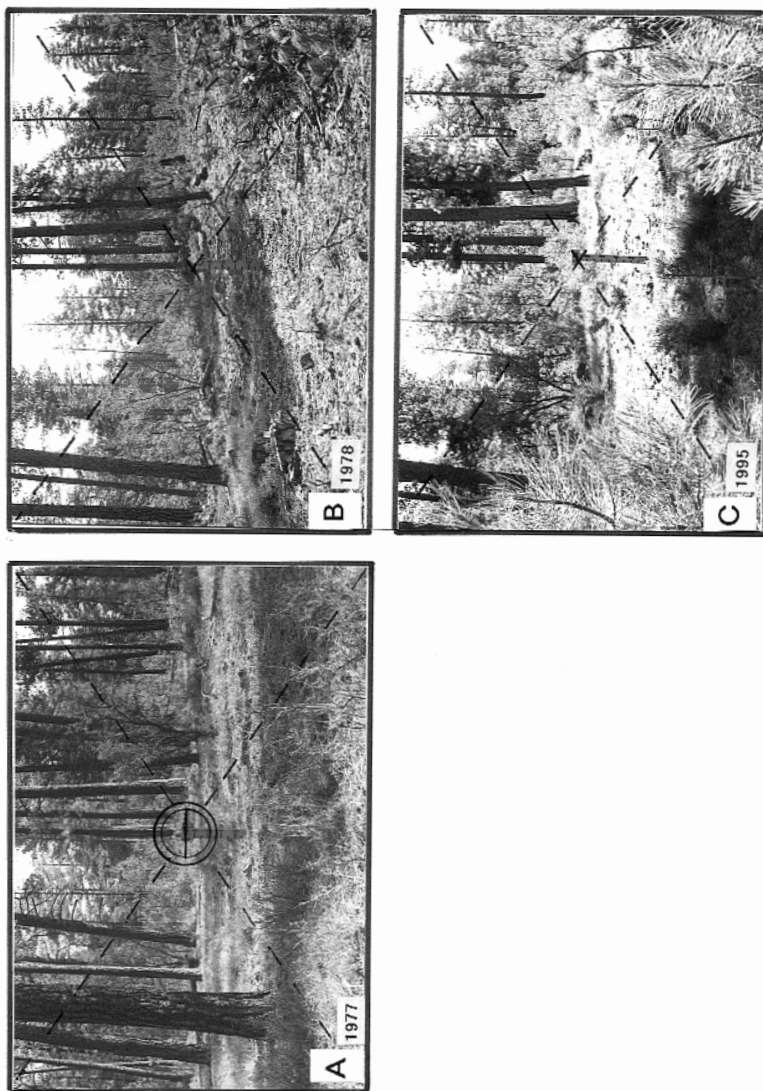


Figure 18—A meter board is used to aim the camera for consistent repeat photography. (A) Placement of the camera focus ring on the 1M," which puts the "1M" in the center of the picture (dashed lines). This orientation produces exact replication of repeat photographs as shown in (B) and (C). Focusing the camera on "1M" provides optimum sharpness and depth of field at the meter board. With an f-stop of 8, everything in the picture will be in focus. This series is part of a study following logging effects on ground vegetation and stand structure (fig. 11). (A) 1977 just before a selection cut, (B) the summer after the cut (a two-turn skid trail crossed the meter board location), and (C) 1995, 18 years later.

locus for focusing the camera for maximum depth of field. With the meter board placed at the topic of interest, the topic should always be in sharp focus.

Other options may be considered with topic photography: close-up pictures of the meter board and overhead photos of tree canopy.

Closeup photos—In many cases, details might be desired that are not accommodated by a meter board 20 to 35 feet (7 to 10 m) distant. Closeup photos, one from each side of the meter board, are recommended (fig. 19). After the general photo is taken, walk up to the meter board and photograph it on each side. With a 50mm lens, stand 7 feet (2 m) away or with a 35mm lens, stand 5 feet (1.5 m) away. Figure 19 illustrates a 50mm lens.

A critical element is to always place the top of the meter board all the way up in a corner of the view (fig. 20). Details on the ground are shown in about a 5- by 5-foot (1.5- by 1.5-m) area on each side of the meter board (figs. 19 and 20). Always take a general photo and two closeup photos to document change (fig. 11).

Figure 11 illustrates use of filing system form “Photo Points and Close Photos” (part B, app. A) for mounting and filing topic photographs. It is the 1977 view of ponderosa pine shown in figure 18.

Overhead canopy—Pictures of the overhead tree canopy may be useful when documenting changes in tree canopy cover. The technique is discussed in “Tree Cover Sampling.” A word of **caution:** camera focal length **must be the same** for all subsequent pictures because there is no size control board by which to adjust different focal length photos to the same size.

An investigator may elect to do all three kinds of photography: topic view, closeups on each side of the meter board, and an overhead view for maximum documentation of treatment effects.

Text continues on page 33.

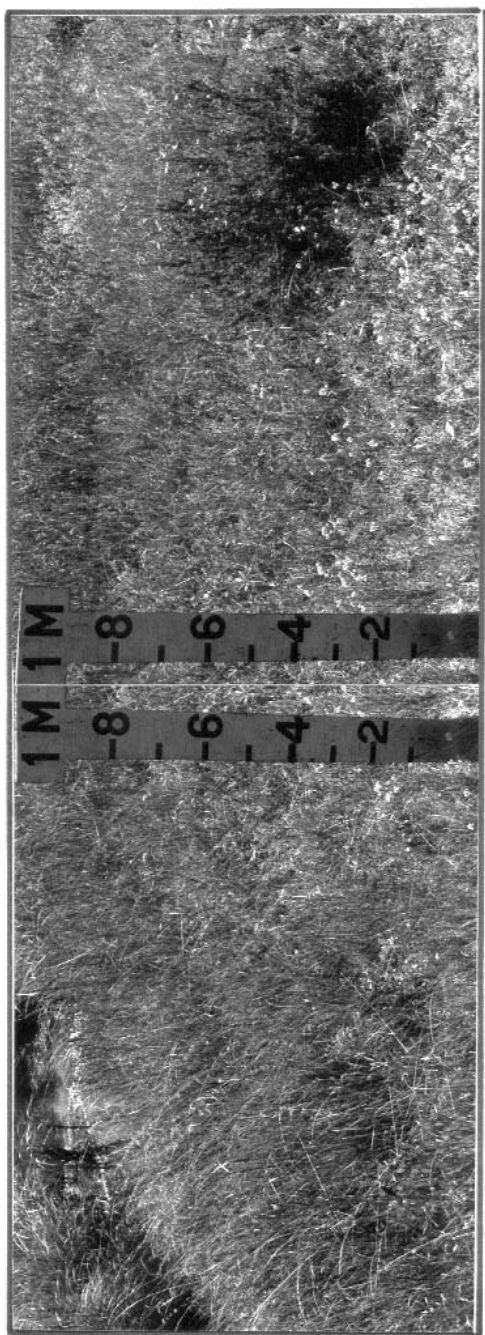
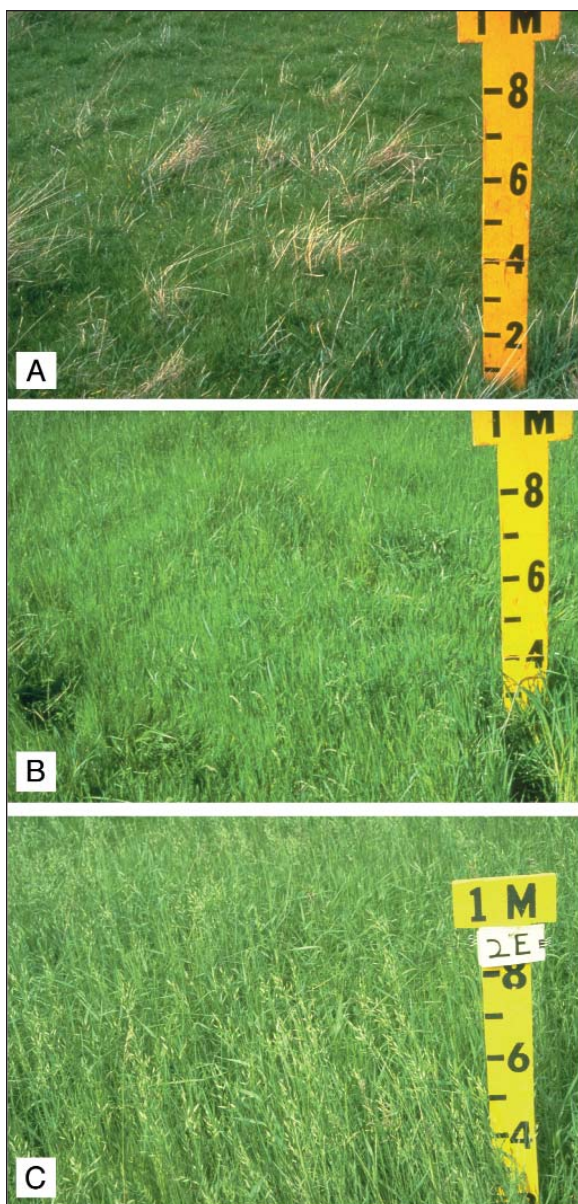


Figure 19.—Technique for documenting ground vegetation by using the meter board. Take one picture to the left and one to the right with the meter board at the corresponding edges of the photographs. Stand 7 feet (2 m) away from the board. Tilt the camera slightly off horizontal to make the meter board parallel with the side of the photograph. Place the “1M” of the board in the upper corner of the view. The 7-foot distance, along with a 50mm lens on a 35mm camera, will place the bottom of the board in the lower corner of the picture (fig. 20). Set the camera to 3 meters (9 ft), which allows the vegetation to be in focus from bottom of the meter board to at least 7 feet (2 m) beyond the board. These are closeup views of figure 4, June 15. If pictures are mounted in this fashion, I overlap the meter boards so that only one is showing.



Analysis of Change

The meter board also is used as a constant size reference point for analyzing changes. The recommended system is grid analysis (discussed in part B). In a nutshell, a clear plastic form with site identification information is taped to the photo and topics of interest outlined. Then an analysis grid is adjusted to exactly match the size of the meter board in the outline and is printed on white paper. The outline form is taped to the grid, and grid intersects within the outlines are counted and recorded. Amount of change between photos can then be determined.

Topic Description

Describe the setting and topic to be photographed each time photos are taken. Figures 13 to 15 show mountain pine beetle effects on lodgepole pine. New conditions are recorded for each repeat photograph. Figure 11 illustrates a general photo and two closeup pictures of ground conditions. Plant species and their estimated canopy cover are recorded for the closeup pictures each time they are taken. The "Photo Points and Close Photos" form provides space for these notes.

- ◀ Figure 20—Orientation for closeup photos of a meter board in dense vegetation. In photograph (A) with 4 inches (1 dm) of stubble height, the meter board bottom can be visually estimated. In (B) and (C) it cannot. Exact reorientation of the photograph is essential: (1) the "1M" must be in the top corner of the view, (2) the bottom of the board must be in the lower corner, (3) the photograph must be taken from 7 feet (2 m) away with a 50mm lens on a 35mm camera, and (4) the camera must be tilted slightly off horizontal to make the board parallel with the side of the view frame. In photograph (B), just 3 months later, grass is over 16 inches (4 dm) tall effectively hiding the bottom of the meter board. Problems with tall vegetation and exact photograph reorientation are shown in (C). The "1M" was not placed in the top corner of the view frame. Instead it is about 8 inches (2 dm) below the corner meaning the bottom of the board is about 8 inches (2 dm) below the bottom of the picture, an unacceptable repeat photograph. Photo (C) also demonstrates a problem photographing plot frames because a frame would not be visible.

Shrub Profile Photo Monitoring

Change in shrub profile area can mean either shrub use or shrub growth. It may be documented through repeat photography with grid analysis and horizontal camera orientation. Permanent camera locations and photo points, marked by steel fenceposts or stakes, are required. Season of photography is a key factor in documenting change and causes of change in shrub profiles.

Concept

The concept of documenting change in shrub profile area is to photograph a shrub on two sides with the camera location moved for a 90-degree difference between views (Reynolds 1999). This photographs all profiles of a shrub. Camera locations and photo points must be marked with steel fenceposts or stakes to assure the same distance from camera to meter board for all future photographs. The same distance need not be used, however, for all camera locations. Adjust distance to suit the topic being photographed. Tall shrubs, where double meter boards are used (fig. 21), require a much greater distance than short shrubs (fig. 25, below).

Once photographs have been taken, use the photo grid analysis procedure (in part B) to document changes in shrub profile area and shape.

Guidelines

All basic photo monitoring requirements for relocating the monitoring area and for maintaining the same distance from camera to meter board must be met. Some guidelines follow.

The primary objective in monitoring change in shrub profile area or shape is to document usage (reduction in area, Reynolds 1999) or growth (increase in area). Thus, season of photography is of critical concern. If effect of animal browsing is the topic of interest, photography both before and after this use may be necessary. This requires selection of two seasons to photograph, such as just before livestock grazing and immediately after. If livestock graze at different seasons in the same pasture over a period of years (such as rest-rotation systems), three dates may



Figure 21—Use of a folding 2-meter board to document height and growth of tall shrubs. This board is hinged in the middle and held upright by a barrel bolt. When folded together (fig. 54, part B), it is a 1-meter board and unfolded it is 2 meters.

be required to document grazing effects over several years. Other dates, established by local knowledge, probably will be required for wild animals.

If growth in shrub profile area is the topic of interest, then photography after termination of growth would be desirable. Dryland shrubs usually have a definite termination of growth and are called determinate shrubs. Some riparian shrubs, such as many willows, continue to grow until environmental conditions, such as frost, cause growth to stop. These are indeterminate shrubs. Season to photograph must thus be based on the physiological development of the shrub species under study.

Procedures

1. Establish a monitoring objective at the same time as the area and species of shrub to evaluate are selected. Determine photography date(s).

2. Make a map to find the monitoring area (fig. 5) and a map of the transect layout (figs. 22 and 23). The transect layout must include direction and distance from the witness mark to the first shrub photo point and then its two camera locations, and from there the direction and distance to the next shrub photo point and its camera locations (fig. 23). All shrub photo points must be tied together for ease in future location. The transect layout need not, probably will not, be a straight line (fig. 23).
3. Placement of the meter board is critical because it will be used to document changes in shrub profile. There are three concerns: (1) Placing the meter board far enough to the side of the shrub to allow the shrub to grow in crown diameter (figs. 24 and 25). Consider a distance that is half the current shrub crown diameter (fig. 24). (2) Placing the bottom of the meter board far enough toward the camera to assure the lowest line of the grid will be **below** the bottom of the shrub if it grows. Consider placing the 2-decimeter line opposite the current bottom of the shrub (fig. 25). (3) Placing the board in one location and moving the camera for a 90-degree change in view (figs. 24 and 25).
4. Select a camera-to-photo-point distance that will permit the shrub to grow in both height and diameter. Consider a distance where the current shrub is about 50 percent of the camera view height and 70 percent of the camera view width (fig. 25, A and B).
5. Try to select a single shrub or several shrubs separated from other shrubs in the camera view. If shrubs increase in area of profile, their outer crown periphery may become difficult to separate from adjacent shrubs (fig. 25). Color photographs greatly aid in shrub profile delineation.
6. Aim the camera so that the meter board is at the extreme left or right of the view (fig. 25). The "Shrub Analysis Grid" (part B, app. A) shows the meter board at the sides (fig. 25). Next,

SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft. Nested Freq. 1 sq.m. Robel Pole (Shrub Form)

Date 1997/6/17

Site Data: Elev. 5200 % slope 1

Area Shrub mtn.

Slope aspect: N-NE E-SE S-SW W-NW

Allot. Pole Camp

Slope position: top up 1/3 mid low 1/3 (bottom)

Cluster No. 1

Micro topography: convex (flat) concave

Transacts: (1) 2 3 4 5

Macro topography: flat undulating (rolling)

Plant community SAGE

steep rough broken

Grazing system:

Geology:

Type rest/rot Date 1977

Deposition: wind (stream) lake colluvial

Type _____ Date _____

Material: limestone mudstone sandstone

Type _____ Date _____

granite serpentinite diorite

Kind of animal: (cattle) sheep

basalt (andesite) rhyolite

horses goats deer

tuffaceous cinders pumice ash

elk _____

Soil:

Location: T. 195 R. 27E

Restrictive layer: absent (clay pan) bedrock

Sec. 29 SW of NE

cemented

Description: Open meadow

Surface compaction: none (moderate) severe

between 43 rd and

Soil profile stone: (absent) gravel stony

Crowfoot Cr. 0.25 mi

Soil texture: sandy loamy (silty) clayey ashy

W. junc. 43/4365 rds

Other notes: 1998/8/1 fence always old

access trail to meadow

MAP

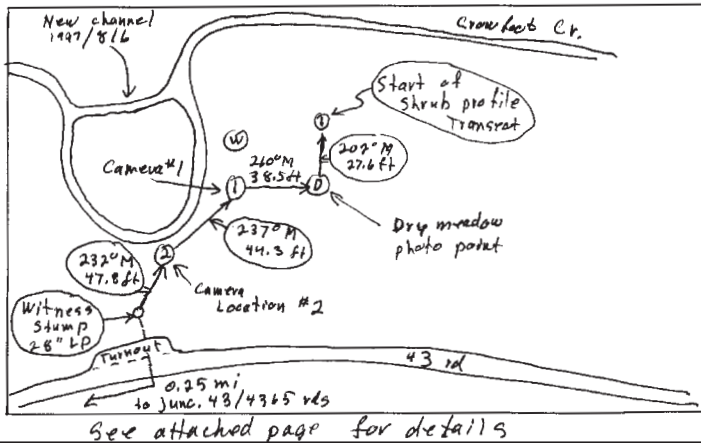


Figure 22—The filing system form "Sampling Site Description and Location" identifies the Pole Camp shrub profile monitoring system. On the first line of the form, circle the monitoring system used, in this case "Shrub Form." Information about the area is entered, and a map is drawn to locate the monitoring system. This shrub profile transect is one of several photo monitoring installations at Pole Camp; figure 6 diagrams five camera locations and four photo points. A note at the bottom of this map says that an attached page has details. This is shown in figure 23.

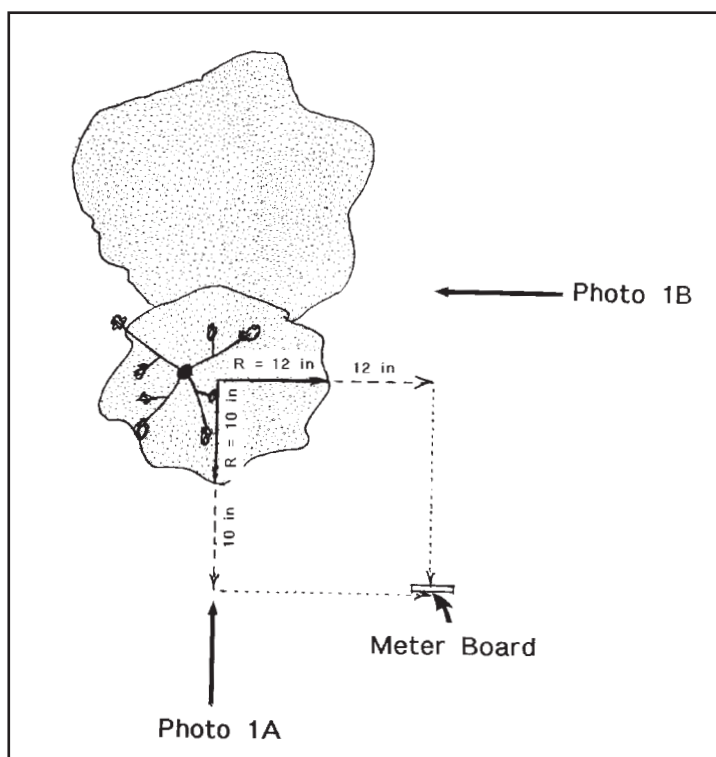


Figure 24—System for locating a meter board when photographing shrub profiles. Measure the shrub radius in two directions, at 90 degrees from each other to correspond to the direction of photographs (12 inches [30 cm] and 10 inches [25 cm]). Move out from the shrub the same distances (12 inches and 10 inches), and locate the meter board at the intersection of the distances. This will place the meter board far enough to the side and front of the shrub so that the shrub can grow and still be covered by a grid. These two views correspond to figure 25, 1A and 1B.

Note the relation between placement of the meter board bottom about 8 inches (2 dm) below the bottom of the shrub and orientation of the camera at the bottom of the meter board. The objective is to document change in shrub profile both upward and outward.

When tall shrubs require double meter boards, such as in figure 21, the boards may be placed in front and the “Analysis Grid-2-Meter” form (part B, app. A) used.

SHRUB PHOTO TRANSECT

Date 9/7/6/17 Cluster 1 Transect ① 2 3 4 5

Area Snow Mt. Dist
 Allot. Pole Camp
 Investigator: SW

Season of use late
 Grazing system: Rest -
Rotation - 3 pasture
 Animals Cow / calf

Direction 202° M
 Distance 2319"

Shrub 1A
 Direction 214° M
 Distance 1410"
 Comments SALIX
GEYERIANA
Browsed 2 yrs ago
CAREX SIMULATA
POA PRATENSIS
POTENTILLA
FLABELLIFOLIA
 suggest a dryish moist
 meadow

Shrub 1B
 Direction 140° M
 Distance 1414"
 Comments SALIX
GEYERIANA
Browsed 2 yrs ago;
2 shrubs

Figure 25—The filing system form “Shrub Photo Transect” (part B, app. A) shows Pole Camp willow transect 1 and both views of shrub number 1. Notes about the vegetation and item photographed are made opposite each photograph. Direction shown is from the **camera** location to the shrub—a reciprocal of the map direction. The form provides for two views each of 10 shrubs with views down the transect from each end. The top photograph (T = transect) is down the transect under which are photo points 1A and 1B. Species are *Salix geyeriana* Anderss., *Carex simulata* Mackenzie, *Poa pratensis* L., and *Potentilla flabellifolia* Hook. ex Torr. & Gray.

Equipment

The following equipment is required for shrub profile sampling:

1. Camera or cameras with both color and black-and-white film, or a digital camera.
2. Forms from part B, appendix A: for transect and shrub identification, "Shrub Photo Sampling" printed on medium blue paper, and data/photo mounting form "Shrub Photo Transect" printed on medium yellow paper.
3. Meter board (part B, app. B).
4. Clipboard with its support for holding the photo identification forms (part B, app. B).
5. Fenceposts and iron stakes sufficient for the number of shrubs desired: 1 fencepost and 2 iron stakes per shrub. Include a pounder.
6. Compass and 100-foot (30-m) tape.
7. Metal detector for locating transect stakes.

Technique

The technique for shrub profile monitoring combines a transect system with principles discussed in "Topic Photography," above, and in part B, "Photo Grid Analysis." A primary objective is to monitor **change** in shrub profile area and not to measure canopy cover of shrubs or shrub profile area per acre (hectare). Shrubs, therefore, are objectively selected for photography. The following technique emphasizes this objectivity.

1. Locate the area of consideration. Walk the area to select shrubs to be monitored. In many cases, shrub distribution does not lend itself to straight line transects, particularly in riparian areas with winding streams. Ask, "Why am I concerned with change in shrub profile area? Is it to appraise usage, assess vigor, or document change in profile area? Is the location of shrubs important, such as creating shade along streams? Each shrub is a topic and becomes the key mapping and photo orientation object.

2. Mark each shrub to be photographed with steel fenceposts or a combination of posts and stakes: a fencepost to mark the meter board and two more posts or stakes to mark camera locations that view the shrub at 90 degrees (two different sides). Whenever possible, select a single meter board position that will accommodate the two camera locations (figs. 24 and 25).
3. After marking all the desired shrubs, diagram the transect layout (fig. 23). Take a direction and measured distance from the witness marker to the meter board position for the first shrub. Diagram the two camera locations with direction and distance **from** the shrub. This aids repeat photography. Find the shrub fencepost or stake, take direction, and measure distance to the camera locations. Fenceposts are easy to find. Stakes require a metal detector, which is greatly facilitated by this location system. The distance and direction should locate a 0.5-meter diameter area in which to find the stake.

Then take direction and measured distance from the meter board for the first shrub to the second shrub, again documenting direction and distance to the camera locations. Continue to the end of the transect (fig. 23). Remember to indicate magnetic or true direction.

4. When ready to photograph, fill out the filing system form "Shrub Photo Sampling" for photograph identification as seen in the three parts of figure 25.
5. Take a general picture of the transect by setting the meter board at shrub number one as shown in figure 25T. Stand 20 to 30 feet (7 to 10 m) from the board and put the "Shrub Photo Sampling" form in view (fig. 25T). Stake the camera location and add the location to the sampling layout diagram.
6. For each shrub, place the "Shrub Photo Sampling" photograph identification form next to the meter board (fig. 25, 1A and 1B). The form has a shrub number and letter for camera

locations for 10 shrubs. Match the shrub number and letter on the form with the transect diagram and circle the number, in figure 25-1A, 1A is circled for camera location "A." To photograph the shrub, focus the camera on the meter board to assure greatest depth of field for the shrub. Then swing the camera either left or right to place the meter board at the side of the frame.

Move to the second camera location (1B), turn the meter board and the photo identification form to face the camera, cross out the last shrub number on the form and circle the current one. In figure 25-1B, 1A is crossed out and 1B is circled representing shrub 1, camera location "B."

Make notes of what is in each photo on the "Shrub Photo Transect" form printed on yellow paper (fig. 25) from part B, appendix A. Identify the shrub, list herbaceous vegetation, and note anything of interest such as browsing and by what.

7. Move to the next shrub and repeat the process until completed.
8. Mount the photographs, as shown in figure 25. The filing system form "Shrub Photo Transect" is designed for 3- by 4½-inch (7.5- by 11.2-cm) photos.
9. Conduct grid analysis of the pictures as discussed in part B (fig. 26).

Tree Cover Sampling

Forest stand density, represented by canopy cover, has direct influences on ground vegetation species through root competition and by casting shade. Trend in density and composition of ground vegetation is often as much influenced by this competition as by grazing or light disturbance. Any photo point placed in a forested setting should consider tree cover photography.

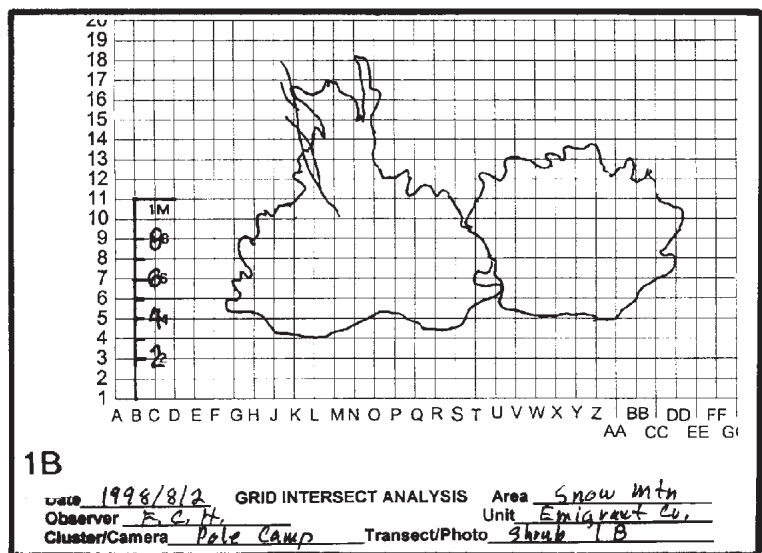
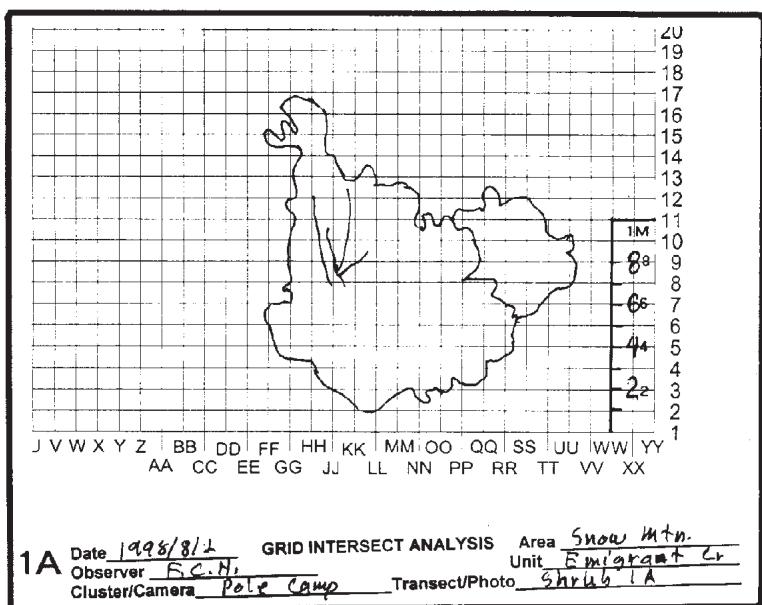


Figure 26—Grid outlines for shrub 1, views (1A) and (1B) on the Pole Camp shrub profile transect. Grids have been adjusted for size by the outlined meter board. Outlines are then taped to the grid. Count grid intersects and record on the filing system form "Photo Grid Summary" (fig. 49, part B).



Figure 27—System to photograph tree canopy cover. The photo point meter board will be crosswise of the view. Place the camera level board on top of the meter board and the camera on the level board. First, center the cross-view level by moving the meter board sideways. Then tilt the camera level board so that the down-the-view level is centered, move your head out of the camera view, and photograph.

Concept

Tree canopies are photographed perpendicular to the ground by using a camera leveling board to assure vertical orientation of the camera. Figure 27 illustrates a 35mm camera with 50mm lens in the correct position.

Whatever focal length is used to begin, the **same focal length** must be used for subsequent photos. There is no measured distance to a meter board or other size control used in the overhead view, therefore pictures **cannot** be adjusted to a common camera focal length to compare canopy cover.

Equipment

The following equipment is required for tree cover sampling:

1. Camera or cameras with both color and black-and-white film, or a digital camera.

2. A camera leveling board (part B, app. B).
3. Form from part B, appendix A, for data and photo mounting, "Photo Points with Overhead Views" (fig. 28)
4. Meter board (part B, app. B) on which to set the leveling board and camera and thus maintain a constant camera height.
5. A compass and 100-foot (30-m) tape.
6. Fenceposts or steel stakes with pounder.
7. Metal detector for locating stakes.

Technique

Position the meter board at the topic of interest following guidelines in "Topic Photography" (above). Hold the camera leveling board on top of the meter board, set the camera on the leveling board with the long axis crosswise to the scene (landscape orientation) and the viewfinder toward the camera location (fig. 27). The easy way to remember this is to view the photo point with the camera in landscape orientation (fig. 28, top view), then move to the meter board and rotate the camera to look up at the canopy (fig. 28, bottom view).

Move the meter board sideways to level the camera board across the view. Then level the camera board down the view, bend down to take your head out of the picture, and photograph (fig. 28, bottom view).

Important criteria—There is neither a size control (meter board) nor photo identification sheet in these pictures. Therefore three procedures **must** be followed:

1. The same focal length lens must be used for all subsequent photographs so that images can be compared.
2. The camera must be the same height aboveground. Use the meter board for consistent heights. Figures 31 and 32 in part B illustrate the effect of change in distance on size and location of objects.

PHOTO POINTS WITH OVERHEAD VIEWS

Date 9/6/85 Camera Wide Thin #3
 Area Prairie City Dist Number of Photo points: 2
 Unit Cold Cr. Observer F.C. Hall
 Comments 25 yrs since pct; clearcut about 1950

Slope 5 Aspect W Slope position mid Topography undulating

Photo Point A
 Compass bearing: 178° M
 Distance 32.0 ft
 Photo comments:
No cow use, trees
new growing at 2-2"
per dec.

Overhead of Photo Point A
 Photo comments:
Ponderosa pine is
fairly good vigor.
100 ft line transect
showed 47% cover



Figure 28—Filing system form "Photo Points with Overhead Views" documenting current tree canopy cover. The form is in part B, appendix A. Remember to make notes on what is in each photo.

- Make sure that the camera is oriented crosswise to the view with the viewfinder toward the camera location (fig. 27). Remember this by viewing the photo point through the camera, then rotating it 90 degrees upward to view the canopy.

Canopy cover also may be determined by using the photo grid analysis technique discussed in part B.

Literature Cited

Borman, M.M. 1995. Photo monitoring. The Grazier. Corvallis, OR: Oregon State Extension Service. 282(May): 2-6

Hedgecoe, J. 1994. Hedgecoe's landscape photography. New York: Sterling Publishing Co., Inc. 224 p.

Johnson, C. 1991. A photo point system: Eco-Area 3. Baker City, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest.

Nader, G; DeLasaux, M.; Delms, R. [and others]. 1995. "How to" monitor rangelands. Handb. Level-1. Alturas, CA: University of California, Cooperative Extension Service, Modoc County. 44 p.

Reynolds, M.P. 1999. Residual leaf area as a measure of shrub use. Corvallis, OR: Oregon State University. 104 p. M.S. thesis.

Skovlin, J.M.; Thomas, J.W. 1995. Interpreting long-term trends in Blue Mountain ecosystems from repeat photography. Res. Pap. PNW-GTR-315. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 102 p.

White's Electronics, Inc. 1996. Classic II SL[™]. Sweet Home, OR: White's Electronics, Inc., 1011 Pleasant Valley Road, 97368.

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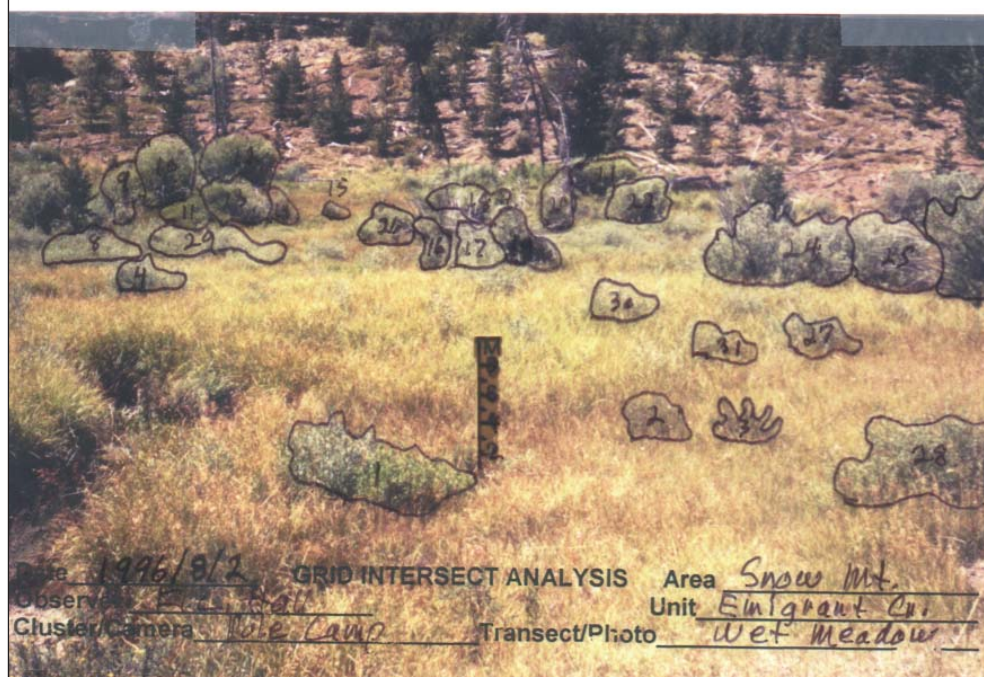
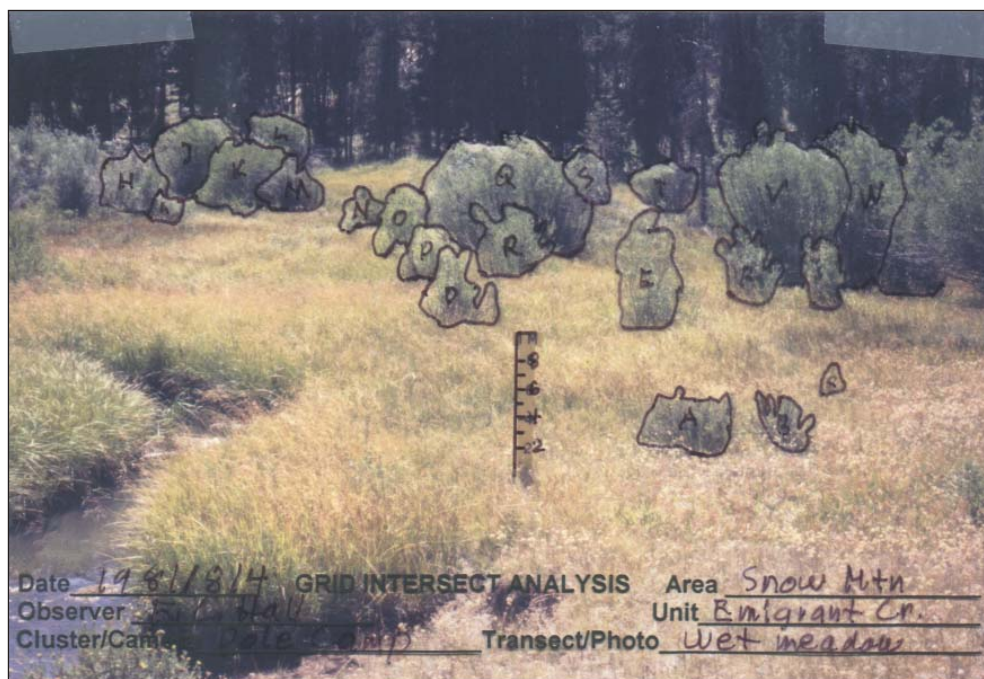
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Photo Point Monitoring Handbook: Part B—Concepts and Analysis

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Abstract

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This handbook describes quick, effective methods for documenting change in vegetation and soil through repeat photography. It is published in two parts: concepts and office analysis in part B, and field procedures in part A. Topics monitored may be effects of logging, change in wildlife habitat, livestock grazing impacts, or stream channel reaction to land management. Land managers, foresters, ranchers, wildlife biologists, and land owners may find this monitoring system useful. In part B, (1) concepts and procedures required to use photographs for analyzing change in photographs are presented, (2) monitoring equipment specifications are given, and (3) forms for recording information and mounting photographs are provided.

Keywords: Monitoring, photography.

Preface

This handbook is an synopsis of repeat photography principles and photo point sampling from the publication *Ground Based Photographic Monitoring*, PNW-GTR-503, which is based on 45 years experience in repeat photography by the author. During those years, many nuances were discovered that bear discussion and emphasis so that new users can avoid the pitfalls I ran into. The terms *should*, *must*, *will*, and *do not* are used to help users avoid problems and are not meant as rules.

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Introduction

Photographic documentation of soil and vegetation topics of interest is an essential first step in photo monitoring. But monitoring implies the need to determine change. This determination has two components: (1) the basics of photographic technique; and (2) a method to assess change—in this case, grid analysis, which may be done by hand or with a computer. Appendices provide forms for photo monitoring and analysis as well as equipment specifications.

Basics

Use of photographic equipment is fundamental to photographic monitoring. The equipment may be either film or digital cameras. The purpose of photo monitoring is to document change in a landscape or topic over time. Measuring change requires photographs of good to excellent resolution and color, both of which are influenced by camera and film.

Cameras

Consumer cameras currently are classed into two broad categories: point-and-shoot automatic and single lens reflex (SLR) for either film or digital use. Point-and-shoot cameras usually provide safe exposure in average light conditions to produce nice snapshots. The SLR cameras use a view-through-the-lens system enhancing photographic composition and have various adjustments for fine tuning exposure. They can take superior pictures. Digital cameras are similar, but their quality tends to center on the number of pixels. Pixels are dots of different colors that form an image. Point-and-shoot digital cameras range from 1.1 to 2.4 megapixels and better quality ones usually have 3.4 or more. If measurements on photographs are contemplated, one must use a camera of 2.4 megapixels or higher.

Film and digital camera characteristics—Both camera formats come in two configurations: (1) viewfinder and (2) view-through-the-lens, or SLR. Many digital cameras use SLR principles with a liquid crystal display (LCD). An LCD is a miniature (2.5- by 3.3-centimeter [about 1- by 1.3-in]) computer monitoring screen that displays the image as seen through the lens (Kodak 1999a). With through-the-lens systems, the image is viewed exactly as it will appear. There is no parallax correction and the image will look fuzzy when out of focus. The SLR cameras are more expensive. Viewfinders are parallel with the lens, and there is an outlined box in the viewer (parallax correction) to show what the image will cover when pictures are taken at close range. The image always will appear sharp.

Both film and digital cameras provide for a strobe flash system. Less expensive cameras often have built-in flash that fires straight ahead and is effective up to 9 feet (3 m) for low-light conditions and as fill-in light for up to 16 feet (5 m). More expensive cameras provide a hot shoe to which a more powerful and adjustable flash system can be attached. Additional flash systems add cost to the camera. Some cameras have both an internal flash and a hot shoe.

Zoom lenses have become popular, particularly with the “point-and-shoot” automatic cameras. They are common on many digital cameras. These lenses add flexibility to the camera, but they tend to be less sharp than a fixed lens. Zoom lenses may pose problems in photo monitoring because lenses need to be carefully set to reproduce the original image. This is difficult, if not impossible, with zoom lenses that might range, for example, from 35mm to 100mm focal length for a 35mm film camera and 9.2mm to 28mm for a digital camera. This allows for a threefold difference in photo coverage. See the section on camera format (below) for details.

The lens speed on film cameras is given in f-stops. The “f” indicates how large a hole is open to admit light into the camera. Small f-stops admit much light and large f-stops admit little. For example, under a given light condition, f-8 might require 1/60 second exposure, but f-5.6 would require 1/120 second because it admits twice the light, and f-3.5 would require 1/250 second because it admits four times the light. The f-stop also influences depth of field. The length of in-focus distance increases with increasing f-stops. When a 35mm camera is focused at 30 feet (9 m), f-8 is sharp from 15 feet (4.5 m) to infinity, f-5.6 from 20 to 60 feet (6 to 18 m), and f-3.5 from 25 to 40 feet (7.6 to 12 m). Digital camera speed usually is provided by the processing unit in the camera computer, and faster speed costs more.

Resolution, the sharpness of the image, in film cameras is a function of (1) lens quality, providing that the camera was properly focused; and (2) graininess of the film as determined by an ISO rating. Cost of film between ISO 100 and 400 is not much, but good lenses (low f-stop such as 1.8) are expensive. Film speed, the light required for an exposure, is characterized by an ISO rating. The graininess of an image also is a product of film speed—larger grain with faster film. Common ISO ratings are 100 for medium speed and relatively fine-grained film, ISO 200, which can be shot at twice the shutter speed and has medium graininess, and ISO 400, which can be shot at four times the shutter speed of ISO 100 but is rather coarse grained.

With digital cameras, resolution is determined by maximum dots per inch (dpi) of the camera. Each image is characterized by dpi across the width and a vertical dpi, such as 1200 by 900 dpi for a total of 1,080,000 dpi, which is referred to as 1.1 megapixels (a pixel is one dot). Digital camera equivalents for film ISO ratings are about 1640 by 1460 dpi for ISO 400 (2.4-megapixel camera), 1960 by 1640 dpi for ISO 200 (3.2-megapixel camera), and 2280 by 1800 dpi for ISO 100 (4.1-megapixel camera). To determine the camera rating, multiply the two pixel numbers: $1200 \times 900 = 1.1$ megapixels.

As of January 2001, most digital cameras started at about 1.1 megapixels, suitable for 4- by 6-inch (10- by 15-cm) snapshots, and went up to 4.4 megapixels appropriate for 14- by 17-inch (35- by 42-cm) pictures. A 2.4-megapixel camera or higher is required for grid analysis (film speed of ISO 400 or less). Resolution also is enhanced by good quality optical lenses. Most digital cameras offer a choice of three to five resolution levels. For example, a 1.1-megapixel camera might offer its best at 1200 X 900 dpi, midresolution at 900 X 700, and lowest at 600 X 400 dpi. Finer resolution results in fewer images on a digital memory card and slower processing. Quality also is influenced by the kind of compression, if any, used to store the image. Compression permits more images to be placed on a memory card.

Film and digital concepts—The digital camera could be considered a special purpose computer designed to take photographs (Kodak 1999b). This dramatically separates it from a film camera, which physically captures images on a role of film. The images cannot be altered on the film, but they may be altered in the printing process. Digital images are captured on an electronic storage or memory card, which must be processed to produce an image. A digital image can be altered by

the camera through different settings. Images are made up of dots called pixels, each composed of three colors: red, green, and blue; intensity of each color can be adjusted. Film and digital storage cards are discussed in the next section.

A camera using slide film exposes an image on film—**period**. Once the exposure is made, there is no recourse through correction. With black-and-white and color negative films there is some recourse through changing print exposure time, selection of paper, and dodging or burning items to be enhanced.

With digital cameras, the image is only one link in the chain to a photograph (Kodak 1999a). This chain is (1) the camera with its dpi, or pixel resolution, lens quality that captures the image, and the camera's ability to modify pixel characteristics; (2) the CPU (the computer) that processes the image with its ability to make major changes in the pixels and thus the image; (3) the monitor with its color projection of the image on the screen, which is used as a basis for changing the image characteristics; and (4) the output device, which either prints the image (printer) or projects it (projector). Resolution (dpi), color quality, and contrast are affected at the camera, CPU, and output device. Best image quality is attained by matching the camera resolution with that of the output device. They may **not** be the same.

Output (a picture) differs between film and digital cameras. Prints are similar because they are an image printed on paper. Prints from color film, black-and-white film, and digital images all share the same end result—a picture one can hold in their hand or mount on a monitoring form.

In contrast, slides made from film and digital images share few common traits. A film image is determined at exposure and can be projected with a slide projector in presentations. A digital image cannot. Generally, the digital image must first be downloaded from the camera and placed into the memory of a laptop computer. Then the laptop must be connected to a digital slide projector for presentation. Recently, cameras have been programmed for download directly to a projector; however, this projects only images in the camera. It does not provide for a presentation using title, data, and instructional images.

Camera focal length—Photo monitoring is greatly facilitated by using the **same** focal length lens for all repeat photos. Use of the same focal length is highly desirable but not essential (Rogers and others 1983). If the same focal length is used, subsequent pictures can be compared side by side. If different focal lengths are used, pictures must be adjusted in size to be compared, which will be discussed in “Camera Format and Distance to Photo Point,” below. Conversion from film to digital cameras usually will result in a change of focal length, because the digital camera must be adjusted to match the film camera lens. Digital camera adjustment often is not precise enough to exactly equal the film camera; for example, setting it at 13mm to copy a 50mm lens. Nothing can be done with slides taken at different focal lengths.

Recommendation—Specify the make and focal length of camera(s) to use in the monitoring.



Figure 29—A system for combining color and black-and-white photography. Both cameras are connected by strap aluminum 1/8 inch thick and 1 inch wide bent into a “U” with holes drilled for mounting screws to connect the cameras (see app. B for details). The cameras operate independently. Identical cameras simplify the photography because all control settings are adjusted in the same way, which helps in avoiding mistakes. Shown here are cameras with black-and-white film at 400 ISO and color film at 200 ISO.

Double camera system—My photography over the last 45 years used a pair of good quality 35mm SLR cameras and 50mm lenses (about \$500.00 each at 2001 prices), one for color and the other for black-and-white film. When both color and black-and-white photographs are to be taken, consider the camera system shown in figure 29. Both cameras are the same make and model to simplify adjustment for lighting and distance. Appendix B has details for constructing the apparatus.

Film and Digital Memory Cards

There are four ways to record images: (1) color slides, (2) color prints, (3) black-and-white prints, and (4) digital. Digital cameras are color and do not use film but, rather, memory cards.

Film—If film is used, both color and black and white are recommended because color film, slide or print, will fade with time and black and white will not. Once an exposure has been made on slide film, nothing can be done to enhance the image. Negative films, for either color or black-and-white prints, offer an opportunity to modify images in the print-making process. Different printing papers may be used, time of exposure can be adjusted, and overexposed or underexposed parts may be “dodged” or “burned” to enhance the image. Similar treatment, by computer manipulation, is available for digital images. But a word of caution, digital images can be so dramatically altered that they may not be admitted in a court of law.

Film comes in various degrees of graininess. This is roughly identified by film speed: the higher the speed, the grainier the film. For example, ISO 100 is relatively fine-grain film whereas ISO 400 is quite grainy. Digital camera equivalents are 4.1 megapixels compared to 2.4 megapixels. Determination of change between photos depends on the precision of measurement that can be made on a photo. Graininess limits precision.

Color rendition of vegetation is influenced by film chemistry. Tones can differ between brands from a single manufacturer, such as Kodak's Kodachrome compared to Ektachrome, and between manufacturers, such as Fuji and Kodak. Film developing may produce different tones from the same kind of film. Color prints from the same negative can differ depending on how the prints were made. Time of exposure and kind of paper are critical. Subtle changes in green as the season progresses might not be captured from one year to another or from one kind of film to another.

Processing of film will influence how well photos can be compared. Most film is sent to a commercial processor where either slides are produced or pictures at a standard size are printed, such as 3 by 5 or 4 by 6-inch (7.5 by 12.5 or 10 by 15 cm). Quality of processing differs. Do not cheapen your product by cutting costs and quality at the final step (Johnson 1991).

Digital memory cards—Digital cameras do not use film but, rather, electronic memory cards (Kodak 1999a). Unlike film, memory cards do not have to be developed; they are processed by computer. Any or all images can be erased and the card reused. The color quality, contrast, and depth can be manipulated. Selected images or all of them can be copied from a memory card to another media, which greatly facilitates their storage and retrieval.

Different makes of cameras use different memory cards. Memory cards come in several configurations: Compact Flash and Smart Media are about half the size of a credit card and about as thick. Some cameras use a 1.44-megabyte floppy (3.5-inch diameter) and others use a 140-megabyte Super Disc floppy.

Memory cards differ in their megabyte capacity. Smart Media offers 2 to 64 megabytes and Compact Flash 2 to 160 megabytes. Many digital cameras are sold with an 8-megabyte card, but larger capacities are usable. Megabyte capacity directly limits the number of images that can be stored. A general conversion from number of pixels in an image to number of images per storage card is a 1:1.2 ratio: a 1-megapixel photo requires about 1.2 megabytes of storage card capacity. For example, an image at 1200 X 900 pixels (1.1 megapixels) would require an entire 2-megabyte card, or 29 photos could be placed on a 32-megabyte card. The same 32-megabyte card would hold 51 photos at 900 X 700 pixels (0.63 megapixels) from a camera's lower pixel setting.

Digital memory cards can be reused. The deleted images, of course, are lost.

Processing memory cards is quite different from film. There are two alternatives: commercial or home processing. Commercial means the memory card is sent to a digital processing laboratory for prints similar to film. Home processing requires use of a CPU with a download system from the camera and a printer. For best image quality, the dpi of the camera and printer should be compatible. Image quality is sacrificed if the printer cannot process the dpi of the camera. And image quality may be sacrificed by color rendition of the printer.

Digital images may be stored in any of three ways: (1) in the memory card used with the camera, (2) by being transferred to a compact disk (CD) or zip disc and the memory card reused, or (3) by being transferred to a computer hard drive with essential information in its file and the memory card reused. If images are stored in a computer, assure that instructions for locating the folder or file are placed in the photo monitoring filing system. Disks should be placed in the monitoring file (see "Filing System" below).

Color prints from film and digital systems are similar in cost; however, slides made from digital memory cards tend to cost more. A negative must be made at about \$5.50 and from it the slide for another \$2.25, for a total of about \$7.75 each. And the need for two steps, from card to negative and from negative to slide, tends to reduce quality of the image.

Recommendation—Specify the brand, type of film, and ISO rating that will be used; for example Kodak Elite Chrome ISO 200 color slide film and TMAX ISO 400 black-and-white film.

Camera Format and Distance to Photo Point

Camera format is the combination of camera body image size and focal length of a lens. Format concepts apply to both film and digital cameras. Exact duplication of camera format is not of critical concern (Rogers and others 1983) when evaluating change in the subject photographed. Images may be enlarged or reduced to a constant area of coverage, printed, and compared.

Concept—With slide film, images taken with different camera formats will project differently on the screen. This is a major concern discussed by Magill (1989) in his analysis of change in campgrounds. He projected slides onto a screen with a grid and adjusted size of the image according to specified criteria prior to analysis.

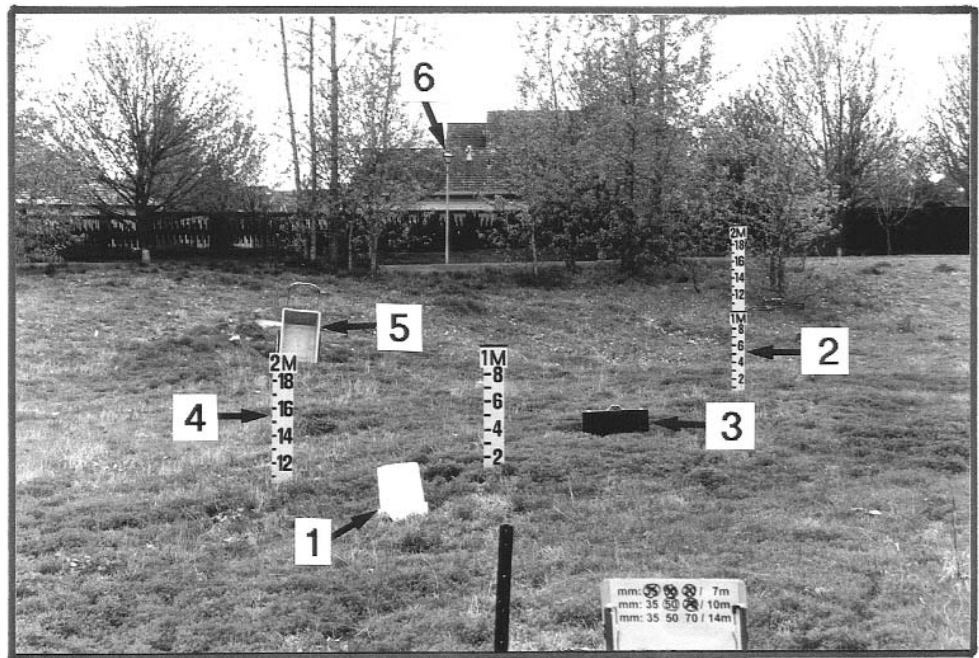


Figure 30—This landscape was used to test effects of camera format (focal length) and distance from camera to photo point (meter board) on determining size and location of objects. Camera format is 35mm image with two focal lengths: 35mm wide angle and 50mm standard. Distances are 23 and 33 feet (7 and 10 m) to the “1M” meter board. Numbered items are outlined and compared: (1) bucket between camera and the “1M” meter board; (2) double meter boards 23 feet (7 m) behind other “1M” meter board; (3) tool box; (4) top of 2-meter board parallel with the “1M” meter board, (5) cart 49 feet (15 m) from the “1M” meter board, (6) lamp pole 164 feet (50 m) from the “1M” meter board. Two situations are evaluated: (A) change both distance and focal length such that the meter board is the same size in both pictures (figs. 31 and 32), and (B) vary the camera focal length at a given distance (figs. 33 and 34). The fencepost at center front marks the 7-meter distance, and the photo identification sheet lists the focal length and distance to identify the negative.

Some examples of common film camera formats that cover about the same area of a landscape are (1) 25- by 35-millimeter (1- by 1.5-in) image size (35mm camera) using a 50mm focal length lens, (2) 2- by 2-inch (50- by 50-mm) image size using a 70mm lens, or (3) a 4- by 5-inch (100- by 125-mm) image using a 128mm lens. All are equivalent to a digital camera at 13mm focal length.

The advent of good quality zoom lenses permits a great variety of camera formats, but zoom lenses have both desirable and undesirable features. A desirable feature is increased flexibility in choosing photographic formats without the need to change lenses. Undesirable features include higher f-stops and no constant focal length when rephotographing monitoring sequences.

Testing in a landscape—The effects of camera format and distance from camera to photo point are shown and discussed in figures 30 through 34. Change in emphasis on a topic through distance is depicted in figure 16 in part A.

Figure 30 is a testing landscape where six objects were positioned, photographed, and outlined to compare their size and location with change in distance and focal length. I used two camera formats with a 35mm camera body; a 35mm wide angle

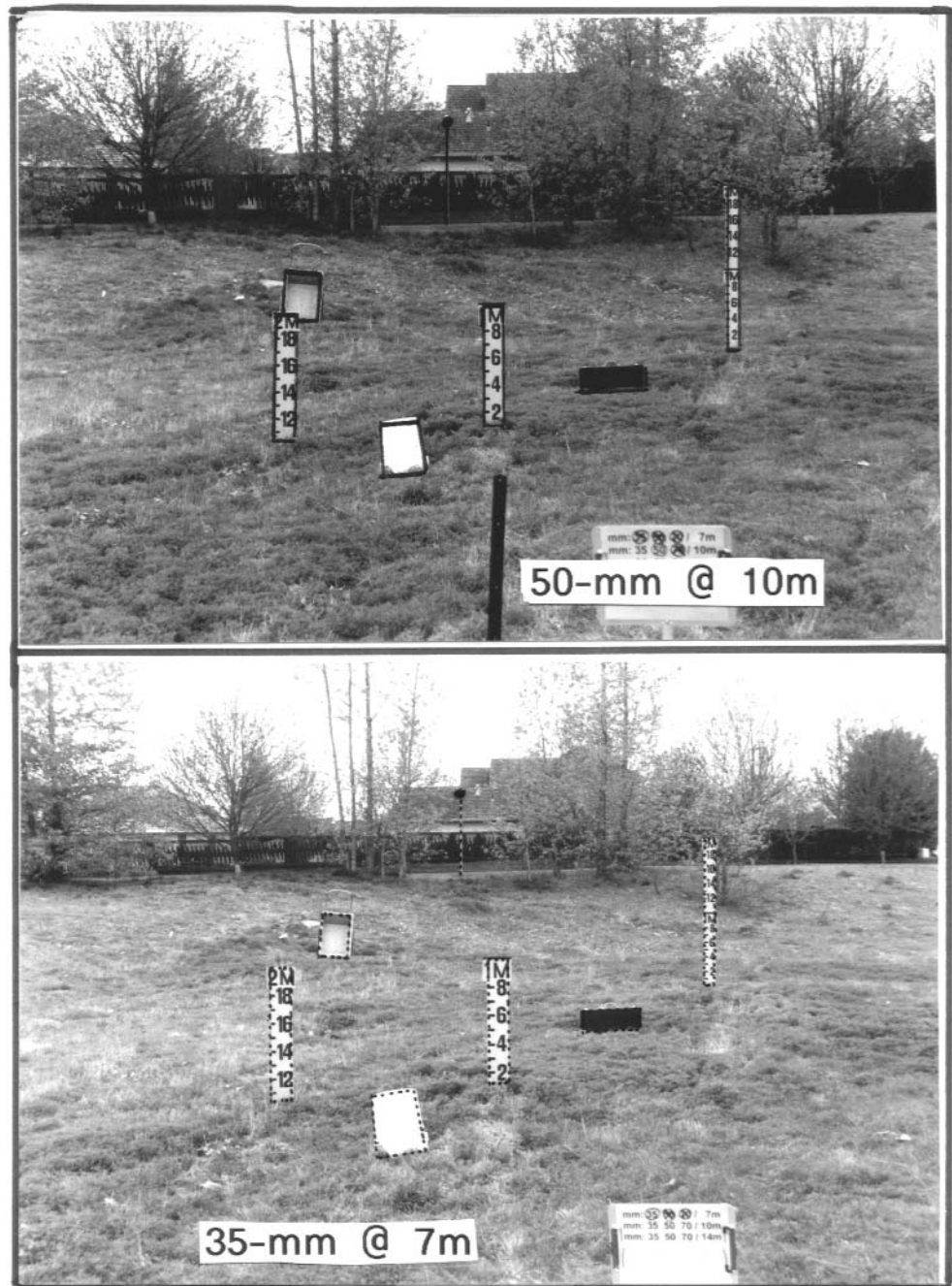


Figure 31—Both focal length and distance to meter board are adjusted to make the meter board the same size in each photograph: 50mm at 33 feet (10 m) and 35mm at 23 feet (7 m). Each of the six items have been outlined on clear plastic overlays as follows: 50mm at 10 meters in a solid line and 35mm at 7 meters in a dotted line. Note differences in backgrounds even though meter boards are the same size. Figure 32 compares the object outlines.

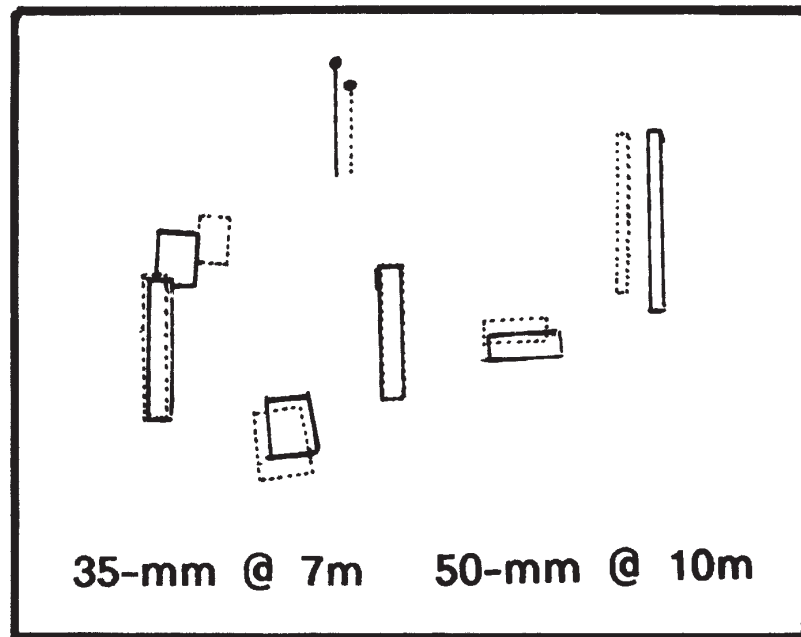


Figure 32—Object outlines from figure 31 overlaid to evaluate the effects of camera focal length and distance from camera to meter board on size and location of objects. The overlays for 35mm at 7 meters and 50mm at 10 meters show both different sizes and locations of objects even though the meter boards are the same size. This is because geometric angles from camera to objects change as distance changes. If objects in photographs are to be measured for change, distance from camera to meter board must remain the same. This is further demonstrated in figures 33 and 34.

lens was compared to a 50mm normal lens as a standard for evaluation. They are equivalent to digital cameras of 9mm and 13mm. The focal lengths were used in conjunction with two distances from camera to meter board: 23 feet (7 m) compared to 33 feet (10 m). Figure 30 illustrates the 50mm lens on a 35mm camera.

Camera format and distance—Both camera format and distance to meter board were adjusted in figure 31 to photograph the meter board at a constant size. The 35mm lens at 23 feet (7 m), dotted outline, gave the same size meter board as 50mm at 33 feet (10 m), solid outline. But note the different backgrounds. Comparison of object outlines in figure 32 shows that all objects are different in both size and location except the meter board. They are different because geometric angles between the camera and objects changed as distance varied from 10 to 7 meters.

Next, focal lengths of 35mm and 50mm were used at a distance of 33 feet (10 m), illustrated in figures 33 and 34. Figure 33 appears to show very different scenes. They are different in what is included within each photo. But when the 35mm image (dotted outline) was enlarged to size the meter board to be equivalent to that taken

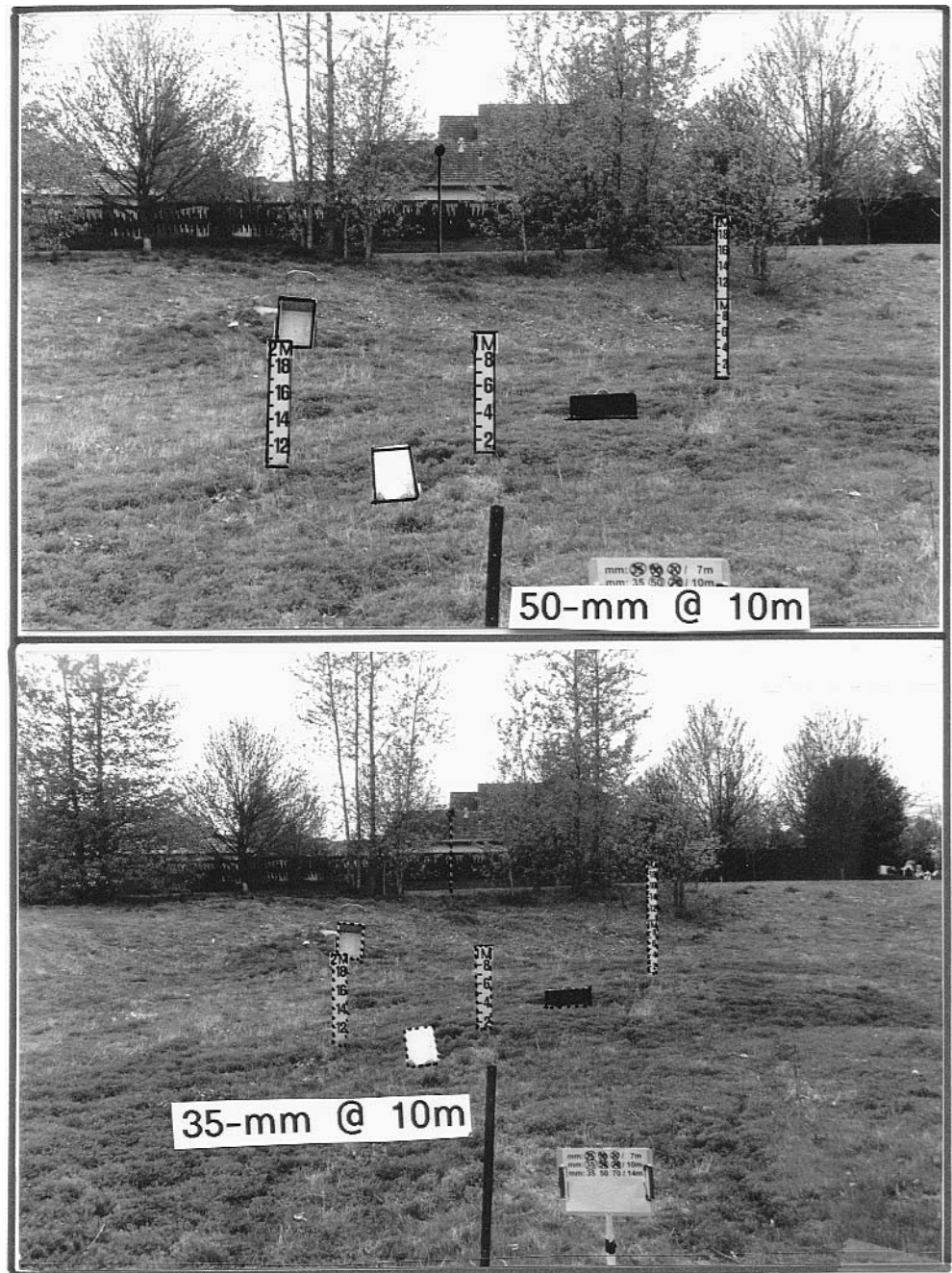


Figure 33—Effects of change in camera focal length of 50mm and 35mm at 10-meter distance from camera to the “1M” meter board. Objects in each photograph were outlined on clear plastic overlays and adjusted in size to the 50mm at 10 meter board as follows: the 50mm at 10 meter “1M” board was measured at 20 millimeters and the 35mm at 10 meter “1M” board at 14 millimeters; the percentage of enlargement was calculated as $20 \div 14 = 143$ percent. The 35mm at 10-meter outline was enlarged 143 percent. They are compared in figure 34.

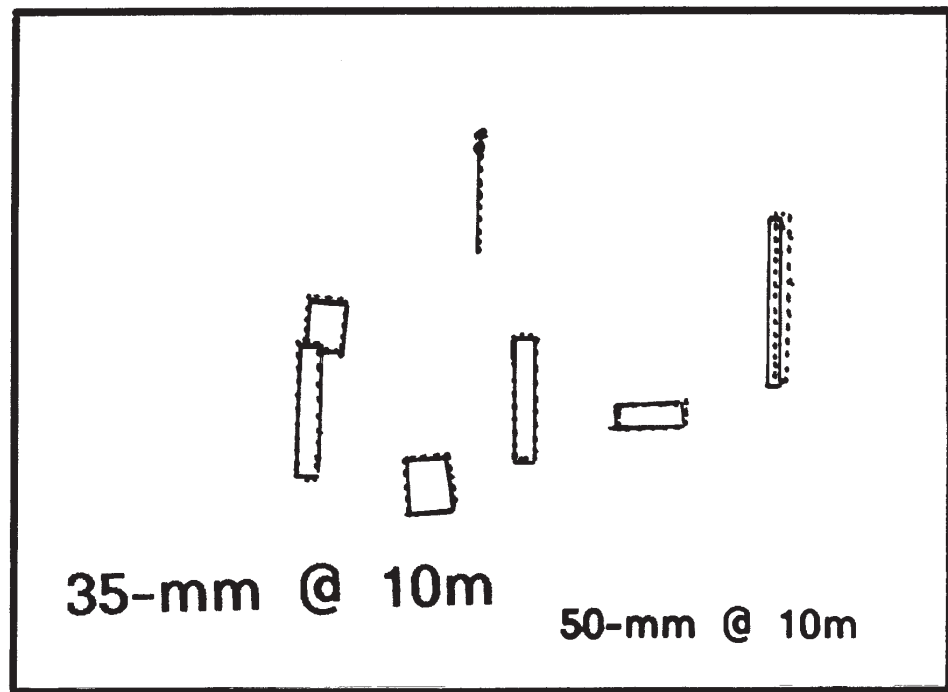


Figure 34—Object outlines for 35mm and 50mm camera focal lengths taken at 10 meters from the “1M” meter board (from fig. 33). Overlaying the enlarged 35mm on the 50mm shows little difference in object size or location. Camera focal length may differ without affecting analysis of photographic items when images are adjusted to a common size meter board. Comparison with figures 31 and 32 clearly demonstrates that distance from camera to meter board must remain the same.

at 50mm (shown in figure 34; solid outline), each object is almost exactly the same size and location. This effect is what Rogers and others (1983) discuss. Figures 31 through 34 clearly indicate that distance from camera to meter board is critical, whereas focal length is not.

Weather

How does current weather compare to conditions of previous photographs (Magill 1989, Maxwell and Ward 1980)? A dense, heavy cloud layer will produce different colors and tones compared to a high, thin overcast, which in turn will be different from full sunlight with attendant deep shadows. Maxwell and Ward (1980) suggest overcast skies to reduce shadows and taking at least three different exposures to achieve comparable color between photos.

Photo Grid Analysis

To quantify changes in vegetation, soil, fuel loading, streambanks, or other photographic topics, outline the selected topic on a clear plastic sheet. Then place a grid under the sheet. Count grid intersects falling on and within the outline, and record. Compare these to counts from previous photographs of the same topic to estimate change. Each plastic sheet with its outlines and associated counts is a set of data and must be identified clearly and then archived.



Figure 35—A 1981 view of the Pole Camp wet meadow photo point, which will be used to illustrate grid analysis. This photograph will be compared to one from 1996. The first step is to attach a clear plastic outline form (shown in fig. 36). Fill in the required site information and outline the shrubs (fig. 37).

An alternative method is digital analysis by computer. The computer cannot differentiate between pixels on the topic and those behind the topic that are of similar color (fig. 35). A plain colored backdrop is needed behind the topic (Reynolds 1999).

Concept

Grid analysis is based on standardized geometric relations between photograph, camera, and meter board. Having the same focal length lens, distance from lens to meter board, height of camera above the ground, and photograph size simplify the analysis. A set distance between camera and meter board for the initial and all subsequent photographs of a specific topic is a **must**. Different distances may be used for different topics (fig. 16 in part A). A standard camera height is desirable, but it is not essential unless the grid is used to track change in position of items over time, a tenuous procedure. Use of the same camera format, such as 50mm lens on a 35mm camera body is recommended but not required. Grids are designed to encompass a view limited to 13 to 15 degrees both horizontally and vertically. This limit is emphasized by heavy lines surrounding the grid see (fig. 39, below).

Obtain a color 8- by 12-inch (20- by 30-cm) photograph of the topic (see fig. 35), for easy viewing. Attach to the photograph a clear plastic sheet with the form “Grid Intersect Analysis” printed on it, for information on date, site location, and topic (fig. 36). This is used to outline objects. Then measure the meter board to calibrate the grid (distance between grid points and area of grid cells). Use a copy machine to precisely adjust grid cells to match the dimensions of the meter board: each grid cell

	Date		GRID INTERSECT ANALYSIS	Area	
	Observer			Unit	
	Cluster/Camera			Transect/Photo	

Figure 36—Form used to identify photographic outlines. Print the form on clear plastic overhead projection sheets. This form has been reduced to 85 percent of the size in appendix A. The full sized form is suitable for 8- by 12-inch color photographs. Use of the clear plastic overlay is illustrated in figure 37.

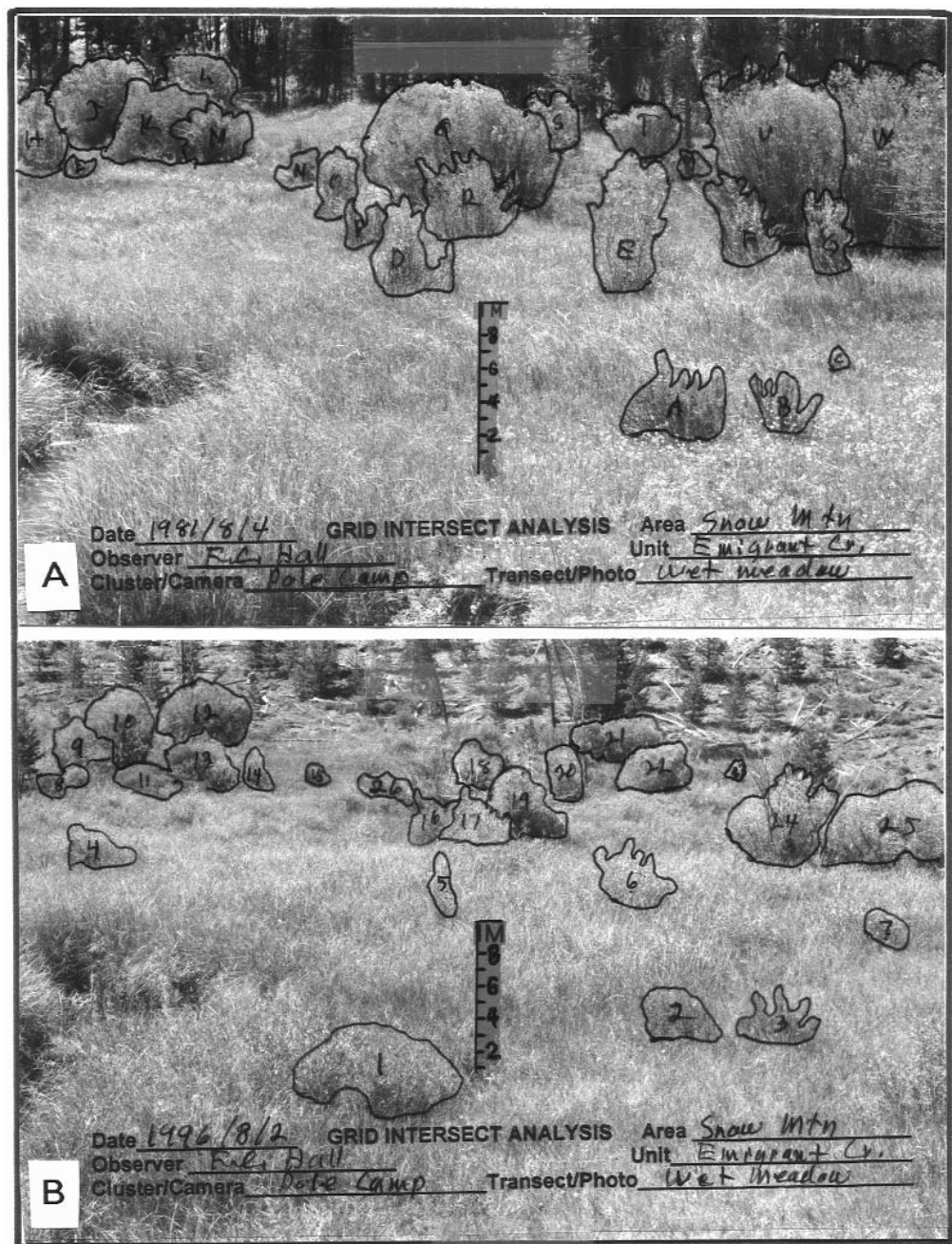


Figure 37—Photographs to be evaluated by grid analysis: (A) 1981 (from fig. 35), and (B) 15 years later in 1996. Clear plastic overlays (fig. 36) have been taped to each photo. Each overlay is a data sheet and therefore must have all information entered to identify the outlines. Date is the **photograph** date, not when the outline was drawn. First the meter board is outlined on its left side and top. Then each visible decimeter line on the meter board is marked and the decimeter number written on the overlay. Finally, each shrub is carefully outlined and given either a letter or number identification. The next step is size adjustment of the analysis grid (figs. 38 and 39).

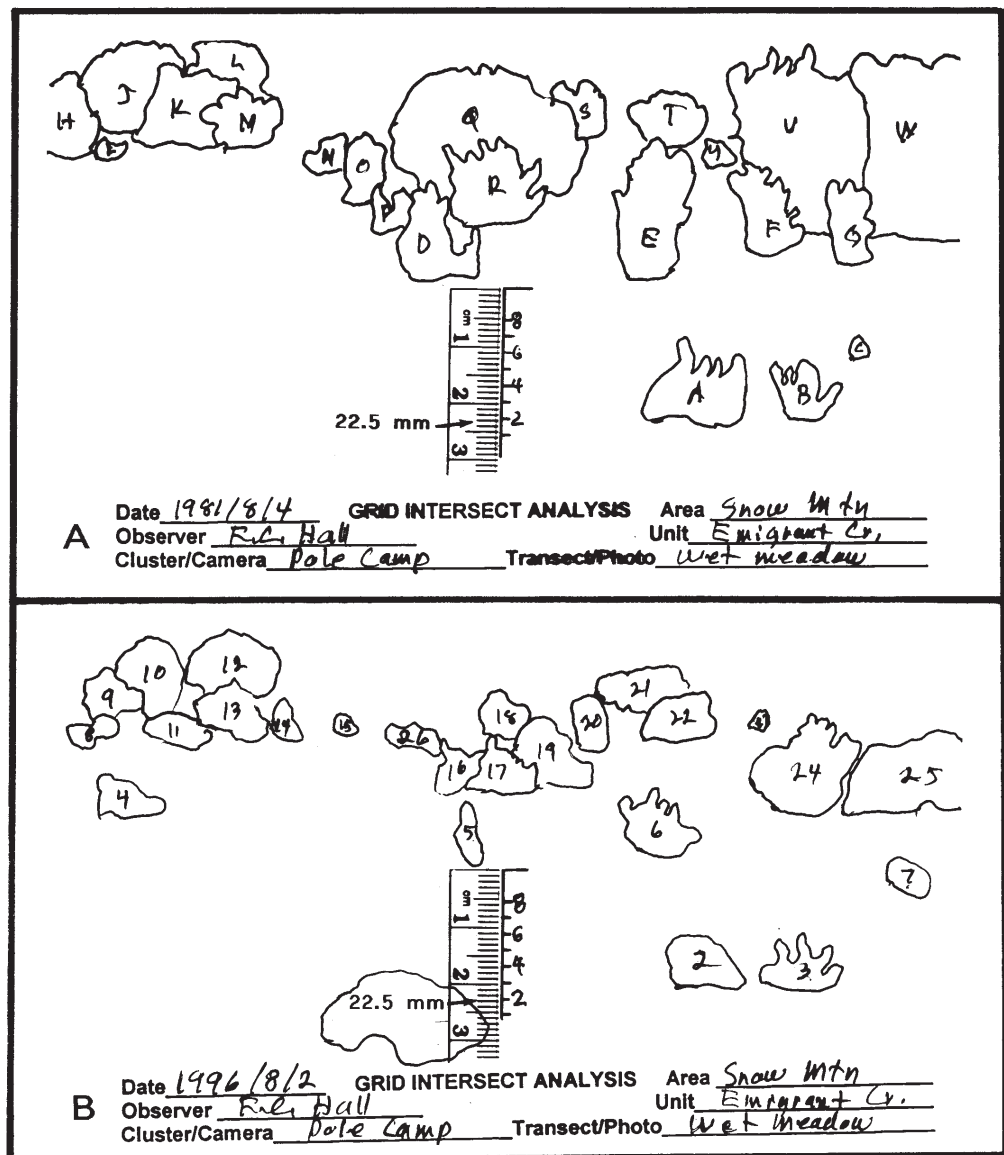


Figure 38—Measure meter boards for size adjustment of analysis grids: (A) 1981 and (B) 1996. Measure from the top down to the lowest visible decimeter mark to the nearest 0.5 millimeter, in these photos the 2-decimeter mark. Both measurements are 22.5 millimeters, which indicates that both are the same distance from camera to board and there was consistent enlargement of the photos. The analysis grid (fig. 39) will have to be reduced in size to exactly match the size of the meter boards in these outlines. An exact match is required for consistency in measurement between photographs.

should span 4 inch (1 dm) on the meter board. Print the adjusted grid on white paper. Outline the meter board and topics of interest in the photo on the clear plastic (fig. 37). For precise grid calibration, the meter board height should be at least 25 percent of the photograph height, preferably 35 to 50 percent. Each individual picture must be measured for grid adjustment. Tape the outline form onto the grid, carefully match the outline meter board with that on the grid, and count grid intersects that fall on and within each outlined topic.

Setting the Stage

Photography suitable for grid analysis includes the following:

1. Camera location and photo point (meter board) must be permanently marked so that exact relocation is possible. Stamped metal fenceposts driven 2 feet (0.6 m) into the ground work well.
2. Choose a distance from 16 to 65 feet (5 to 20 m), appropriate to the topic, for each site. Place a size control board (a 1-meter board or a double, 2-meter board; see figs. 21 and 35 in part A) such that the visible part of the board occupies at least 25 percent of the picture height. Then the meter board can be used to orient the photograph and adjust size of an analysis grid.

With a 50mm lens on a 35mm camera, a single meter board set 33 feet (10 m) from the photo point would span 25 percent of the photo height (figs. 31 and 33); at 23 feet (7 m), 36 percent. A double meter board, 7 feet (2 m) tall (app. B), spans 25 percent of photo height at 66 feet (20 m).

When grid analysis is planned, clip vegetation away from the front of the meter board to expose the bottom decimeter line. This will provide for maximum precision in grid adjustment.

3. When photographing, aim the camera view at the meter board. Place the ring in the viewfinder on the "1M" and focus (fig. 18 in part A). This provides for (1) reorientation of all subsequent photographs, (2) a sharp image at the topic marked by the meter board, and (3) an optimum depth of field.

Materials

Materials and equipment required for grid analysis are as follows:

1. Photographs of the setting. Print all photographs to be compared at the same size, preferably about 8 by 12 inches (20 x 30 cm), and in color for best differentiation of items to analyze. Figure 35, for example, is the wet meadow photo point at Pole Camp as taken in 1981. It will be compared to a photo taken in 1996 to appraise change in shrub profile area (fig. 37).
2. Clear plastic sheets used for overhead projection, such as 3M or Labelon Overhead Transparency Film. Film is designed specifically for various copy machines, such as inkjet, plain paper, or laser. Imprint these sheets with site information by using the form in figure 36 ("Grid Intersect Analysis") from appendix A.
3. A grid master form, which is shown in figure 39 (form is in app. A). Adjust the grid in size to precisely fit each picture and the outlined meter board as shown in figure 39. Instructions for grid size adjustment are given below.
4. Photo Grid Summary form (fig. 41 and app. A).
5. Permanent markers, such as Sanfords Sharpie Ultra Fine Point Permanent Marker, for drawing on clear plastic. Use different colors to aid in differentiating items when their outlines overlap, figures 38 and 40. Black, red, and blue work well together.

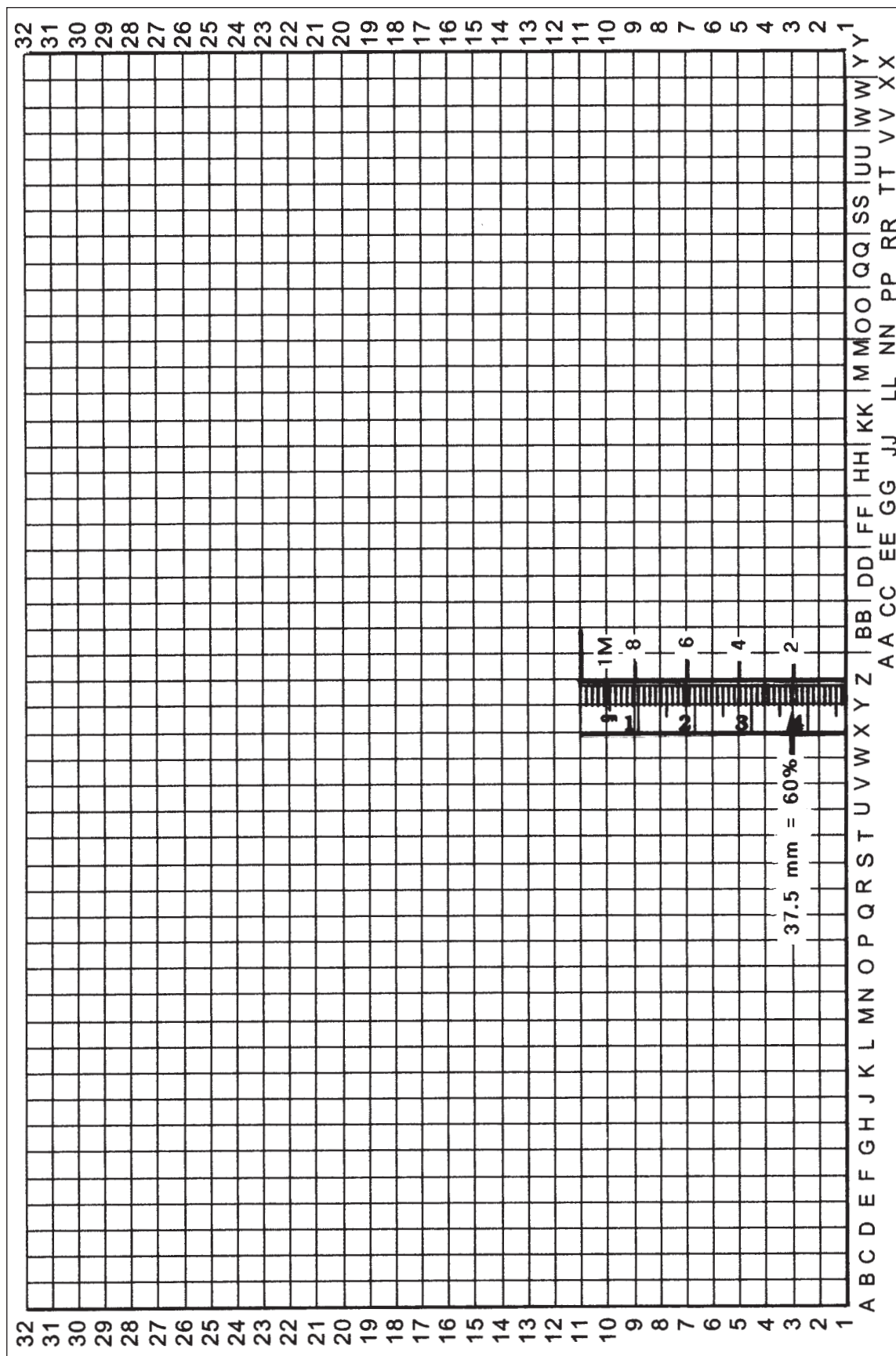


Figure 39.—The master analysis grid is in appendix A. Measure from the top of the meter board to the 2-decimeter mark used in the outlines. This measurement is 37.5 millimeters. Divide 22.5 millimeters from the outlines in figure 38 by 37.5 for a reduction to 60 percent of the grid. Print the grid on white paper at 60 percent of its original size. The outline is laid over the reduced grid to check alignment of the meter board marks. Minor adjustments in grid size are made so that marks of the overlay and grid meter boards match exactly (fig. 40).

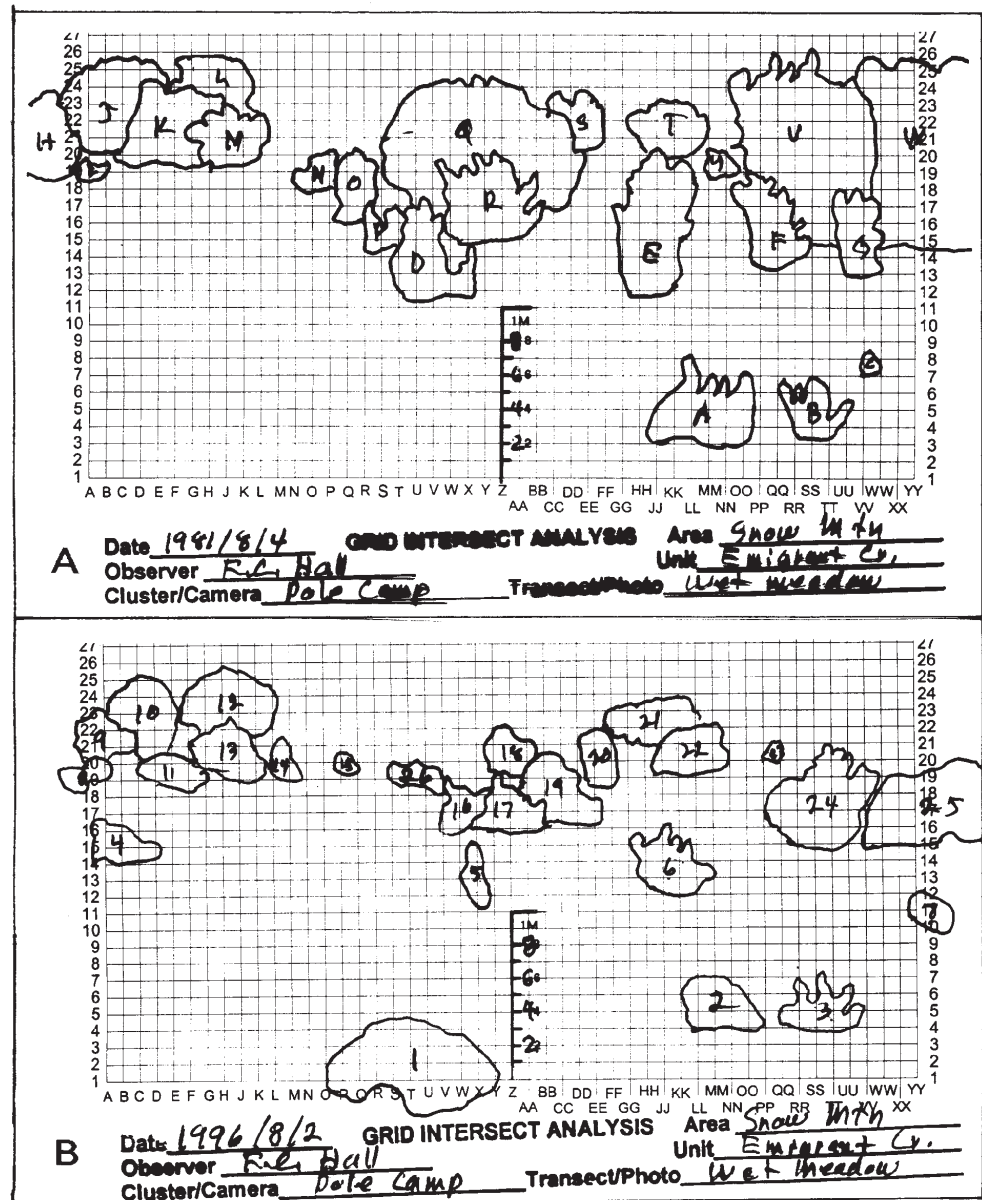


Figure 40—Outline overlays are placed on analysis grids for (A) 1981 and (B) 1996. The next step is to count grid intersects on and within each outline. When an outline crosses a grid intersect, such as between shrubs 17 and 19, AA-18 in photo (B), count the intersect for the shrub in front (number 17). Also count intersects along the grid edge, such as the five intersects in shrub 25 on line YY, photo (B).

6. Good quality hand lens to identify the periphery of items being outlined, in this case shrub profiles.
7. A copy machine that will produce clear plastic overhead projection copies and can adjust the size of the master grid to fit the photographs. Many copy machines can reduce to 50 or enlarge to 200 percent. Tape one grid, adjusted for size and printed on white paper, under each outline for analysis (fig. 40). Precisely align the outline meter board with the grid meter board.

PHOTO GRID SUMMARY

Date 1996/8/4 Observer F. C. Hall
Area Snow Mtn Unit Emigrant Cr.
Cluster/Camera Pole camp Transect/Photo Wet meadow

[illegible]

$$\frac{259}{401} = 0.648 = 65\%$$

67

Grid Adjustment

Outline interpretation requires use of a grid whereby each grid intersection on and inside an outline is counted and recorded. The grid must be adjusted in size based on the meter board outlined on each overlay.

1. Measure height of the meter board as it appears on the overlay to the nearest 0.5 millimeter. If the bottom line on the board is not visible, measure to the lowest visible decimeter mark. In figure 38 it is 2 decimeters, and measures 22.5 millimeters from top to 2 decimeters. Similar measurements between the 1981 and 1996 photographs indicate that distance from camera to meter board was the same and that both pictures were enlarged identically.
2. Next, measure height of the meter board on the grid. In figure 39 it is 37.5 millimeters from top to the 2-decimeter grid line (second from the bottom).
3. Determine the percentage of change required for the master grid: $22.5 \div 37.5 = 60$ percent. On a copy machine, reduce the grid to 60 percent and print on plain paper. Overlay the outline on the grid to determine any additional size adjustment (fig. 40). This usually requires two or three trials.
4. Place the clear plastic overlay with its outlines on the grid and ensure that grid divisions exactly match those on the overlay meter board. Orient the overlay on the grid by using the left side of the meter board outlines (fig. 40). When both overlay and grid meter board marks match exactly, tape the overlay to the grid.

Note the borders on the grid (fig. 39). These mark the maximum 12- to 15-percent angle useful for grid analysis.

Analysis of Photographs

Select a topic—For this example, change in willow profile area is the topic, thus, no other item—grasses, sedges, forests, or water—is outlined. Decide if individual shrubs will be evaluated or if all shrubs will be lumped together. In this case, individual shrubs will be evaluated. Proceed as follows.

1. Fill out all information on the clear plastic overlay ("Grid Intersect Analysis," app. A). It becomes the permanent data record and must be identified (fig. 36). Date is the **photograph** date, not the date of the outline.
2. Attach the plastic overlay to the photo at one edge, such as the top, so that it can be lifted for close inspection of the photograph and then replaced exactly (fig. 37).
3. With use of a straight edge, mark the left side of the meter board and its top on the overlay of each photo (fig. 37). Next, mark each decimeter division on the meter board and identify even-numbered decimeter marks by their number, such as 2, 4, 6, and 8 (figs. 38 and 40).
4. Select the topic; for example, shrub profile area. Start in front and work from left to right. Outline each element of the topic (shrub in this case) and label it with a letter or number (fig. 37). Labeling ensures that grid intersects on and inside an outline are not repeated or missed when recording data.

If identifying change in specific shrubs is desirable, each shrub identified in the initial photo will have to be identified in all subsequent photos, and the letter or number used initially will have to remain exclusive to the shrub or to the location where the shrub used to be. Any new shrubs will require their own exclusive new identification, such as shrub 1 in figure 37B.

5. When outlining, pay particular attention to the periphery of the shrub by following as carefully as possible the foliage outline. Do not make a general line around the outside of the shrub. Mark directly **on** the foliage, not outside of it. Check outlines by lifting the overlay to check the foliage and inspect with the hand lens.
6. Work back into the photograph. Overlapping shrubs are identified by the letter inside the front shrub outline (fig. 37). Overlapping outlines may be enhanced by using different colored marking pens. Intersects often will occur under an outline; count them for the shrub in **front** only (do not count the intersect twice).

Do not count intersects on outlines outside the grid.

7. On the filing system form "Photo Grid Summary" (fig. 41), fill in the required information and enter the year of the photograph in the "Date" column. This is the date on the plastic outline. List shrubs by letter or number in the "Item #" column. The form provides space for recording intersects for three photographs. Note that items, shrubs in this case, are not required to have the same identification. Here, shrubs from 1981 are letters and those from 1997 are numbers, because exact relocation of shrubs was not possible.
8. Starting in front and working from left to right, count the number of grid intersects on and within each outline. An intersect is where a horizontal and vertical grid line meet (intersect). Many times, the outline will separate two shrubs. When the outline covers an intersect, count it for the shrub in front. Do **not** count the intersect twice. See figure 40A: intersect BB-18 is on shrub "R" outline with shrub "Q" behind it. Record the intersect only for shrub "R." This is why outlining **on** rather than outside of shrub foliage is important. Do not try to count intersects of the shrub behind when they cannot be seen; for example, in figure 40A, intersects of shrub "Q" behind shrub "R." Count intersects on the edge of the grid but not beyond even though the shrub or outline might extend beyond the grid. The grid, not the photo coverage, defines the area of analysis.
9. Record the intersects for each shrub beside its letter or number (fig. 41). Recording by shrub letter or number is designed to simplify record keeping. One may stop or be disturbed at any time and still know what shrubs they have recorded and where to begin again. When finished, sum all the intersects.

Important note—Each picture is produced by enlargement of a negative. Seldom are two enlargements made at exactly the same scale even though the negatives might be precisely sized. Therefore, grids must be sized **independently** for each photograph (fig. 37).

Table 1—Effect of camera-to-meter-board distance on grid coverage at distances of 10, 20, 30, and 60 meters (33, 66, 98, and 198 ft) from the camera

Distance from camera to meter board	Ratio	Angle	Grid size at distance from camera of:			
			10 m	20 m	30 m	60 m
<i>Meters</i>		<i>Percent</i>	<i>Decimeters</i>			
5	1:50	2.0	2.0	4.0	6.0	12.0
7	1:70	1.4	1.4	2.8	4.2	8.4
10	1:100	1.0	1.0	2.0	3.0	6.0

height. Grids 2.2 percent larger in height are also 2.2 percent wider, which results in a 4.4-percent increase in outlined area. Thus the number of intersects on and within an outline can change by 4.4 percent.

A meter board occupying 33 percent of photo height would measure 1.2 inches (30 mm) in figure 38. A 0.02-inch (0.5-mm) difference here is only 1.7 percent change in grid size. The 1.7 and 2.2 percent represent measurement-precision errors.

Distance from camera to meter board also affects precision of measurement on items beyond the meter board. Table 1 illustrates the effects of three distances between camera and meter board and how they affect grid precision at various distances beyond the meter board. Because grids are adjusted to size at the meter board location, each grid is 4- by 4-inch (1 by 1 dm) in size at that location but changes as distances increase.

A grid adjusted to a meter board 16 feet (5 m) from the camera measures 8 inch (2 dm) between grid lines at 33 feet (10 m) from the camera. This is two times greater than a grid adjusted at 33 feet (10 m) from the camera. At 98 feet (30 m) from the camera, a grid adjusted to a board 16 feet (5 m) from the camera will cover an area 24 by 24 inches (6 by 6 dm). When adjusted to a meter board set 33 feet (10 m) from the camera, it will cover an area only 12 by 12 inches (3 by 3 dm)—one-half the dimensions and one-quarter of the area—a significant improvement in precision. Monitoring objectives help determine the optimum distance from camera to meter board when grid size adjustment and outline precision are being balanced.

Observer variability—“Perfect” outlines are influenced by three kinds of differences among observers.

1. Size adjustment of grids is influenced by observer skill. With a meter board at 25 percent of photo height, 0.02-inch (0.5-mm) measurement difference of the meter board can mean as much as 2.2 percent difference in grid dimensions and 4.4 percent difference in area. Meter boards closer to 33 percent of photo height and larger photographs help to reduce this error. I recommend 8- by 12-inch (20- by 30-cm) color photographs. A meter board at 33 percent of an 8- by 10-inch photo height would measure about 2.6 inches (66 mm). A 0.02-inch (0.5-mm) measurement difference would be only a 0.8-percent error.

Shrub	FCH	CE	DE	SE	MR	CQ	MN	Mean	Std.Dev.	5% CI	CI%Mean
A	10	9	12	8	13	8	7	9.571429	2.22539	0.8242813	8.611894322
B	4	3	5	2	4	3	2	3.285714	1.1126973	0.8242813	25.08682259
C	6	5	6	5	5	4	3	4.857143	1.069045	0.7919439	16.30472673
D	3	3	7	2	10	4	1	4.285714	3.1471832	2.3314196	54.39979127
E	22	13	26	22	23	17	15	19.71429	4.7509398	3.5194755	17.85241217
F	28	24	28	25	32	21	19	25.28571	4.4614753	3.3050415	13.07078572
G	17	12	18	14	19	15	11	15.14286	3.0237158	2.2399555	14.79215911
H	24	23	26	22	26	24	22	23.85714	1.6761634	1.2416946	5.204707832
J	30	23	26	24	30	25	21	25.57143	3.4086724	2.5251297	9.874808968
K	23	24	28	13	34	13	21	22.28571	7.6095178	5.6370978	25.29466952
L	86	81	79	91	82	81	77	82.42857	4.6853368	3.4708772	4.210769515
M	65	58	59	72	43	68	56	60.14286	9.5118973	7.0463722	11.71605833
N	6	6	5	6	6	6	5	5.714286	0.48795	0.3614713	6.325747193
O	7	4	5	4	6	5	5	5.142857	1.069045	0.7919439	15.39890858
P	14	14	14	12	16	13	13	13.71429	1.2535663	0.9286365	6.771307827
Q	9	12	11	11	7	14	9	10.42857	2.2990681	1.7031397	16.33147648
R	17	16	20	14	18	9	15	15.57143	3.5050983	2.5965616	16.67516637
S	24	23	22	16	22	24	21	21.71429	2.75162	2.0383881	9.387313837
TOTAL	395	353	397	363	396	354	323	368.7143	28.347335	20.999583	5.695353784
								MEAN	3.2249101	2.3432062	15.4060848

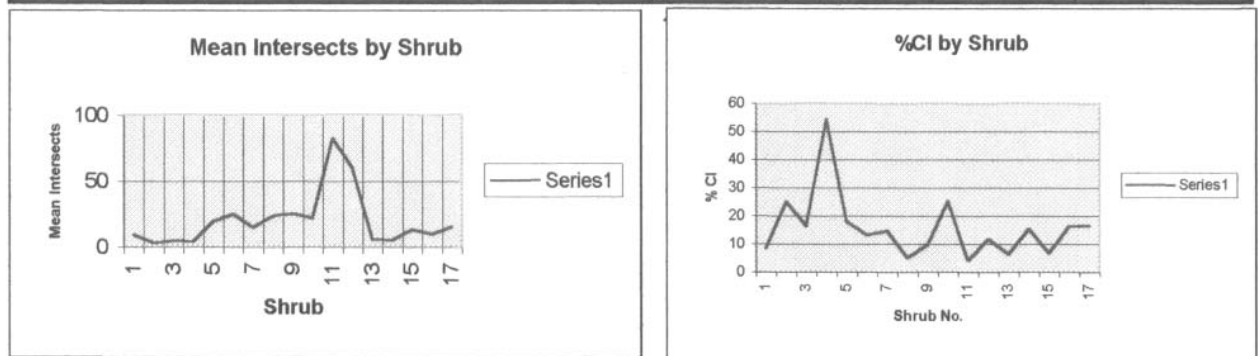


Figure 43—Summary of seven observers determining grid intersects on 18 shrubs in the same photograph. Variation among observers is characterized by the 5-percent confidence interval (5%CI) and expressed by dividing the 5%CI by the mean intersects by shrub and multiplying by 100 (CI%Mean). The mean and CI% Mean are graphed by shrub below the summary data.

2. The grid must be oriented exactly along the left side of the meter board as viewed (that is, the observer's left side) and precisely at the top and bottom or lowest clear decimeter mark. Orienting precision is subject to observer skill.
3. Interpretation of what constitutes the periphery of a shrub profile is subject to observer variability. One must make choices about where to place an outline and how precise it will be, particularly on overlapping shrubs. Note that an intersect is counted if the outline crosses it. The desirability, good or bad, of the topic being outlined tends to influence a person's willingness to include or exclude marginal parts. Outlining on clear plastic without grid lines tends to reduce observer bias.

A test was made in January 1998 of observer variability in outlining the shrub profile area shown in figures 35 and 37A. Results of the seven observers are given in figure 43. Color prints, 6 by 9 inches (15 by 22 cm) with properly sized grids, were provided. Observers placed the grids, outlined shrubs, and summarized intersects

Outline Analysis - 2 photos, 99/3

Photo	FH1	FH2	EC	DR	DF	MN	SE	CQ	Mean	Std.Dev.	Cof.Var.	Max.	Min.	Range	% Range	5%CI	CI%mean
1975	376	364	394	473	386	330	359	393	384.38	41.59305	10.82096	394	330	64	0.1665041	28.8219	7.49839184
1995	201	241	255	232	208	152	263	196	218.5	36.53961	16.72293	263	152	111	0.5080092	25.3202	11.5881706

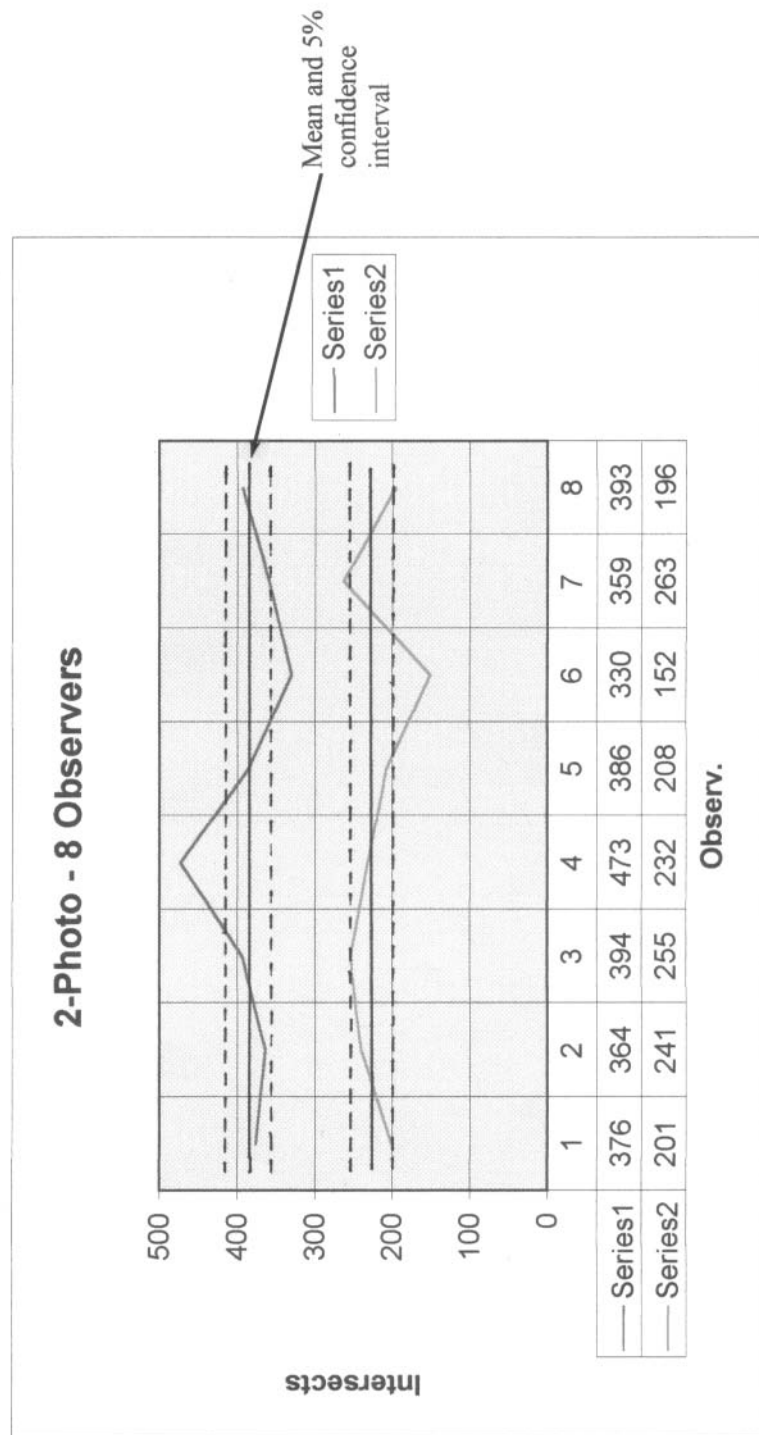


Figure 44—Outline analysis test for variation among eight observers in estimating shrub profile intersects. Photographs from 1975 (series 1) and 1995 (series 2) at the Pole Camp wet meadow photo point were compared. The 5%CI for 1995, 11.6 percent of the mean, is used to determine a significant change in shrub profile. FH1 and FH2 were observations by the same observer made 2 months apart to illustrate single-observer variability.

within each outline. Variation among observers was measured by the 5-percent confidence interval (CI). The CI also was calculated as a percentage of the mean: CI divided by the mean times 100 equals the CI% for each shrub, total of all shrub intersects, and an average CI. Low CI%, such as 5 percent (shrub H), is interpreted as low observer variability and that a change of more than 5 percent in intersects probably is a significant difference. High CI%, such as 25 percent (shrub B), means high observer variability and greater than 25 percent change is required.

The percentages for confidence intervals ranged from 4.2 percent (shrub L) to 54.4 percent (shrub D, fig. 43). The average CI% among the observers was 15.4 percent, which suggests that, to be significant, a change of more than 15 percent in intersects is required owing to observer variability. However, the CI% for total intersects of all shrubs combined was only 5.7 percent, indicating good concurrence between observers for the entire scene, a relation tested in 1999 and reported below.

The number of intersects in an outline seems to influence the CI%. Graphs at the bottom of figure 43 show higher CI% with lower intersects per shrub.

Differences in shrub profile area are rather clear in figures 41 and 42. Profile area in 1996 was 65 percent of that in 1981. Change in shrub profile is illustrated in figure 42. However, the reader may wish to test this for observer variability. Count the shrub profile intersects in figure 40 and compare to the data in figure 41.

Because CI% was rather high for individual shrubs, another observer variability test was conducted in winter 1999. Eight observers were provided with two photographs, one from 1975 and another from 1995, and asked to count total intersects of shrub profile. The CI% for 1975 was 7.5 percent and that for 1995 was 11.6 percent (fig. 44). The 1995 photo was more difficult to interpret.

The graphs in figure 44 illustrates the mean, 5-percent confidence interval, and observer variability by year. Using the largest CI%, 11.6 percent, the averages are significantly different at the 1-percent level of probability. Considering a maximum of 12-percent observer variability here and 15 percent for total individual shrubs, a value greater than 12 percent of the average intersects is proposed as being significant at the 5-percent level of confidence for observer variability. For example, a mean of 384 intersects must change by more than 46 to say that the change was real and not due to observer variability at the 5-percent level of confidence ($384 \times 0.12 = 46.1$). This may be expressed as 384 ± 46 and thus intersects greater than 430 or less than 338 may be considered a real change.

Studies, such as at Pole Camp where photographs are taken every year, are amenable to regression analysis of grid intersects. If the outlines are done by the same person, observer variability is reduced. Figure 45 illustrates regression on shrub profile intersects at Pole Camp from 1975 to 1997. Regression for the entire data set showed a decline at -0.63. However, when data were selected for the time when beavers were in the area, 1983 to 1994, the regression was at -0.90, highly significant. Trend lines such as these seem very useful.

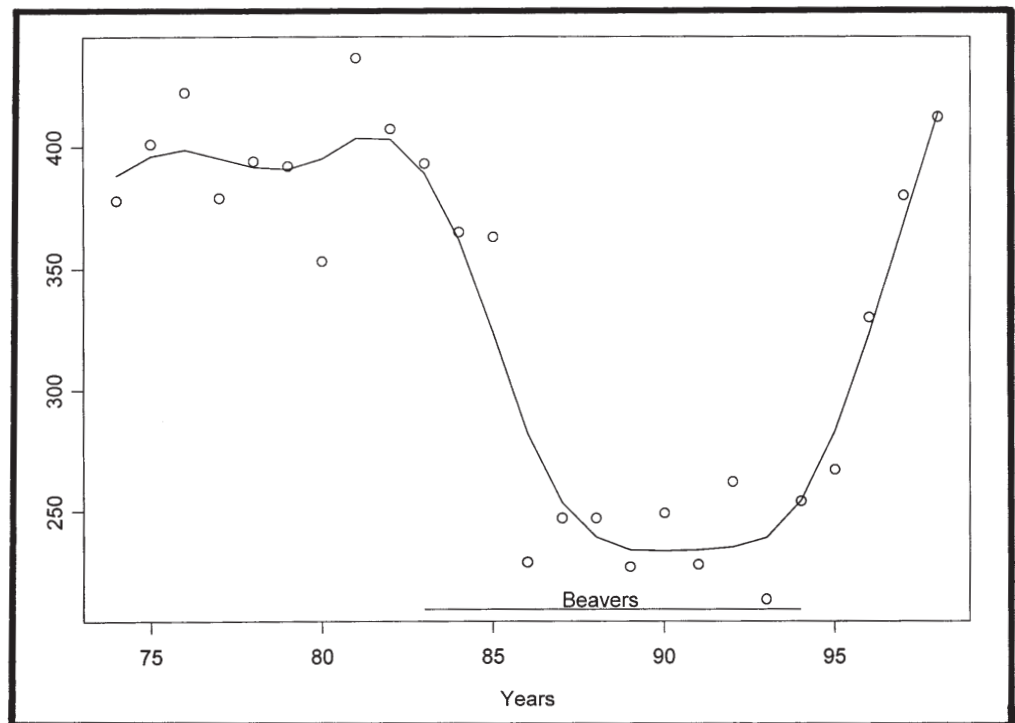


Figure 45—Regression of outline intersects from 1975 through 1997 for shrub profile changes at the Pole Camp wet meadow photo point. One observer made all 25 grid measurements. Intersects are totals from inside the grid area. Circles are the yearly total shrub intersects. The line is a smoothing spine regression. A note at the bottom of the graph indicates years when beavers were present.

Analyzing Location

Documenting change in position of items on a photograph requires precise photography. Three kinds of precision are required: (1) distance between camera location and meter board must be the same for all repeat photos, (2) height of camera above the ground and placement over the camera location stake must be the same for all repeat photos, and (3) sizing and orientation of the grid must be precise.

These variables do not consider observer interpretation. They do suggest that attempts to use photographs for monitoring change in position of objects is questionable if they are distant from the meter board. Table 1 illustrates effects of distance on grid precision. If documentation of position change is desired, place the meter board near the topic of interest, such as a streambank, and measure on the ground from the meter board to the object of interest.

Shrub Profile Grid Analysis

A review of photo grid analysis is required for this evaluation. Only highlights specific to shrub grid interpretation are presented here.

Photograph the shrubs from two directions as illustrated in part A, "Shrub Profile Photo Monitoring."

Print the photographs to be analyzed at 8- by 12-inches (20 by 30 cm) and in color for good resolution.

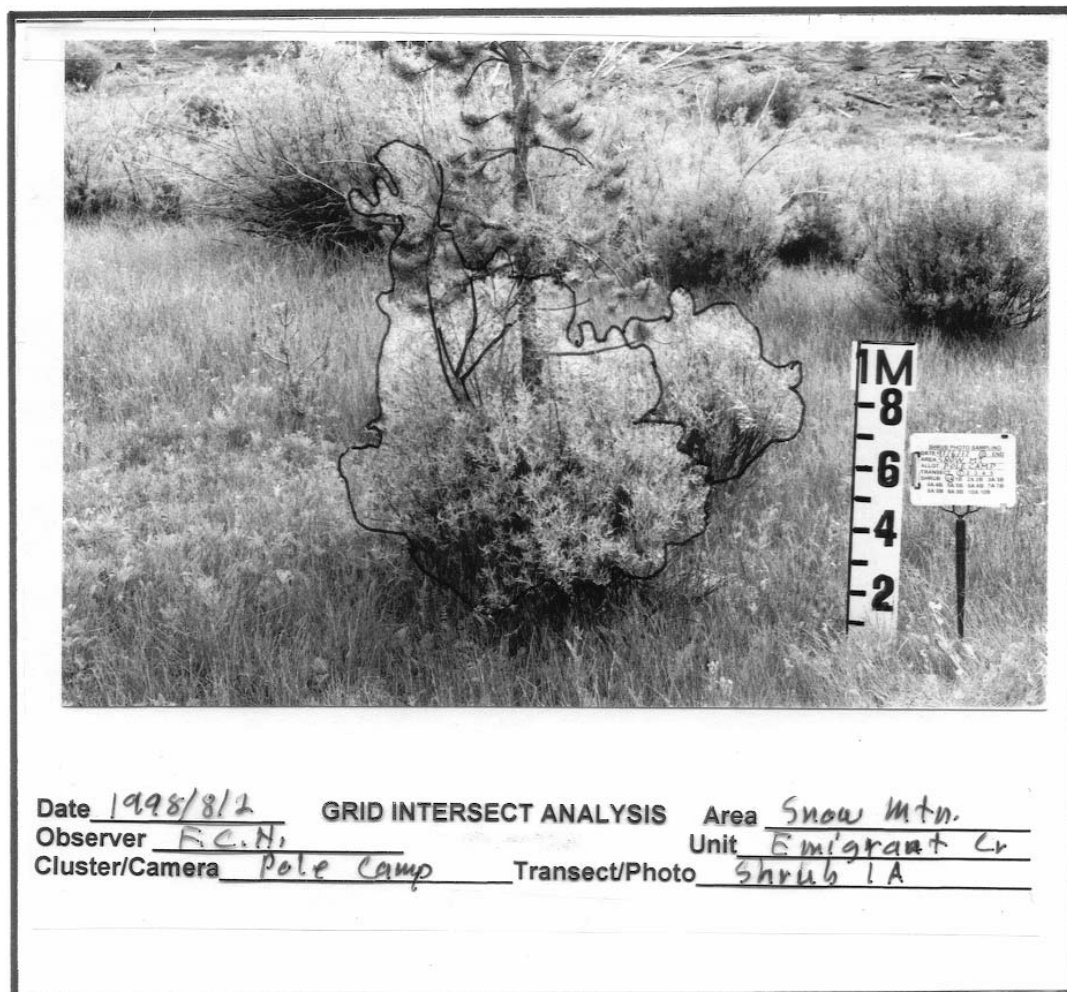


Figure 46—Grid analysis of shrub 1 on the Pole Camp shrub profile transect (see map, fig. 23, part A). This view is "1A" of the two photos of shrub 1 (1A and 1B, figs. 23 and 25). Both photos of shrub 1 are shown in figure 25, part A. The "Grid Intersect Analysis" outline form has been placed on the photo, information filled in, and the meter board marked. Outline as carefully as possible the shrub profiles. Do the same for the other photo of shrub number 1 (figs. 25, 1B, part A, and 47).

From appendix A, select the "Grid Intersect Analysis" form and duplicate on clear plastic. Fill out all information at the bottom of the form. "Date" is date of the **photograph**, not when the outline was made. The completed outline will become a basic data file and must be identified. Tape the outline form to the photograph along one edge such that the outline may be lifted for close inspection of the photo and then replaced exactly.

Outline the shrub or group of shrubs in the photo. Two shrubs are shown in figures 46 and 47. They have been separated for illustration purposes. Do not try to guess the outline of a shrub hidden behind another. Outline only what can be seen. Be as precise as possible. In figures 46 and 47, large willow branches have been marked on the overlay. The branches are clearly shown in figure 25 in part A.

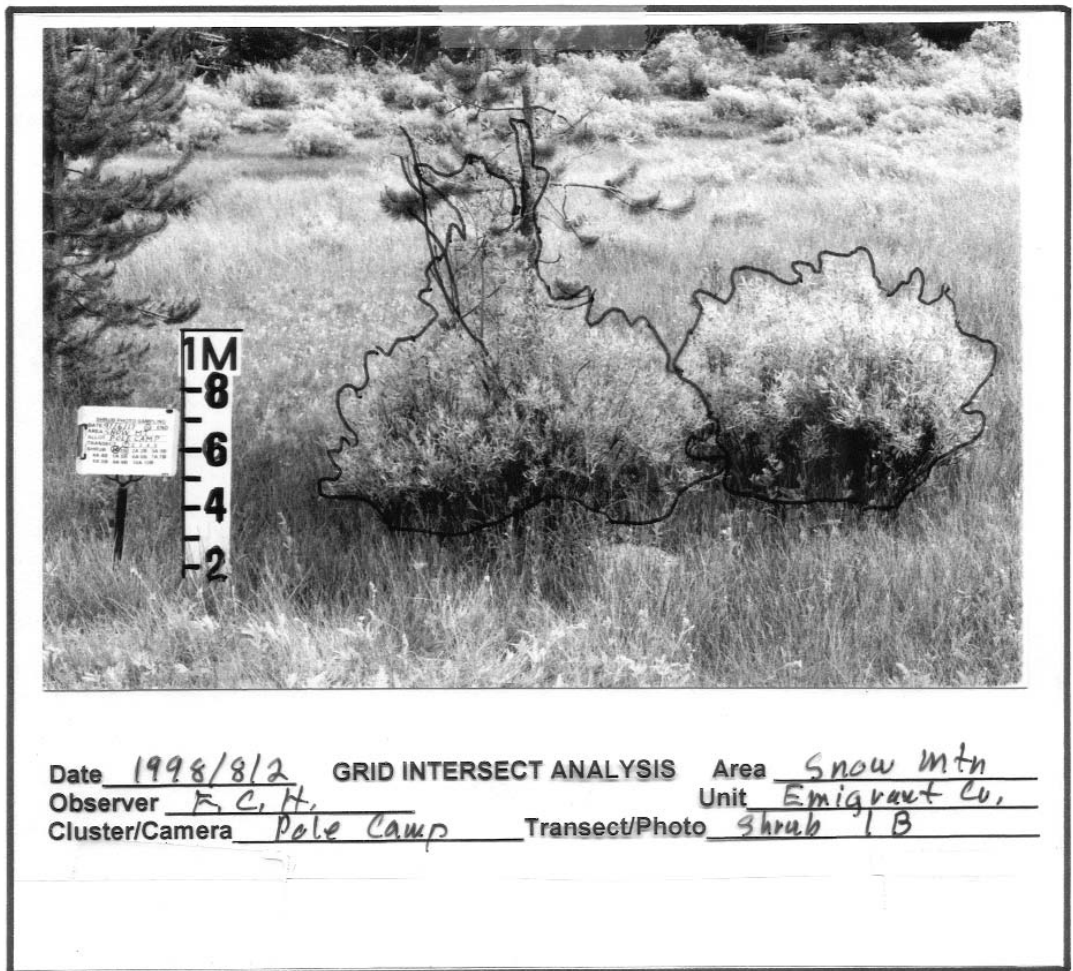


Figure 47—Outline of the second photo of shrub 1 (1B, fig. 25, part A), on the Pole Camp shrub profile transect. When two shrubs are present, separate their outlines as shown. Information at the bottom of the clear plastic overlay must be filled in for each photo. Remember to outline and mark the meter board. Outline **on** the foliage, not around it, to increase precision.

Next, adjust the shrub analysis grid, the one with meter boards at each side (app. A), to exactly match the outline meter boards as discussed in "Photo Grid Analysis," above. Tape the outline form to the adjusted grid (fig. 48).

Count intersects within each outline including those falling under an outline (fig. 48), and enter on the filing system form "Photo Grid Summary" (fig. 49). Refer to the section "Analysis of Change, Observer Variability," above, for a discussion of what constitutes a significant change in shrub profile area.

The reader may wish to test observer variability. Count grid intersects in figure 48 and compare to the results shown in figure 49. Expect a difference of three to six grid intersects.

Text continues on page 80.

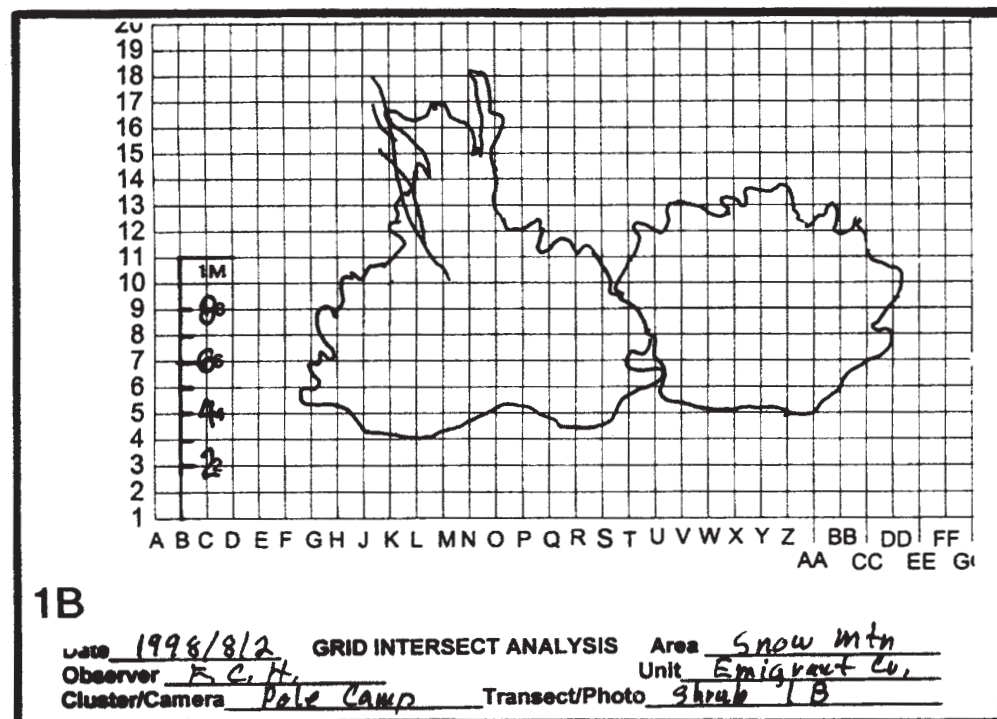
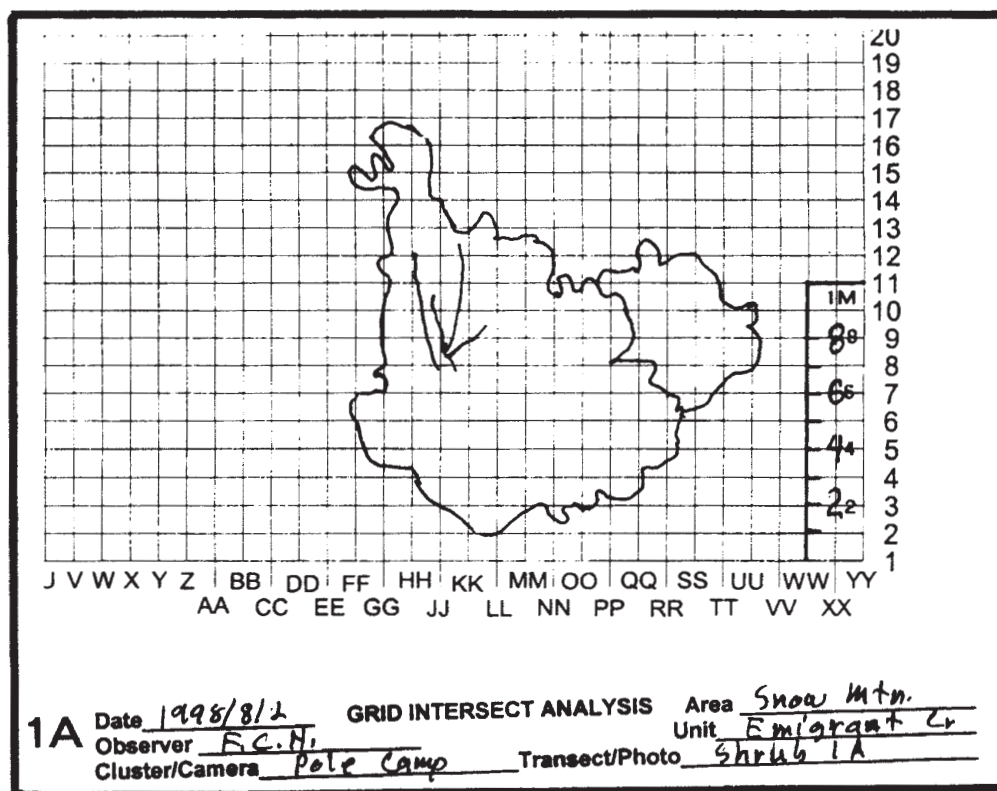


Figure 48—Grid outlines for shrub 1, photos (1A) and (1B) (figs. 46 and 47), on the Pole Camp shrub profile transect. Grids have been adjusted for size by the outlined meter board. Outlines are then taped to the grid. Count grid intersects and record on the filing system form "Photo Grid Summary" (fig. 49).

PHOTO GRID SUMMARY

Date 1998/8/4 Observer F. C. H.
Area Snow Mtn Unit Emigrant Cr.
Cluster/Camera Pole Camp Transect/Photo Shrub transect

[illegible]

79

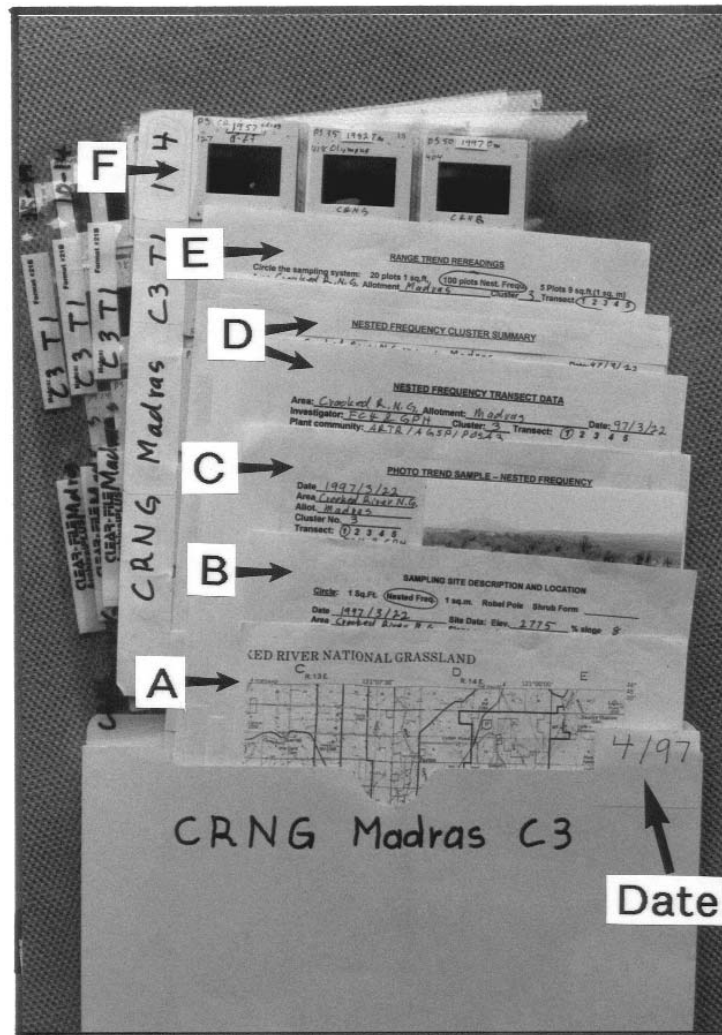


Figure 50—File folder contents for the Crooked River National Grassland trend cluster C3. Several sizes of expanding folders may be used: two-fold shown here, four-fold, or eight-fold to fit the file size. Each folder is labeled and the last date of sampling is attached to the upper right corner (arrow). All items pertaining to the sample location are included in the file: (A) general area map (fig. 5); (B) the form “Sampling Site Description and Location” for a plot layout map (fig. 6); (C) a form for attaching photographs and recording data shown here as the “Photo Trend Sample - Nested Frequency,” similar to figure 11; (D) data summary forms shown here as “Nested Frequency Transect Data” and “Nested Frequency Cluster Summary”; (E) trend interpretation using “Range Trend Rereadings”; and (F) clear plastic holders for slides. Not shown are black-and-white negatives in their envelopes identified by date, cluster, and transect.

Filing System

Photo monitoring requires a way to file maps, data, slides, prints, negatives, or digital memory cards. My system places each study in an expandable file containing everything (fig. 50): local map to find the study site (fig. 5, part A), the “Photographic Site Description and Location” with map of the photo monitoring layout (fig. 6, part A), photo mounting forms for color or black-and-white prints (figs. 2 and 11, part A), analysis grids if used, and clear plastic slide holders. Negatives are filed in their envelopes from processing. Two prints are made of each negative, one for mounting and one to be kept in the envelope for future use. Digital images may be filed as memory cards or as compact disks (CDs), which are recommended. The disk

should have an index card where identification of each image is stored. If images are stored on a computer (not recommended), identify the location and name of the computer, and the file where stored.

The expandable files are in a file cabinet dedicated to sampling and organized first by geographic location and then by date for next photography. Filing of studies by geography greatly facilitates travel planning. Noting the next photography date on each file helps in seasonal planning (fig. 50).

Literature Cited

Johnson, C. 1991. A photo point system: Eco-Area 3. Baker City, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest.

Kodak. 1999a. Digital learning center. <http://www.kodak.com/US/en/digital/cameras>. (March 2000).

Kodak. 1999b. Learn about digital cameras. <http://www.kodak.com/US/en/digital/cameras>. (March 2000).

Magill, A.W. 1989. Monitoring environment change with color slides. Gen. Tech. Rep. PSW-117. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 55 p.

Maxwell, W.G.; Ward, F.R. 1980. Guidelines for developing or supplementing natural photo series. Res. Note PNW-358. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Reynolds, M. 1999. Residual leaf area as a measure of shrub use. Corvallis, OR: Oregon State University. 104 p. M.S. thesis.

Rogers, G.F.; Turner, R.M.; Malde, H.E. 1983. Using matched photographs to monitor resource change. In: Bell, J.F.; Atterbury, T., eds. Renewable resource inventories for monitoring changes and trend: Proceedings, international conference. Corvallis, OR: College of Forestry, Oregon State University: 90-92.

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Appendix A: Forms

This appendix contains forms for photo point monitoring. They may be copied onto three colors of paper or clear plastic for overhead projection, depending on their use.

Paper Color

Office forms are printed on standard white paper.

Field forms should be printed on either of two paper colors: blue for forms placed in photographs to identify each photo or yellow for field forms to ease eye strain. Outline forms for grid analysis are printed on clear plastic. Grids and summary forms are printed on white paper. Paper color suitable for each form is shown in **bold**.

Blue paper is Hammermill Brite Hue Blue or Georgia Pacific Papers Hots Blue to be used in photographs to identify the slide or negative. This shade of blue has proven to be least sensitive to changes in sunlight, from full sun to shade, and has the least tendency to “bleach out” in full sun.

Yellow paper is Champion Goldenrod or Hammermill Copy Plus GOLDENROD to be used for field forms. It has proven to be least annoying to eyes under direct sunlight when recording data, maps, diagrams, and other descriptions.

Clear plastic sheets for printing outline overlays are 3M or Labelon Overhead Transparency Film. These films are specifically designed for different printers such as laser, inkjet, or plain paper.

White paper is used for summary forms and for grids adjusted to the size of the outline overlays.

Forms and References

Forms are listed below by page number, and examples of their use are shown by figure number (figures are from both part A and part B). Several forms consist of two or three pages. The first page lists all pertinent items and the photo number. A second page leaves the photo number blank to be filled in as required. For example, "Camera Location and Photo Points" lists photo "A" and "B" on the first page and has a blank for photo points on the second page. Print enough of the second pages to mount pictures of the photo points established. Similar multipage forms are "Photo Points and Close Photos," "Photo Points with Overhead Views," and "Shrub Photo Transect."

Form	Page	Figure examples
Paper colors for field use	85, 87	None
Photograph identification forms; print on blue paper		
Camera-Photo	89	2, 10
Shrub Photo Sampling	90	25
Sampling location maps; print on yellow paper :		
Photographic Site Description and Location (map)	91	6, 12
Sampling Site Description and Location (map)	92	22, 23
Photo mounting and data forms; print on yellow paper :		
Camera Location and Photo Points	93	13 - 15
Photo Points and Close Photos	95	11
Photo Points with Overhead Views	97	28
Shrub Photo Transect	99	25
Grid Intersect Analysis Outline Form; print on clear plastic	102	36, 37, 38, 40, 42, 46 to 48
Analysis Grids: adjust size and print on white paper		
1 meter	103	39, 40
2 meter	104	none
Shrub Analysis	105	48
Photo Grid Summary Form; print on white paper	106	39, 49

Paper found best for photo identification is this color blue.

It is **Hammermill Bright Hue Blue[®]**

or **Georgia Pacific Papers Hots Blue[®]**

This page was intentionally left blank.

Paper color that is easy on the eyes and used for mapping the monitoring system and recording field notes for mounting photographs.

It is **Champion Goldenrod®**

or **Hammermill Copy Plus GOLDENROD®**

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DATE

AREA

UNIT

CAMERA: 1 2 3 4 5

PHOTO: A B C D

E F G H I J

SHRUB PHOTO SAMPLING

DATE _____ 0 _____ END _____

AREA _____

ALLOT. _____

TRANSECT 1 2 3 4 5 _____

SHRUB 1A 1B 2A 2B 3A 3B

4A 4B 5A 5B 6A 6B 7A 7B

8A 8B 9A 9B 10A 10B

PHOTOGRAPHIC SITE DESCRIPTION AND LOCATION

Date _____ Area _____

Unit _____ Observer: _____

No. of Camera locations: _____ No. of Photo points: _____

Plant community _____

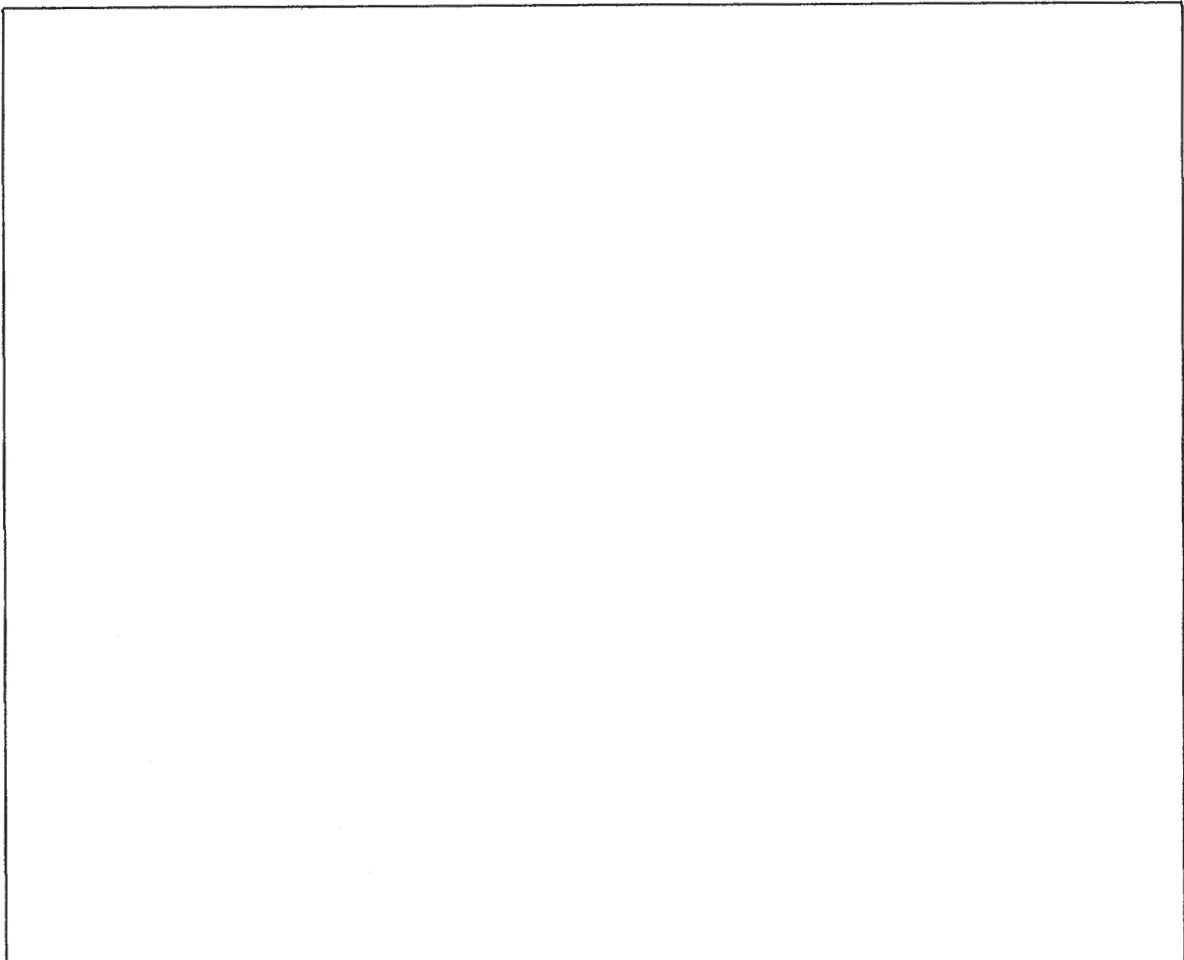
Location: T. _____ R. _____ Sec. _____

Location description _____

Photo purpose: _____

Discussion: _____

MAP



Use back of sheet for additional details.

SAMPLING SITE DESCRIPTION AND LOCATION

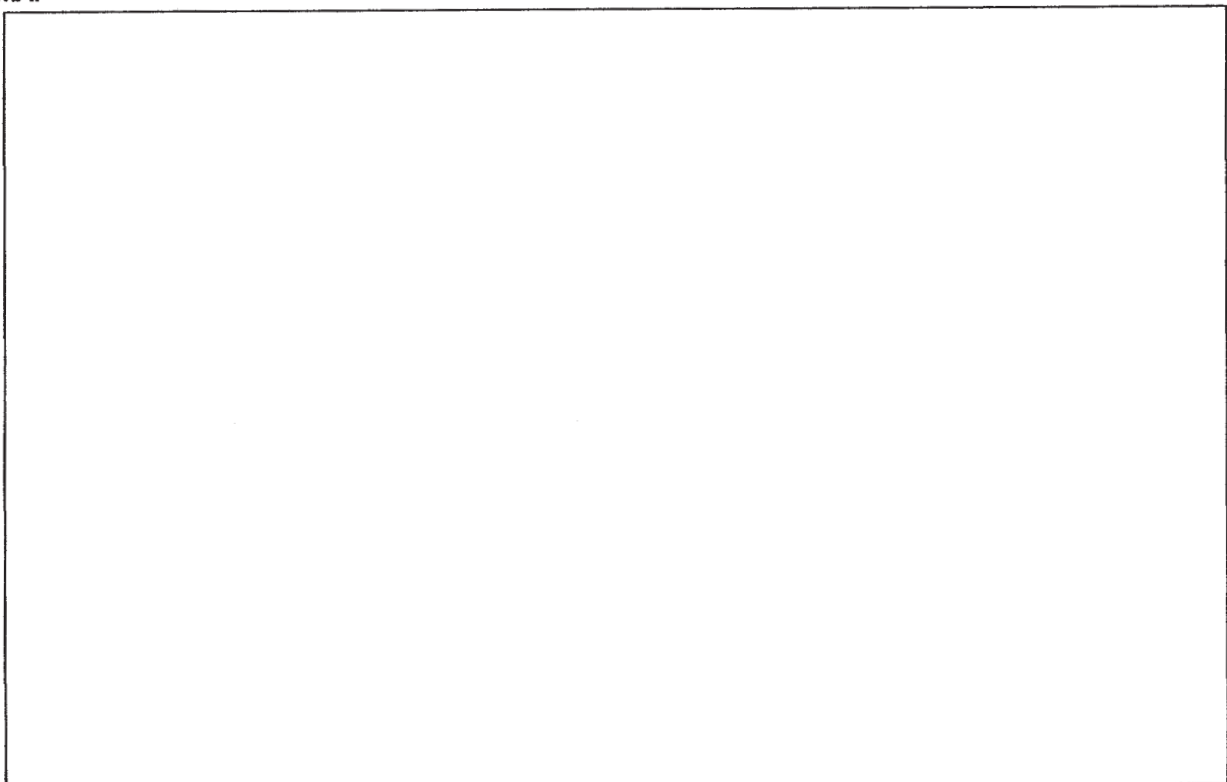
Circle: 1 Sq.Ft. Nested Freq. 1 sq.m. Robel Pole Shrub Form _____

Date _____ Site Data: Elev. _____ % slope _____
Area _____ Slope aspect: N NE E SE S SW W NW
Allot. _____ Slope position: top up 1/3 mid low 1/3 bottom
Cluster No. _____ Micro topography: convex flat concave
Transects: 1 2 3 4 5 Macro topography: flat undulating rolling
Plant community _____ steep rough broken

Geology: _____
Grazing system: _____ Deposition: wind stream lake colluvial
Type _____ Date _____ residual _____
Type _____ Date _____ Material: limestone mudstone sandstone
Type _____ Date _____ granite serpentine diorite
basalt andesite rhyolite
Kind of animal: cattle sheep
horses goats deer
elk _____ tuffaceous cinders pumice ash

Soil: _____
Restrictive layer: absent clay pan bedrock
cemented _____
Location: T. _____ R. _____
Sec. _____ Surface compaction: none moderate severe
Soil profile stone: absent gravel stony
Description: _____ Soil texture: sandy loamy silty clayey ashy
_____ Other notes: _____

MAP



CAMERA LOCATION AND PHOTO POINTS

Date _____

Camera Location

Area _____ **Number of Photo points:** _____

Unit _____ Observer _____

Comments

Slope _____ Aspect _____ Slope position _____

Photo point A:

Compass bearing: _____

Distance: _____

1. *Journal of Management Studies*, 1997, 34, 1, 1-14.

Photo point B:

Compass bearing:_____

Distance: _____

Photo Point A

Photo Point B

CAMERA LOCATION AND PHOTO POINTS

Date _____ Camera Location _____

PhotoPoint _____
Compass bearing: _____
Distance: _____

Photo point _____

Photo Point _____
Compass bearing: _____
Distance: _____

Photo point _____

Photo Point _____
Compass bearing : _____
Distance: _____

Photo point _____

PHOTO POINTS AND CLOSE PHOTOS

Date _____ Camera _____

Area _____

Unit _____

Photo point: A

Observer _____

Remarks _____

Photo point A:

Left of meter board

Species/cover: _____

Comments: _____

Photo point A:

Right of meter board

Species/cover: _____

Comments: _____

General photograph of point A

Close photo to left of meter board

Close photo to right of meter board

PHOTO POINTS AND CLOSE PHOTOS

Date _____
Area _____
Unit _____
Camera _____
Photo point: _____
Observer _____
Remarks _____

General photograph of point _____

Photo point _____
Left of meter board
Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point _____
Right of meter board
Species/cover: _____

Close photo to right of meter board

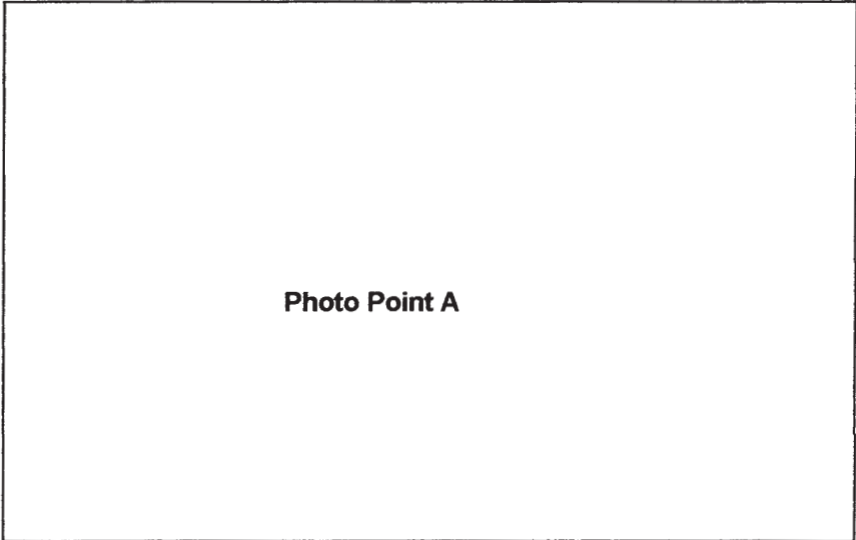
Comments: _____

PHOTO POINTS WITH OVERHEAD VIEWS

Date _____ Camera Location _____
Area _____ Number of photo points _____
Unit _____ Observer _____
Comments _____

Slope _____ Aspect _____ Slope position _____ Topography _____

Photo Point A
Compass bearing _____
Distance _____
Photo comments: _____



Overhead of Photo Point A
Comments: _____

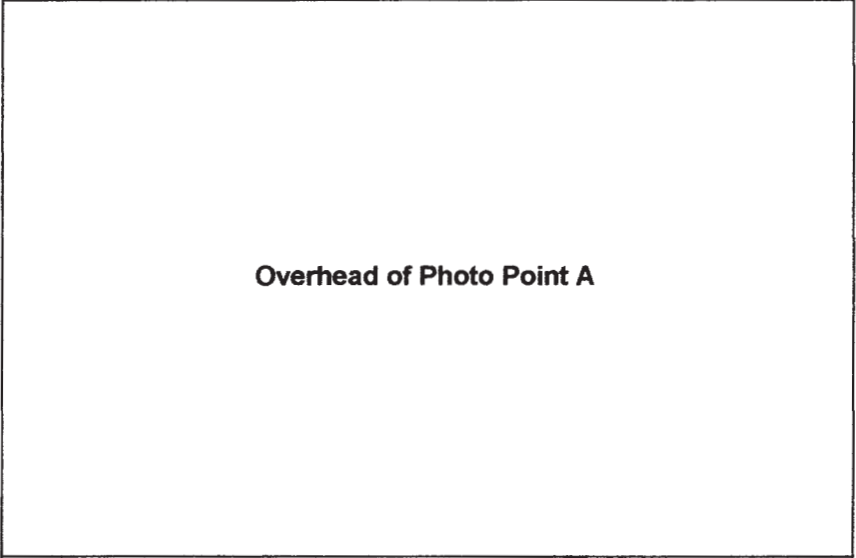


PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point _____
Compass bearing: _____
Distance _____
Photo comments: _____

Photo Point _____

Overhead of Photo Point _____
Photo comments: _____

Overhead of Photo point _____

SHRUB PHOTO TRANSECT

Date _____ Cluster _____ Transect 1 2 3 4 5

Area _____

Allot. _____

Investigator: _____

Season of use _____

Grazing system: _____

Animals _____

Direction _____

Distance _____

General photograph down the transect

Shrub 1A

Direction _____

Distance _____

Comments _____

Shrub 1A

Shrub 1B

Direction _____

Distance _____

Comments _____

Shrub 1B

SHRUB PHOTO TRANSECT

Shrub ____A

Direction _____

Distance _____

Comments _____

Shrub ____A

Shrub ____B

Direction _____

Distance _____

Comments _____

Shrub ____B

SHRUB PHOTO TRANSECT

Shrub ____A

Direction _____

Distance _____

Comments _____

Shrub ____A

Shrub ____B

Direction _____

Distance _____

Comments _____

Shrub ____B

View up the transect:

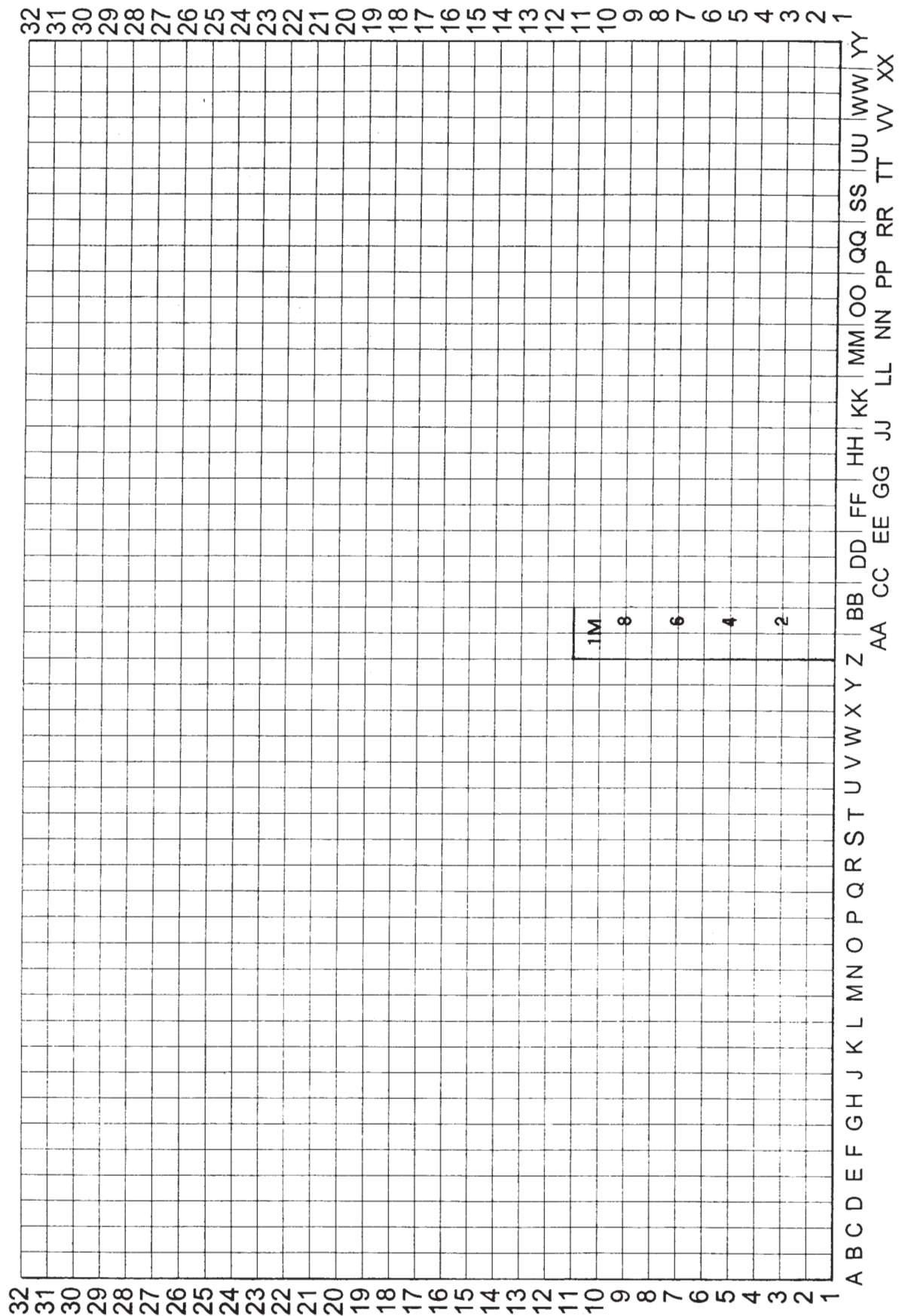
Direction _____

Distance _____

Comments _____

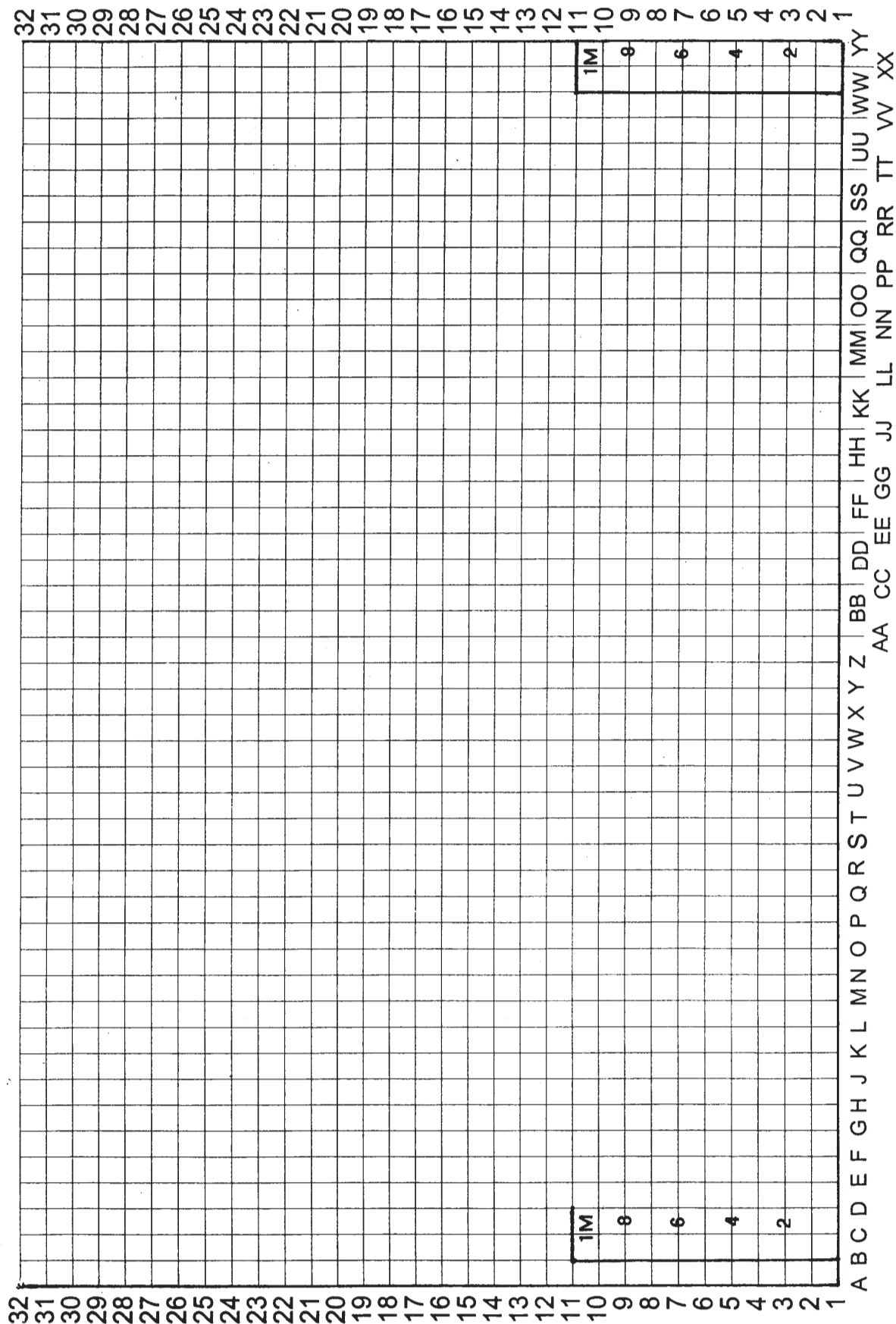
General view up the transect

Date	_____	GRID INTERSECT ANALYSIS	Area	_____
Observer	_____	Unit	_____	_____
Cluster/Transect	_____	Transect/Photo	_____	_____



ANALYSIS GRID - 1 METER

ANALYSIS GRID - 2 METER



ANALYSIS GRID - SHRUB ANALYSIS

1999/2/19

PHOTO GRID SUMMARY

Date _____ Observer _____

Area _____ Unit _____

Cluster/Camera _____ Transect/Photo _____

[illegible]

Appendix B: Equipment

Introduction

This appendix illustrates equipment required for photo point monitoring. Six items are discussed: meter boards, photograph identification sheet holder, camera leveling system for overhead photography, bracket for using two cameras (one with color and the other with black-and-white film), orange tags for identifying monitoring sites, and flimsy fenceposts.

Meter Boards

Meter boards are used to mark photo points. They help in taking consistent repeat photographs by orienting the camera on the "1M" of the board. Sharp exposure at the meter board is assured by focusing the camera on the "1M." The meter boards also provide a size control in photographs that can be used to adjust analysis grids when measuring attributes in a photo. This section describes how to construct meter boards.

1-meter board—

Materials—Prices given are in dollars as of 2001.

	Cost
	<i>Dollars</i>
1 piece ½-inch, 4-ply plywood, finished on one side, exterior, 1 foot by 4 feet @ \$20 per sheet	3
3/16-inch-diameter steel rod, 36 inches long	1
Numbers:	
5¼ inches tall, on a reflector, adhesive, packet of 10 (need 2, 4, 6, 8)	4
(Alternative is 4-inch nail-on numbers [5 @ \$2 each])	(20)
Line or pocket level 4 to 5 inches long	4
16-ounce can of yellow spray paint, exterior	4
Screws:	1
2 line level screws #4 ⅝ inch	
9 spike plate screws #6 ¾ inch	
1 role black electricians tape	4
Total	21

Construction—Meter boards are constructed from ½-inch 4-ply plywood, at least exterior quality and preferably marine quality (waterproof glue). Waterproof glue is desirable when sampling in riparian areas is expected because the meter board often will be placed in water. Dimensions and layout are shown in figure 51. Cut out according to specifications (fig. 51).

Prime the front of the board before painting. Then apply two coats of dull textured yellow to reduce reflection from the sun. Yellow is used for visibility. If dull yellow is not available, do not sand or smooth the front of the board. Roughness tends to diffuse sun reflection because it adds roughness to the paint. Most of a 12-ounce pressure can will be required for two coats.

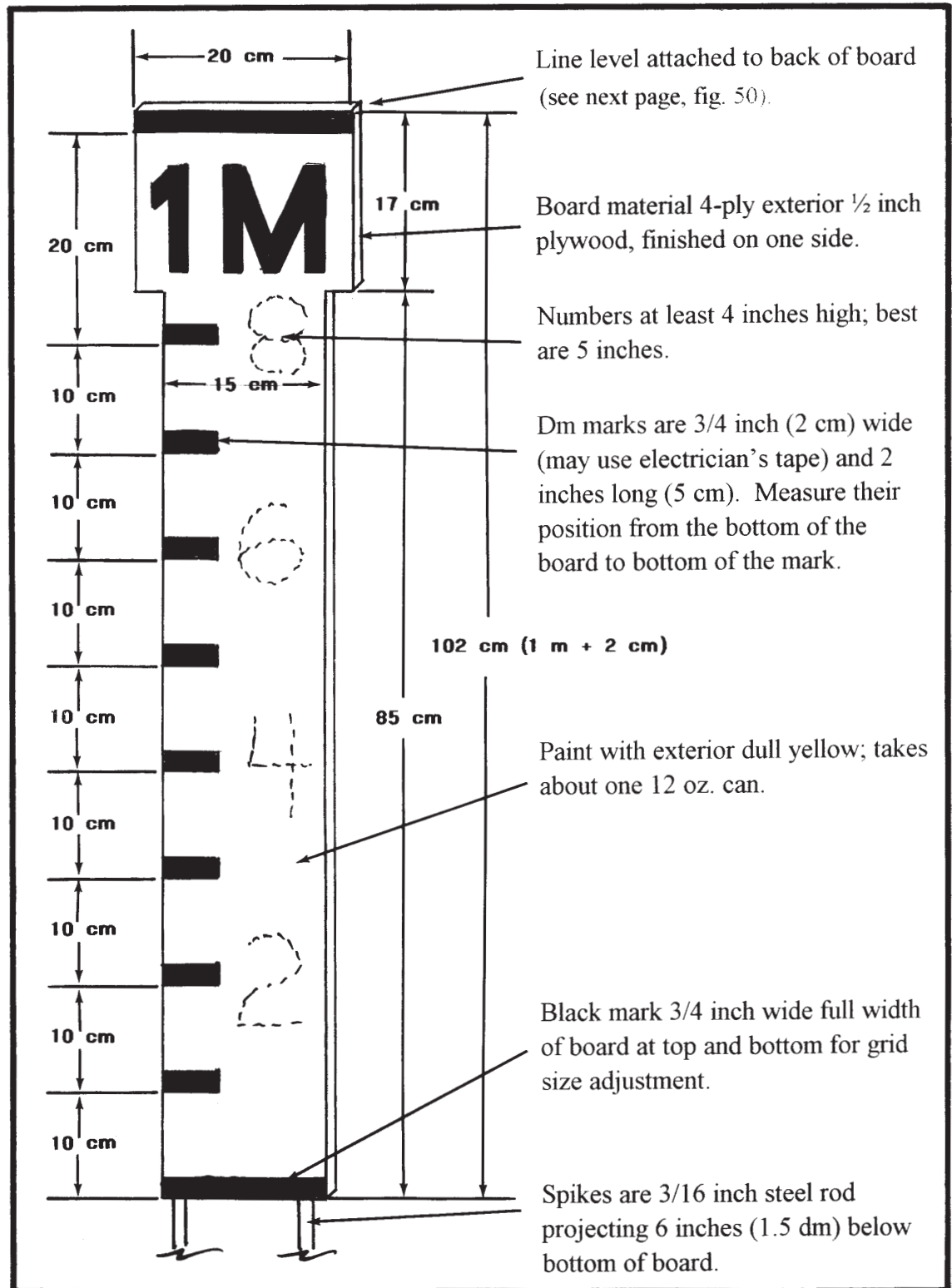


Figure 51—Construction details of a 1-meter-tall meter board. The same measurements are used for the 1-meter-tall folding board. A 2-meter folding board, hinged at 1 meter, has a 2-centimeter difference in board heights. See figure 54 and text for details.



Figure 52—A line level is used to orient the board vertically. Obtain a 4- to 5-inch-long (10- to 12-cm) line level and drill a hole in each end for a screw. Attach one end of the line level to the back of the meter board $\frac{1}{2}$ inch (1 cm) from the top. Then orient the board vertically by using a carpenters level along one side. Hold the board in position, adjust the line level to horizontal, and carefully screw in the other end.

Numerals—The numerals 2, 4, 6, and 8 should be black and at least 4 inches tall. My preference is 5 inches tall for good readability when slides are projected. All illustrations in this publication show 5-inch numbers. There are many sources of these, including paste-on numbers, numbers on a card that must be cut out, and nail-on numbers. I use $5\frac{1}{4}$ -inch-tall numbers on a reflective card with adhesive on the back. Each number must be cut out and applied to the painted surface. The “M” for “1M” is made from electrician’s tape or it may be painted on.

Black marks at each decimeter and bands at top and bottom may be applied in either of two ways: painted at 0.78 inch (2 cm) wide or by use of black electricians tape, which is $\frac{3}{4}$ of an inch wide (1.8 cm). The top, bottom, and decimeter marks are used to adjust grid size before grid analysis of items in the photographs. The marks on the meter board, therefore, must be positioned exactly (fig. 51).

Line level—A line level is attached to the back of the board at the top (fig. 52). This allows the board to be oriented vertically, which not only is essential for grid analysis but also makes pictures look good.

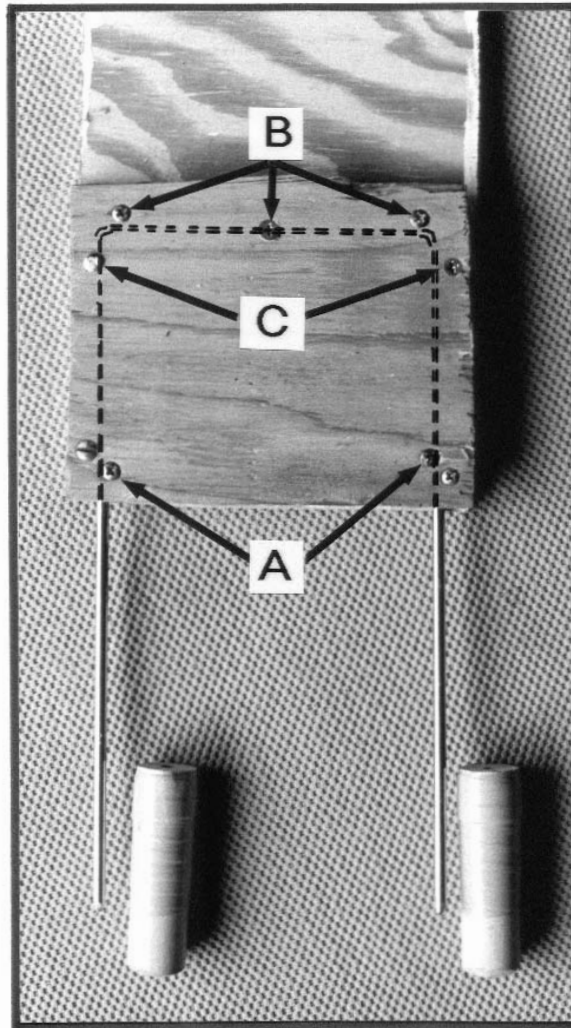


Figure 53—Spikes in the bottom of the board are pushed into the ground to hold the board upright. Use 3/16-inch-diameter steel rod about 30 inches (75 cm) long. Bend it into a “U” shape as shown by the dotted line. It is placed under a plywood plate and held in place by nine screws. Leave about 6 inches (1.5 dm) of rod below the board. (A) Insert screws on each side of the rod at the bottom; (B) insert three at the top to prevent upward and downward movement of the rod; and (C) place one at each side at top to prevent sideways movement. Drill out doweling to fit over the spikes for safety.

Steel spikes—Steel spikes are attached to the bottom of the board (fig. 53) to hold it in the ground. Steel rod 3/16-inch in diameter works well because it is strong enough to hold the board upright and small enough in diameter to be pushed down into rocky soil. Spikes should extend 6 inches (15 cm) below the bottom of the board (fig. 53). Rods come in 36-inch lengths. About 30 inches is required. Bend the rod into a “U” shape to match the dotted outline in figure 53. Doweling drilled out to fit the rod is placed over the spikes for safety.

For convenience, a carrying handle may be attached to the edge of the board around the 5-decimeter position.

2-meter folding board—Two 1-meter boards may be connected by a hinge.

Double meter boards 2 meters in height are used when shrubs or other vegetation exceeds the height of a 1-meter board (fig. 21, part A). They are simply two single meter boards attached by hinges and a barrel bolt so that either the 1- or 2-meter length may be used.

Materials—Prices given are in dollars as of 2001.

	Cost
	<i>Dollars</i>
2 pieces ½ inch, 4-ply plywood, finished on one side, exterior, 1 foot by 4 feet, each @ \$20 per sheet	6
3/16-inch-diameter steel rod, 36 inches long	1
Numbers: 5¼ inches tall, on a reflector, adhesive, 2 packets of 10 (need 2 each of 2, 4, 6, 8)	8
Line or pocket level 4 to 5 inches long	4
Two 16-ounce cans of yellow spray paint, exterior	8
2 strap hinges, heavy duty, 4-inch size	5
1 barrel bolt, heavy duty, 5-inch size	8
Screws:	2
2 line level wood screws #4 ⅝ inch	
9 spike plate wood screws #6 ¾ inch	
1 sheet metal screw #10 ½ inch, placed under barrel bolt (sheet metal for hardness)	
10 hinge wood screws #10 1 inch	
8 barrel bolt wood screws #10 ½ inch	2
1 roll black electricians tape	4
Total	\$46

Construction—Construct two 1-meter boards as discussed previously with one important difference. The top board will **not** be 1 meter 2 centimeters tall. Instead it will be exactly 1 meter tall. The top board has its bottom decimeter mark supplied by the lower (1-meter) board (fig. 54).

Construct the bottom (1-meter) board, with spikes at the base and numerals as shown in figure 51. On the top board, use “2M” at the top instead of “1M”, and add numeral “1” to each of the decimeter numbers as shown in figure 54. The numeral “1” may be made from electricians tape. The top board will **not** have a decimeter bar at its base; this bar is supplied by the bottom board.

Hinge system—Figure 55 illustrates the hinge, barrel bolt, and position of the line level between the two halves of the meter board. The barrel bolt holds the boards open and prevents them from flopping in wind.

1. Refer to figure 55. First, measure thickness of the barrel bolt. Cut plywood from the same thickness as the barrel bolt and glue to both meter board halves. The 5-inch bolt shown in figure 55 required 3/8-inch plywood. These plywood blocks separate the meter board halves when folded so that the barrel bolt will clear both its connecting strap and the line level.
2. Attach the hinge straps to the top board first. Use a straight edge to align both meter board halves in a straight line, then attach the bottom straps to the bottom board while holding both halves firmly together.



Figure 54—The 2-meter board system. In the top photo, a standard 1-meter board is shown with the 2-meter half folded under it. In the bottom photo, the folded board has been turned over showing the 2-meter section. “No dm mark” designates the lack of a decimeter mark at the base of the top board; it is at the top of the 1-meter board shown directly above. Length of the 2-meter section must be 2 centimeters shorter (exactly 1 meter instead of 1 meter 2 centimeters) than the 1-meter board to account for this decimeter mark.

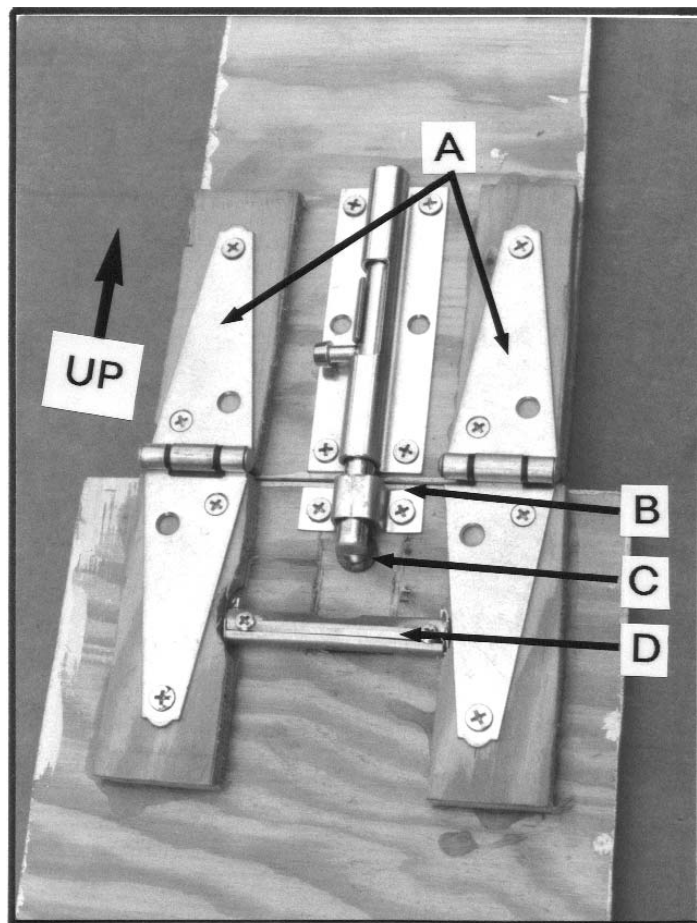


Figure 55—Hinges and a barrel bolt connect the two meter boards. (A) When installing hinges, attach to the top board first, carefully align the boards in a straight line, then attach the lower straps of the hinges. (B) The barrel bolt should be oriented to fall down when the board is unfolded. Position the bolt and its strap at the edges of the board halves so that the bolt protrudes about $\frac{3}{8}$ inch below the strap. (C) Install an adjusting screw (see fig. 56) to force the barrel bolt against its strap to stiffen the two boards when unfolded. (D) A line level is placed an inch (2.5 cm) below the barrel bolt on the lower board half so that it can be seen from above when the boards are folded and from behind when they are unfolded as shown.

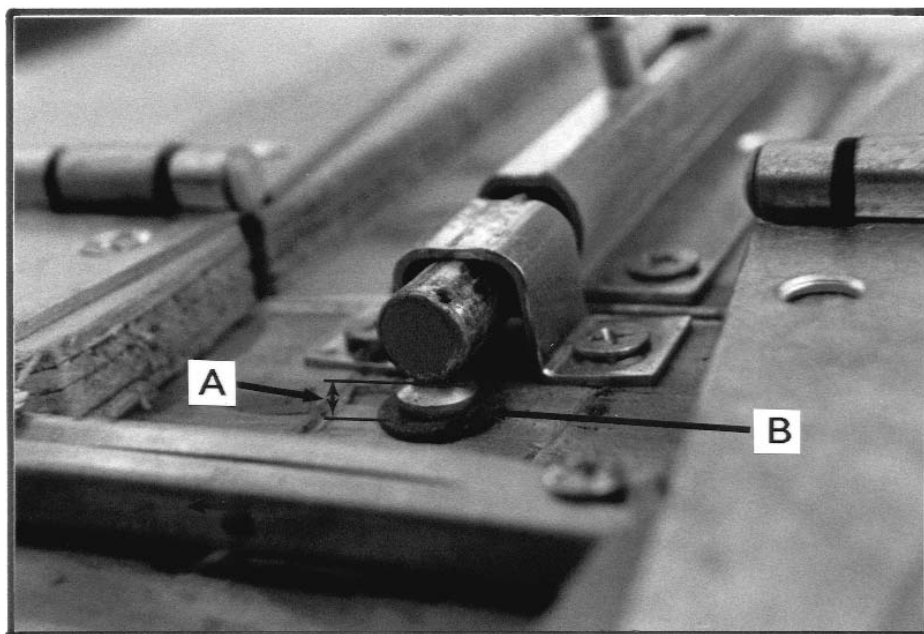


Figure 56—Adjusting screw and washer used to remove play between the barrel bolt and its strap to stiffen the two halves of a 2-meter board when unfolded. (A) Measure distance between the bolt and the board. (B) Insert a round headed sheet metal screw with enough washers to make the bolt fit firmly under the strap. Sheet metal screws are preferred because of their hardness. Pound the flange down if necessary.

3. Install the barrel bolt next (fig. 56). Position the barrel bolt at the very bottom of the top meter board so that the bolt drops down when the boards are erected. Place the barrel bolt strap as close to the top of the bottom board as possible without screws splitting the wood (fig. 55). The bolt should protrude about $\frac{3}{8}$ inch below the strap. Insert a sheet metal screw under the bolt end with sufficient washers to hold the bolt firmly against the strap. This will prevent flexing of the erected boards (fig. 56).
4. Position the line level on the bottom (1M) board where it can be seen from above when the boards are folded for 1-meter use, and from the back when unfolded for 2 meters (fig. 55). One can see the line level with boards folded by viewing down through the strap into which the barrel bolt drops.

Folding 1-meter board—If field transportation of a meter board is a concern, the 1-meter board can be made to fold at the 4-decimeter mark. The hinge system is described and shown in figures 55 and 56. Figure 57 illustrates dividing the board at 4 decimeters to provide protection for the spikes.

Photograph Identification Sheet Holder

Each photograph taken in photo monitoring should be identified. General and topic photos taken of the meter board are identified by a form attached to a clipboard and positioned between the camera and meter board. The clipboard and an adjustable post to hold it are described.

Clipboard—The clipboard is shown in figure 58. It is a standard 12-inch (30-cm) clipboard with the addition of a second clip removed from another clipboard and attached by rivets or screws as shown. The critical factor is to place the clips no closer than 10½ inches (26 cm) apart to avoid covering any information on the identification paper. Two clips are required to prevent the identification sheet from blowing in the wind.

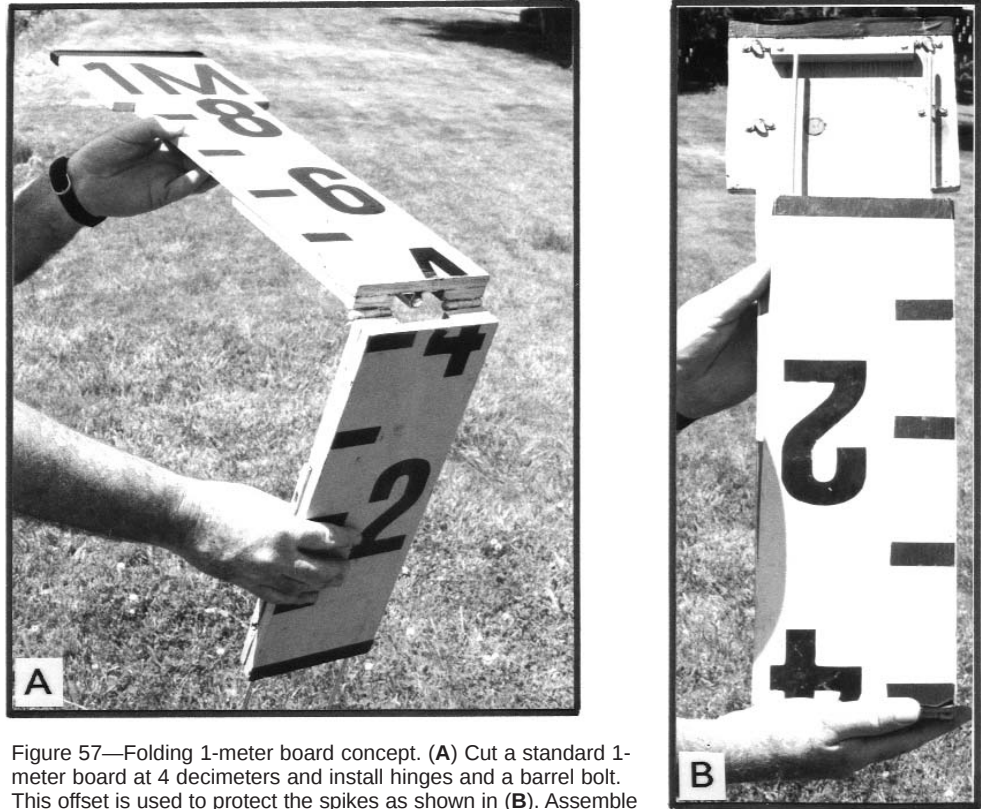


Figure 57—Folding 1-meter board concept. (A) Cut a standard 1-meter board at 4 decimeters and install hinges and a barrel bolt. This offset is used to protect the spikes as shown in (B). Assemble the board before painting and application of decimeter marks to assure correct measurements.

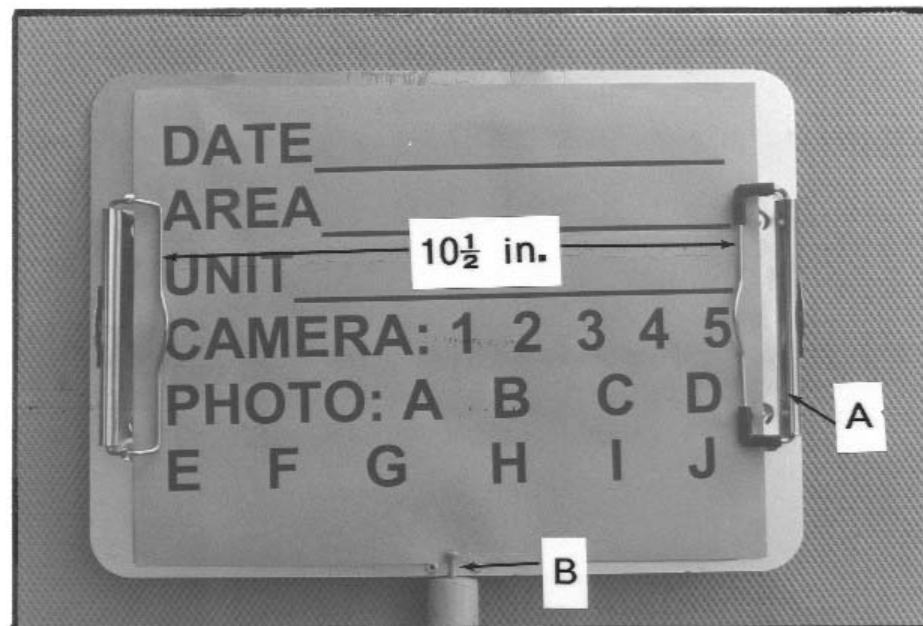


Figure 58—Clipboard for displaying photo identification forms. It includes a second clip (A) taken from another clipboard that is either screwed or riveted in place. Distance between the clipboard clips should be 10½ inches (26 cm) to (1) hold the sheet in windy conditions, and (2) not cover essential information. The clipboard is placed on the ground for plot photos or on top of a clipboard post (fig. 59) to be set in front of the camera. When placed on the post, a screw (B) inserted into the wooden block holding the ¼-inch rod behind the clipboard (figs. 58 and 61) prevents the clipboard from rotating in the wind. The form shown, "Camera-Photo" (app. A), is used for general photography.

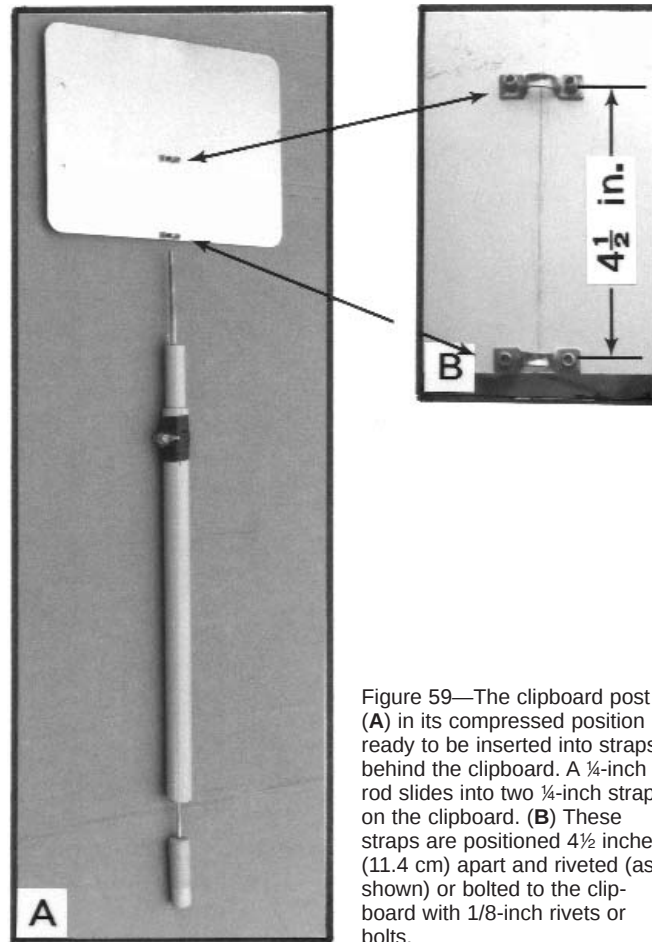


Figure 59—The clipboard post (A) in its compressed position ready to be inserted into straps behind the clipboard. A 1/4-inch rod slides into two 1/4-inch straps on the clipboard. (B) These straps are positioned 4 1/2 inches (11.4 cm) apart and riveted (as shown) or bolted to the clipboard with 1/8-inch rivets or bolts.

Materials—Prices given are in dollars as of 2001.

	Cost
	<i>Dollars</i>
2 clipboards 12 inches long @ \$4.50 each; second clipboard for its clip	9
6 each 1/8-inch diameter bolts or rivets to attach the clipboard clip and straps for the clipboard post	1
2 each 1/4-inch line guides or straps	1
Total	11

Construction—Remove the clip from the second clipboard and attach it to the first with either two bolts or two rivets (fig. 58).

Clipboard post—The clipboard post is an adjustable pole 1 inch in diameter with a spike on the end to be placed in the ground, a telescoping inside pole, and a rod at the other end on which the clipboard is placed (fig. 2 in part A; figs. 59 to 61). It is composed of telescoping plastic pipes each 18 inches (45 cm) long (fig. 60). It is 22 inches (56 cm) long when compressed and 32 inches (81 cm) long when extended. An adjustable hose clamp is attached to the upper end of the larger pipe, which compresses around the inside pipe to hold it in place (fig. 61).

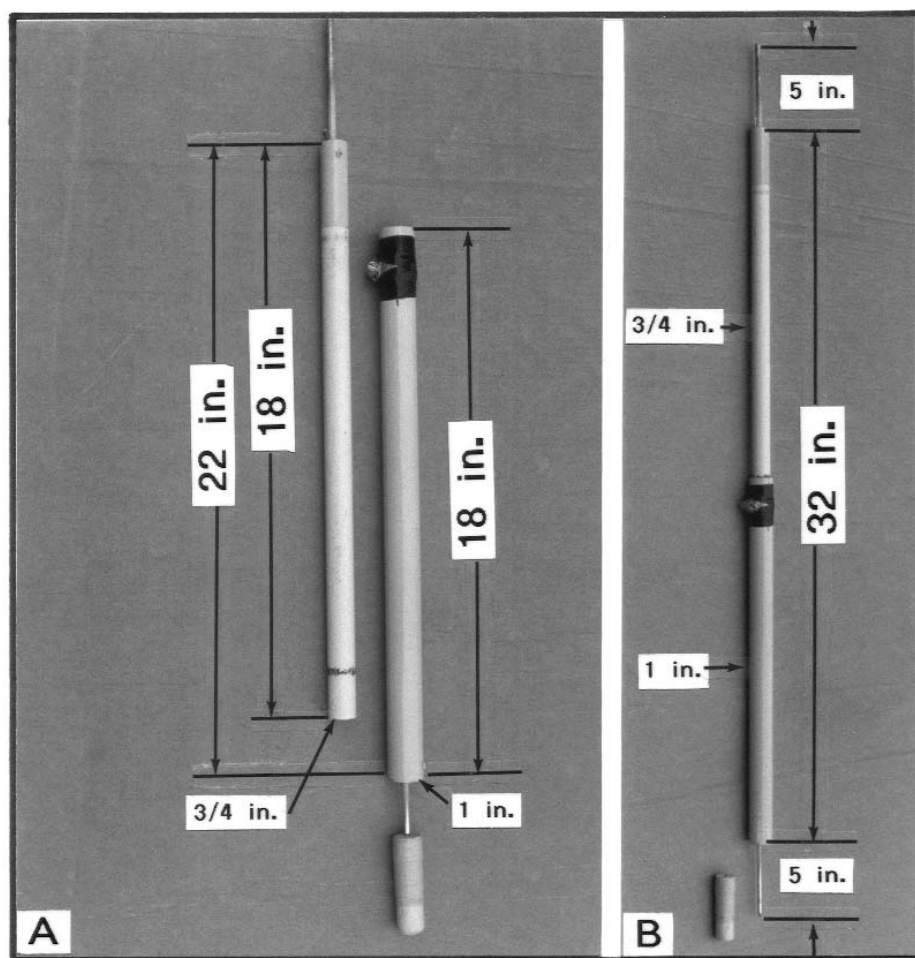


Figure 60—Construction details for the photo identification clipboard post. In (A), 1-inch PVC pipe CL 200 and 3/4-inch PVC pipe CL200, which fits inside the 1 inch pipe, are each 18 inches (46 cm) long. When the 3/4-inch pipe is inserted into the 1-inch pipe and compressed, they are 22 inches long (56 cm). In (B), the 18-inch inside pipe has been extended 14 of its 18 inches (36 of its 46 cm), increasing the length to 32 inches (81 cm). The 1/4-inch diameter spikes at the bottom and top both extend 5 inches (12.7 cm) beyond the pipe and are imbedded into doweling inserted in the pipe.

Materials—Prices given are in dollars as of 2001.

	Cost
	<i>Dollars</i>
PVC pipe 1 inch CL 200 at \$1 per 10 feet	1
PVC pipe 3/4-inch CL 200 at \$1 per 10 feet	1
Hose clamp 1-inch diameter	1
Steel rod 1/4-inch diameter, 36-inch piece, cut two 7 inch pieces	1
Electricians tape	1
Total	5

Construction—Figure 59 illustrates the clipboard post in its compressed position. Two straps capable of having a 1/4-inch-diameter rod inserted are attached to the back of the clipboard at the middle, as shown. They are centered 6 inches (15 cm) from each end and placed 4 1/2 inches (11 cm) apart so that the 5-inch (13-cm) rod will engage each.

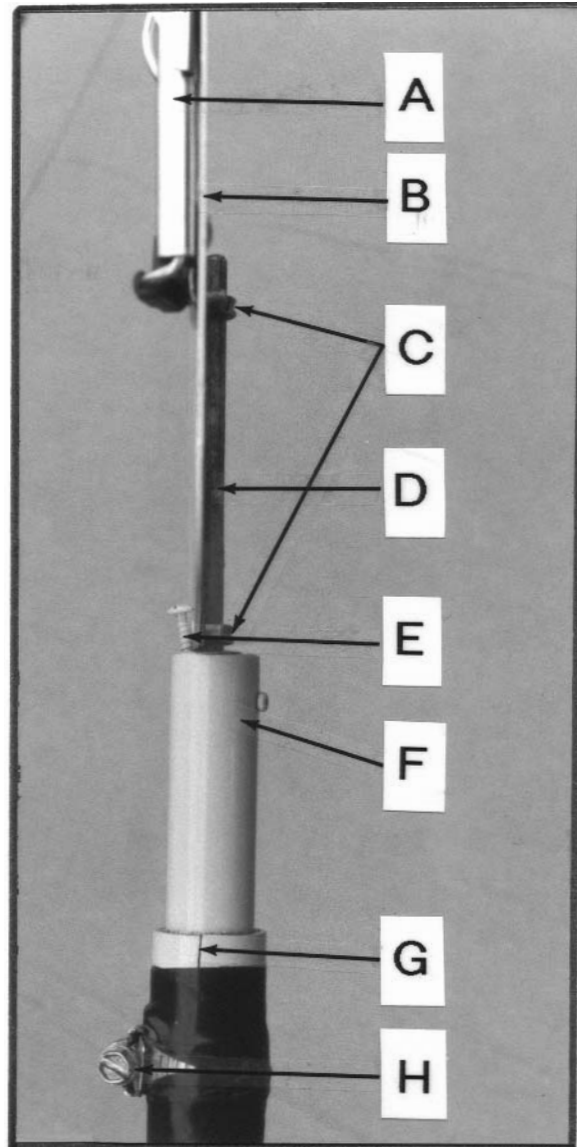


Figure 61—Details of how the clipboard is placed over the rod as viewed from the edge of the clipboard. (A) The clip of the clipboard. (B) The edge of the clipboard, in this case an aluminum board. (C) The $\frac{1}{4}$ -inch straps into which the $\frac{1}{4}$ -inch rod of the post is inserted. (D) The $\frac{1}{4}$ -inch rod of the post inserted into the clipboard straps. (E) A screw is inserted into the wood doweling that holds the $\frac{1}{4}$ -inch rod. The screw prevents the clipboard from rotating in the wind (fig. 58). (F) A piece of doweling fitted inside the $\frac{3}{4}$ -inch PVC pipe is drilled out for a $\frac{1}{4}$ -inch steel rod and is held in place by a screw. (G) With a saw, cut down 2 inches (5 cm) into the 1-inch PVC pipe so that the pipe can be compressed by the hose clamp (H) to hold the inside pipe at the desired height. At (H), secure the hose clamp with electricians tape.

The clipboard post is composed of two parts (fig. 60). One is 1-inch CL 200 PVC pipe and the other is $\frac{3}{4}$ -inch CL 200 PVC pipe, both 18 inches long. The $\frac{3}{4}$ -inch pipe fits inside the 1-inch pipe with some slack. If pipe specifications other than these are used, be sure that one pipe will fit inside the other. When compressed, the clipboard holder is 22 inches (0.5 m) tall. When extended with 4 inches of interior pipe inside, it is 32 inches (0.8 m) tall (fig. 60).

To make the clipboard post adjustable, saw down 2 inches (5 cm) into the upper end of the 1-inch pipe (fig. 61). Then attach a 1-inch hose clamp an inch below the top of the pipe and secure it with electricians tape. Tighten the hose clamp so that the inside $\frac{3}{4}$ -inch pipe can just be moved up and down to adjust height of the clipboard above vegetation or other obstructions.

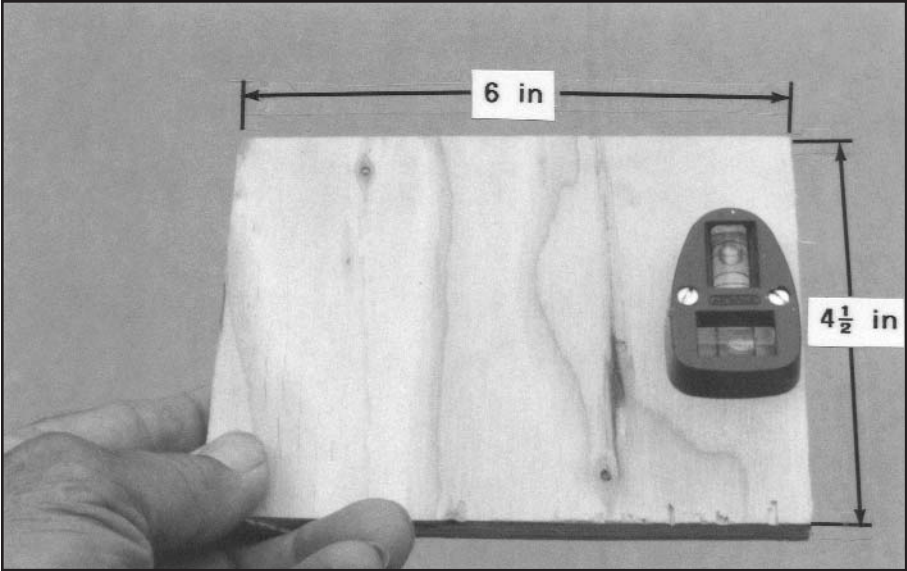


Figure 62—A leveling board for taking photos of tree canopy cover directly overhead measures 4½ by 6 inches (11.2 by 15.3 cm) and has a two-way level attached. It is made from scrap ½-inch plywood.



Figure 63—The camera leveling board is used to take repeat photographs of the tree canopy with some consistency. Place the leveling board on top of the meter board for consistent height above the ground. Place the meter board at right angles to the photo view. Move the meter board sideways to center the cross-view bubble, then tilt the level board to center the down-view bubble, move your head back, and photograph.

Camera Leveling System

Photographs taken by looking up at the tree canopy require a camera leveling system for consistent repeat photography. A leveling system described here uses the top of the meter board as one axis for consistently orienting the camera and a leveling board for the other axis (fig. 62). Figure 62 illustrates the camera leveling board and figure 63 illustrates use of the board.

Materials—Prices given are in dollars as of 2001.

	Cost
	<i>Dollars</i>
One two-way level or two line levels	4
Scrap piece of ½-inch plywood 4 by 6 inches (10 by 15 cm)	—
Total	4



Figure 64—Double camera bracket for use when photographing in both color and black and white. The bracket is made from 1-inch by $\frac{1}{8}$ -inch aluminum bar-stock with holes drilled to mount the cameras. Identical cameras are recommended to simplify camera adjustments. Figures 65 and 66 illustrate construction details.

Construction and use—Figure 62 illustrate the dimensions of the camera leveling board and placement of the two-way level. Figure 63 illustrates use of the leveling board. Place the board on top of the meter board, move the meter board left or right to center the cross-view level, then tilt the board to center the down-view level. Move your head out of the way and photograph.

Double Camera Bracket

Two cameras reduce complications when photographs are needed in both color and black and white. A bracket to hold both cameras together allows for simple and effective manipulation of the cameras (fig. 64), and identical cameras simplify adjustment. When ready to photograph, simply shoot with the top camera, then the bottom, and advance the films.

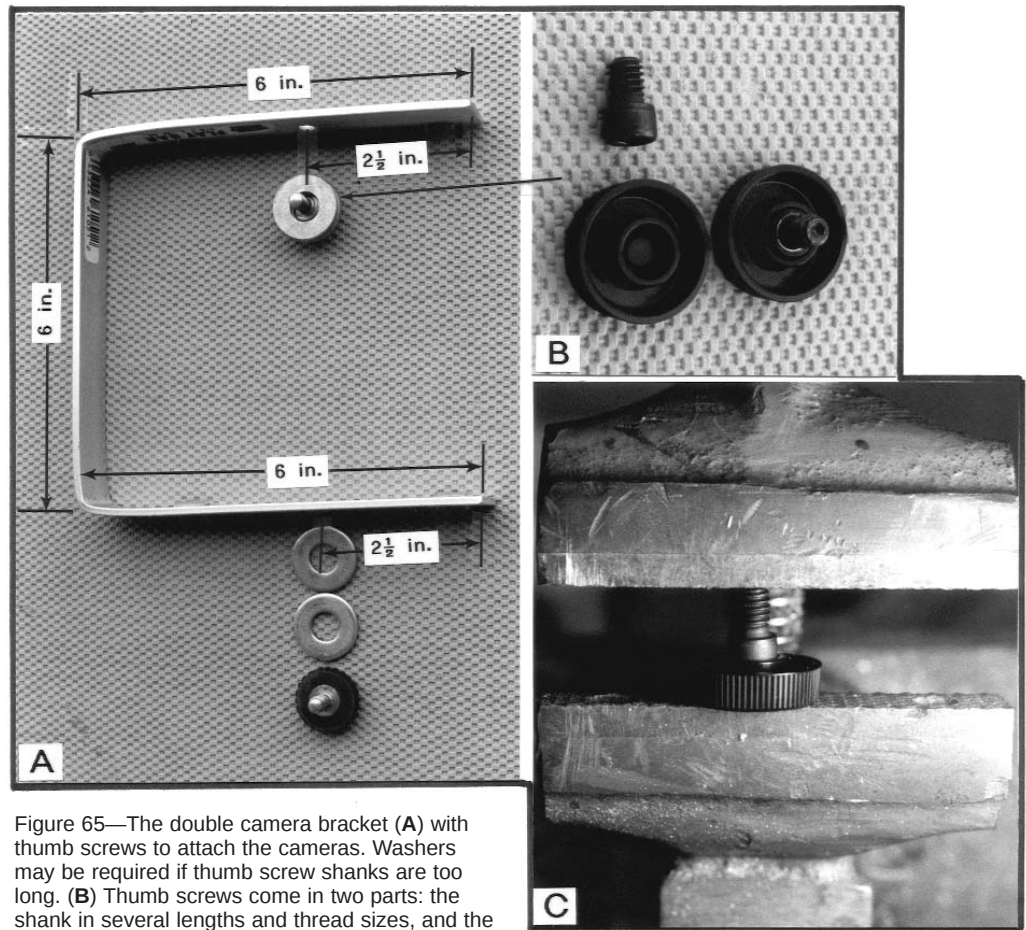


Figure 65—The double camera bracket (A) with thumb screws to attach the cameras. Washers may be required if thumb screw shanks are too long. (B) Thumb screws come in two parts: the shank in several lengths and thread sizes, and the head. The head must be forced onto the shank by using a vise (C). A shank diameter of 1/4 inch, length of 3/8 inch, and 20 threads per inch fits many cameras.

Materials—Prices given are in dollars as of 2001.

	Cost
	<i>Dollars</i>
Aluminum bar stock 1 inch (2.5 cm) wide by 1/8 inch (3 mm) thick, @ one 6-foot piece (will need 18 inches [45 cm])	8
Two instant thumb screws:	
Shank 1/4-inch diameter, standard 20 thread, 3/8 inch long (2)	1
Instant thumbs (2)	1
Total	10

Construction—The aluminum bar stock, cut into an 18-inch (45-cm) piece, is bent into equal 6-inch (15 cm) segments to form a "U" (fig. 65). Then 1/4-inch holes are drilled 2 1/2 inches (7.5 cm) in from the ends (fig. 66) to hold the cameras. Make sure the holes hold the camera in such a position as to make the rewind button available (fig. 66B).

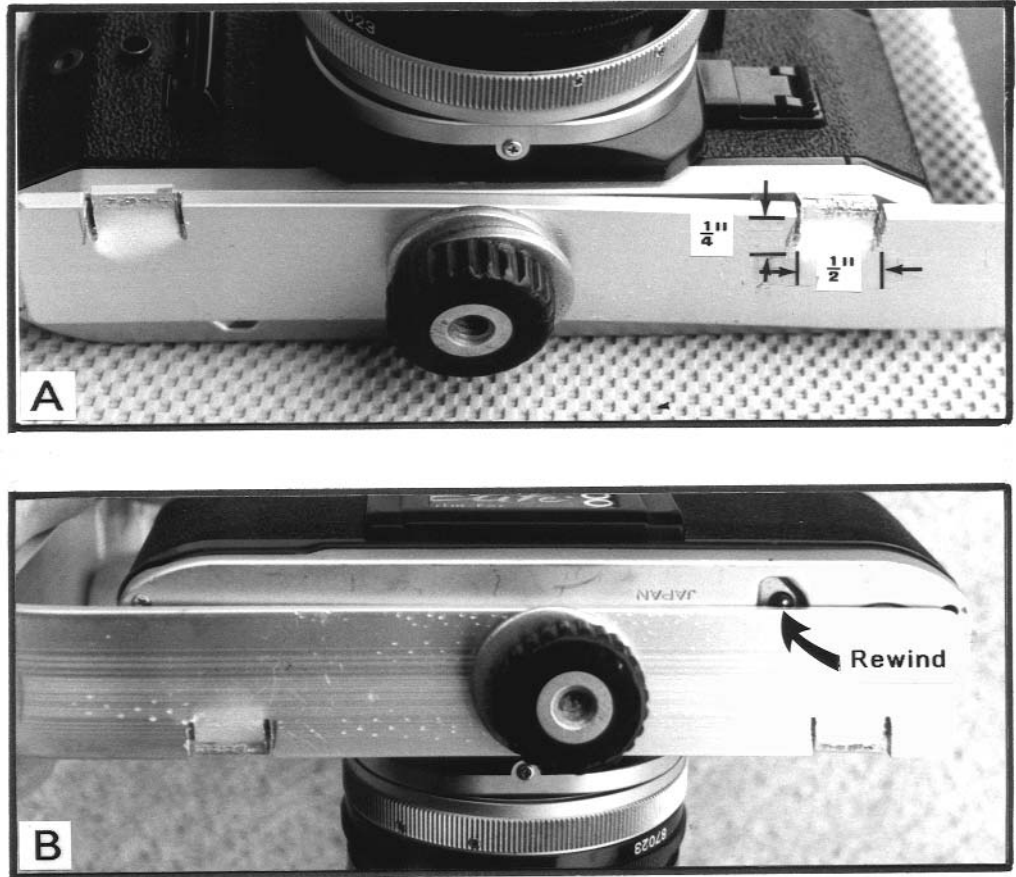


Figure 66—Two factors are important in attaching a camera to the bracket. (A), Make two cuts $\frac{1}{4}$ of an inch deep and $\frac{1}{2}$ inch apart into the front of the bracket. Bend up to about a 30-degree angle to prevent rotation movement of the camera. (B) Make sure the bracket clears the rewind button so that film may be changed while the camera is attached to the bracket.

Next make two $\frac{1}{4}$ -inch (6 mm) cuts $\frac{1}{2}$ inch (12 mm) apart into the aluminum toward the front of the camera and bend the $\frac{1}{2}$ -inch piece upwards to about a 30-degree angle (fig. 66A). Do not bend more than 30 degrees or the aluminum will break. These will prevent the cameras from rotating on the bracket.

Finally, assemble the thumb screws, which come in two parts: the shank and the thumb head. Make sure the shank will fit the camera mounting socket. Usually a $\frac{1}{4}$ -inch diameter, 20-thread shank $\frac{3}{8}$ inch long will work. Press the head onto the shank as shown in figure 65C by using a vise. Generally, heavy pliers do not apply sufficient force to seat the thumb head.

ECOLOGY PLOT REFERENCE SIGN
U.S. FOREST SERVICE - AREA 3

T. _____ R. _____ S. _____

ECO PLOT NO. _____

DISTANCE _____

BEARING _____

DATE _____ BY _____

16-1

Figure 67—Orange identification tag used to mark photographic monitoring sites. Inscribe, with a carbon point instrument, the monitoring identification name or number, date, person installing the system, and direction and measured distance to key items, such as camera locations or photo points. Mount the tag on a witness post or tree specified in the map on the "Photographic Site Description and Location" or "Sampling Site Description and Location" form.

Orange Identification Tags

Photo monitoring sites may be identified in the field by an orange tag attached to a witness post, tree, or other item identified on the sampling location maps. One kind of tag is shown in figure 67. It was custom printed for use with ecology plots. Other formats are available. The sign in figure 67 costs \$1.45 each in minimum lots of 50. New, custom printing costs \$20 for set up (prices in 2001). They may be obtained from:

Dixie Seal and Sign Co.
P.O. Box 54616
Atlanta, GA 30306
Phone: 404-875-8883
FAX: 404-872-3504

Flimsy Fenceposts

My preferred system for marking camera locations and photo points is flimsy, stamped metal fenceposts 5 feet (1.5 m) long (fig. 68). They are preferred over strong, T-bar posts for several reasons: (1) they are low in cost, about \$2.50 each; (2) they are lightweight such that four or five may be carried for the weight of one

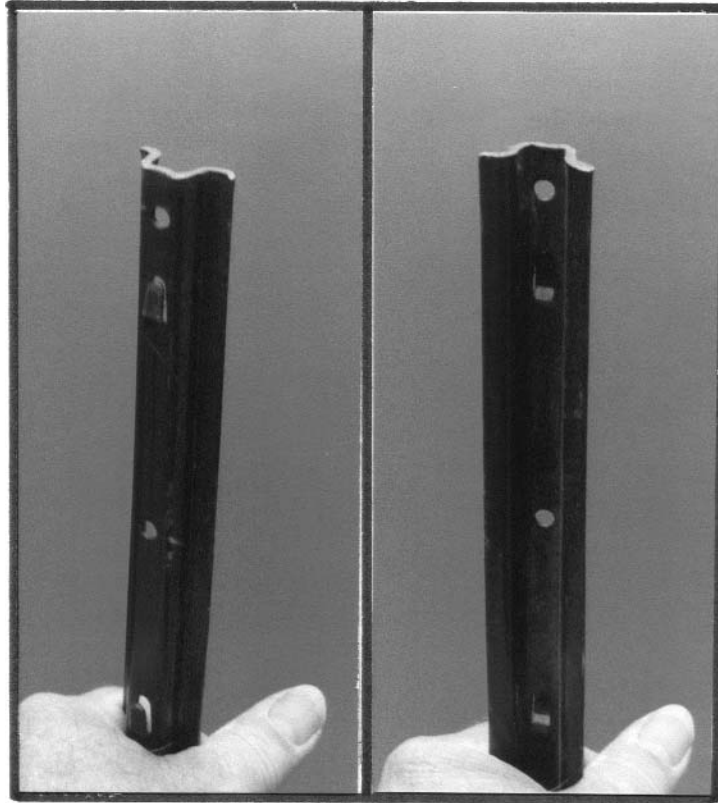


Figure 68—Flimsy stamped metal fencepost used to mark camera locations and photo points. Flimsy means the post can be twisted by hand. A 5-foot (1.5-m) length allows for pounding it 2 feet (0.6 m) into the ground, which tends to deter theft because the effort needed to remove it is not warranted by the post's value.

T-bar; (3) they are easy to pound, and the pounder weighs half of that used for T-bar; (4) of this 5-foot length, about 2 feet is in the soil when the top is even with a meter board, sufficient to require more effort to remove than the flimsy post is worthy of, thus deterring theft; (5) the flimsy strength means an animal can run into it and only be scratched, not impaled, or it can be driven over with minimum vehicular damage; and (6) the post will bend flat with the ground and remain in place when crushed by ice, logs, animals, or vehicles instead of being pulled out.

These posts are available at many large building material stores. My supply is through Home Depot. The manufacturer is Keystone Steel and Wire, 1-800-447-6444; select "Sales" from their menu, and ask for the representative in your area (such as Oregon) for a sales outlet. Ask for "5-foot, **light** duty, stamped metal fenceposts." They are also manufactured in medium duty, which are about an inch broader and stronger, an unnecessary attribute. The "light duty" posts probably will have to be ordered because they have limited usefulness.

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Bold = page where major discussion occurs

Italic = page with an illustration

Italic = page with an illustration and a major discussion

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Ground-Based Photographic Monitoring

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Abstract

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Land management professionals (foresters, wildlife biologists, range managers, and land managers such as ranchers and forest land owners) often have need to evaluate their management activities. Photographic monitoring is a fast, simple, and effective way to determine if changes made to an area have been successful. Ground-based photo monitoring means using photographs taken at a specific site to monitor conditions or change. It may be divided into two systems: (1) comparison photos, whereby a photograph is used to compare a known condition with field conditions to estimate some parameter of the field condition; and (2) repeat photographs, whereby several pictures are taken of the same tract of ground over time to detect change. Comparison systems deal with fuel loading, herbage utilization, and public reaction to scenery. Repeat photography is discussed in relation to landscape, remote, and site-specific systems. Critical attributes of repeat photography are (1) maps to find the sampling location and of the photo monitoring layout; (2) documentation of the monitoring system to include purpose, camera and film, weather, season, sampling technique, and equipment; and (3) precise replication of photographs. Five appendices include (A) detailed instructions for photo sampling, (B) blank forms for field use, (C) specifications and photographs of recommended equipment, (D) filing system alternatives, and (E) suggestions for taking photographs and analyzing change over time.

Keywords: Monitoring, photographs, landscapes, transects, animal sampling, riparian, succession, forests, rangeland.

Preface

This document started as an update of my 1976 publication on photo monitoring to appraise rangeland trends. The update was stimulated by a desire to document 40 years of experience in rephotography. This included about 150 ecology sample plots rephotographed at 5- to 10-year intervals, 25 years of herbage production, 25 years of riparian change photographed three times per season, and up to 40 years of rephotography of about 80 other situations, including wildfires, prescribed fires, tussock moth and spruce budworm damage, mountain pine beetle effects on lodgepole and ponderosa pine, fenceline contrasts between good and poor range condition, logging, revegetation, research studies and various landscape views. There is a great breadth of ground-based photographic monitoring in the literature. One aspect I found was use of photographs to estimate various existing conditions of vegetation and soil, such as comparison photo monitoring following Maxwell and Ward's (1976a) guides to estimate fuel loading, fire intensity, rate of spread, and resistance to control. Another was use of remotely controlled cameras to monitor presence of animals as illustrated by Kristan and others' (1996) video monitoring of osprey nest activities. And finally, repeat landscape photography of pictures taken at the dawn of cameras and exploration of the west, as exemplified by Progulske and Sowel's (1974) rephotography of Colonel Custer's exploration of the Black Hills in 1874—100 years of change. It is hoped that the information gained by personal experience and literature review will provide some guidelines for successful ground-based photo monitoring.

Fred Hall

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Introduction

Ground-based photographic monitoring is designed for use by land managers, such as foresters, wildlife biologists, range managers, ranchers, and forest land owners. It is a way to document management activities and evaluate changes. For many people, photographs are faster and easier to interpret than measurements, and measurements, if needed, can be made from the photographs.

The system uses cameras at ground level rather than aerial photography or other aboveground sensing. It includes several applications using either still picture or video media. For example, fuel loading conditions found in the field can be compared with photographs of known fuel characteristics to estimate tonnage per acre, flame length, rate of spread, and control problems; this is known as *comparison photo-graphy*. Or, cameras can be remotely controlled to document animal activities, which is *remote photography*. Camera locations also may be established and the same scene rephotographed periodically for *repeat photography*. Photographs produce a unique kind of monitoring not duplicated by measurement or inventory systems, although photography is subject to requirements that limit its application and use.

I begin with definitions and concepts, then discuss items common to all photography, followed by comparison photo monitoring, remote photography, repeat photography, and end with relocation of photo monitoring sites.

Definitions

Discussion of ground-based photo monitoring should start with a few definitions:

Monitoring is detecting change or condition of various topics. In this paper, it includes detecting change in riparian shrub cover, healing of disturbed soil, identifying presence of animals, documenting air quality, or estimating condition of some item such as fuel loading or percentage of utilization of herbage.

Photography refers to photographs or video or digital images, color or black and white, taken or used at the site, as opposed to aerial photograph interpretation and Landsat image analysis. The concept of ground-based photo monitoring therefore means using photographs taken on the ground to evaluate change or condition of various items.

Camera format specifies a focal length of the lens and ultimate image size. Some common formats are 50-mm lens on a 35-mm camera, 70-mm lens on a 2- by 2-in camera, or a 128-mm lens on a 4- by 5-in camera. All are comparable insofar as what part of the landscape is included in the final image. Formats may differ for the same camera. A zoom lens on a 35-mm camera can change from 35-mm focal length wide angle to 110-mm telephoto. Most photographs in this publication were taken with a 35-mm camera and a 50-mm lens.

Three terms are used to identify types of photography:

Landscape photographs are of distant scenes or of a broad, general area often more than 10 ha.

General photographs document a topic being monitored and commonly cover 0.25 to 10 ha. They may be used alone or in conjunction with closeup photographs.

Closeup photographs are made of a specific topic on a small tract of ground often from a few decimeters to 10 by 10 m. They have no horizon reference, and the locations from where the photographs are taken therefore must be marked with stakes or fenceposts.

Finally, three terms are important in photographic sampling systems:

Witness site is an easily identified reference used to locate the monitoring area. It provides compass direction and distance to the camera locations.

Camera location is a permanently marked location for the camera.

Photo point is the direction of the photograph from the camera location. It is marked permanently by a steel stake or fencepost and commonly involves a size control board located in the center of the photograph. More than one photo point may be taken from a single camera location, and more than one camera location may photograph a single photo point.

Comparison and Repeat Photography

Comparison—In comparison photo monitoring, existing conditions are compared with conditions shown in a set of photographs. For example, Maxwell and Ward (1976a) produced a color photograph field guide for estimating logging fuel loading in tons per acre by size class with estimates of fire intensity, rate of spread, flame length, and resistance to control. Kinney and Clary (1994) developed a guide for estimating the percentage of utilization of riparian grasses and sedges by using photographs of various stubble heights. And Magill (1990) evaluated public concern over logging by having people rate a set of color landscape photographs taken at different camera focal lengths to simulate various distances from the scene.

Repeat—Repeat photography is characterized by taking multiple photographs of the same landscape, tract of ground, or activity, such as animal presence. It's particularly useful in three situations:

1. Landscape photography, where change is documented for landscape-sized areas over time. Some classic examples are Progulske and Sowel's (1974) documentation of Colonel Custer's exploration of the Black Hills wherein they rephotographed pictures taken in 1874. Another is panoramic photography using special camera equipment to take 360-degree views of landscapes, as Arnst (1985) shows for the Cascade Range of the Pacific Northwest.
2. Remotely operated cameras used to monitor animal behavior such as that of nesting ospreys (Kristan and others 1996), evaluate air quality (Fox and others 1987), or document animal distribution (Kinney and Clary 1998).

3. Site-specific repeat photography identifies specific topics on selected tracts of ground to document change or lack of change in vegetation and soil. Gary and Currie (1977) show a 40-year record of plant and soil recovery on an abused watershed in Colorado, and Smith and Arno (1999) document 88 years of change in managed ponderosa pine forests through 14 camera locations.

Clearly, photo monitoring is not a simple, routine procedure, but rather a multifaceted concept covering various purposes or objectives. To discuss this topic, the paper is organized into seven main parts: items common to all photo monitoring, comparison photos where current conditions are compared to a series of photographs and their condition rated, repeat photography of landscapes, photo monitoring by remotely operated cameras, site-specific repeat photography, and lessons in relocation of repeat photography.

The appendices cover many items in detail: Appendix A gives the methodology for monitoring change in vegetation and soil, appendix B contains blank forms for both office and field ready to copy, appendix C has plans for construction of meter boards and plot frames, appendix D discusses filing systems for photo monitoring, and appendix E illustrates photographic tips.

Common Items

Common to all photographic monitoring are (1) determining specific objectives, (2) using a repeatable technique, (3) choosing appropriate camera and film, and (4) developing a filing system.

Select Specific Monitoring Objectives

The first and most important item in any monitoring project is to have specific objectives. Questions answerable by photography must be asked before any kind of monitoring can be developed and installed. Consider a five-part query to develop these objectives: why to monitor, where to locate the sampling, what specific topic to evaluate, when to do the photography, and how to accomplish the photography (Borman 1995; Nader and others 1995; U.S. Department of the Interior, Bureau of Land Management 1996).

Why—Why to monitor asks for definition of the question needing an answer. Implementation monitoring asks if what was done was what was indicated, effectiveness asks whether the treatment did what was wanted, and validation asks if the treatment met the objectives. *Why* sets the stage for all other questions.

Where—Where to monitor depends upon the *why*. Where will the selected representative tracts, animal activity areas, treatment sites, or particular kinds of treatments be located? Will number, size, and location of activities such as fire, logging, revegetation, livestock grazing or flood affect the selected site(s)? Ask where the best location is that will answer the questions. Critical documents are a map to locate the site and a site map to document all camera locations and photo points.

What—Which items on the selected tract—vegetation, soil, streambanks, animals, air quality—will be monitored to support the *why*? Ask what the critical few items are that must be documented. What is expected to change? What will the picture demonstrate? Why should I take this picture (Johnson 1991)? The *what* dictates sampling layout.

When—When to monitor supports the *why* and *what* questions. Does monitoring encompass one year or multiple years? One season or more? Specific dates and time(s) of day? All are important in both animal and site monitoring. Scheduling includes time before treatment as well as after and frequency after initial treatment. Unplanned disturbances, such as fire or flood, pose special problems. A monitoring protocol may have to be developed on the spot to determine when and where during the event to establish photo points and to define a followup schedule.

How—How to monitor is determined by *what*, *why*, and *when*. It encompasses detailed protocols for photographic procedures used to obtain qualitative data (estimates) or quantitative data (measured in the field or measured on photographs). (Appendix B contains detailed instructions for both systems.) An example might be dealing with effects of livestock grazing on a riparian area: (1) Are streambanks being broken down? (2) Are riparian shrubs able to grow in both height and crown spread? (3) Is there enough herbage remaining after grazing to trap sediments from flooding? (4) Is herbaceous vegetation stable, improving, or deteriorating? Answering these questions will require selection of a sampling location and establishment of photo points and camera locations sufficient to gather adequate data. Try to select camera locations that will photograph more than one photo point. The time or times of year to take photos then must be specified, such as just prior to animal use of the area, just after they leave, or fall vegetation conditions. Will this riparian site be monitored for high spring runoff, late season low flows, or during floods? Monitoring of stream flows probably requires different scheduling from monitoring of animal use.

Repeatable Photo Technique

A second common item in photo monitoring is a repeatable technique that can be used by various people to attain similar results. For a technique to be repeatable, it must be simple, thoroughly documented, and illustrated. The following items are key elements in a well-documented and -illustrated technique:

1. A map locating the photo monitoring site and one or more maps of the photo monitoring layout for the site.
2. Camera locations and photo points permanently marked with steel fenceposts or iron stakes. Iron stakes should be flush with the ground to prevent tire and foot (hoof) damage. They are difficult to relocate but can be found with a metal detector. Positions of camera location and photo points are critical (Rogers and others 1983). The need for a constant distance between camera and photo point for all repeat photography is demonstrated under "Camera Format," below.

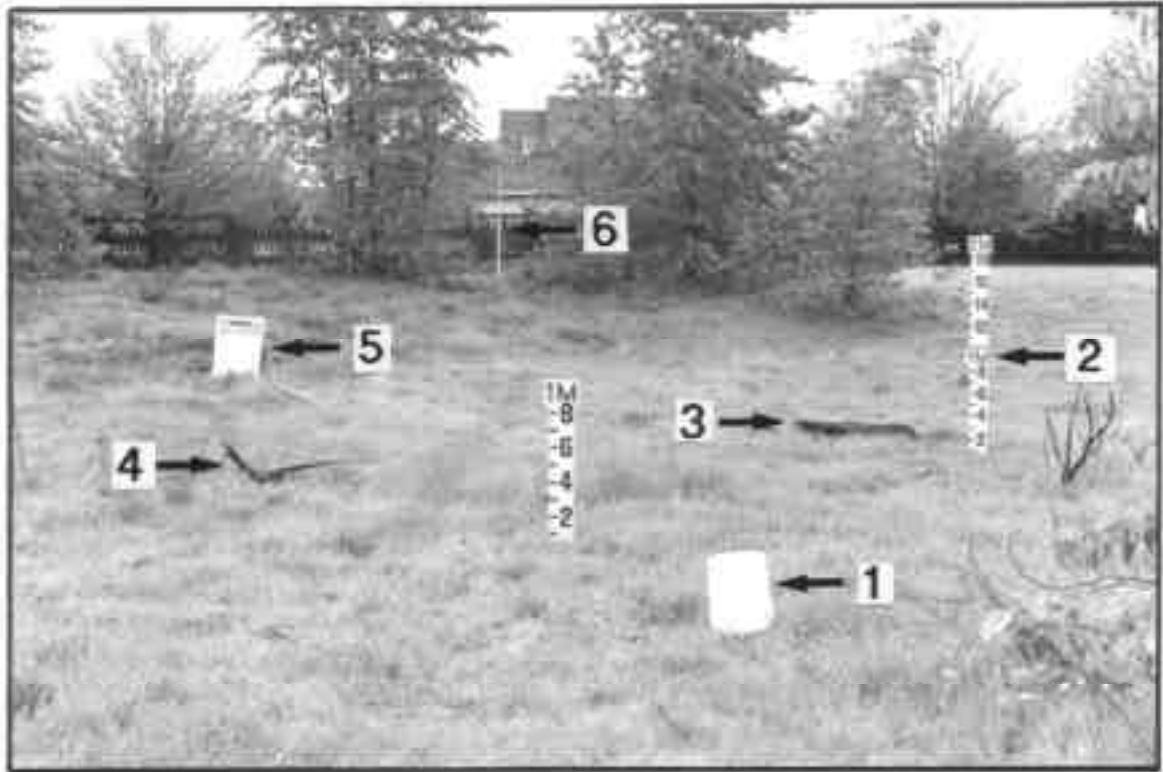


Figure 1—Landscape used to test effects of camera format (focal length), distance from camera to photo point (meter board), and camera position on size and location of items. Camera format is 35-mm using three focal lengths (lenses): 35-mm wide angle, 50-mm standard, and 70-mm telephoto. Distances are 7, 10, and 14 m. Camera positions are eye level (1.8 m), breast height (1.4 m), and offset right by 4 dm. Numbered items are outlined and compared: (1) bucket between camera and meter board, (2) double meter boards, (3) log on the ground, (4) root wad, (5) cart 15 m from the meter board, and (6) lamp pole 50 m from the meter board. Four situations will be evaluated: (A) varying the distance from camera to meter board but using the same focal length camera (figs. 2 and 3); (B) varying both distance and focal length such that the meter board is the same size in all pictures (figs. 4 and 5); (C) varying the camera focal length at a given distance (figs. 6 and 7), and (D) varying camera position over the camera location fencepost (figs. 8, 9, and 10).

3. Precise description, by time of day, weather, and season, of when landscape or general and closeup scenes are to be photographed—all are directly related to the objectives for monitoring; for example, before 10 a.m. and after 3 p.m. if back-lighted vegetation is needed (app. E), visibility of 25 or more miles for repeat landscape photography, high overcast to avoid shadows in forest photography (app. E), bird monitoring in spring, livestock grazing at mid or late season, or documenting high and low stream flows in spring and late summer. Special instructions, such as key landscape items to identify in landscape photography, also are needed.
4. A description of how to photograph and show camera locations and photo points on the site map. A size control board (fig. 1; app. C), such as a meter board, is needed for general photos and appropriate plot frames for closeup photos (app. C).
5. Suitable forms and field instructions for accomplishing the monitoring (apps. A and B).

6. An equipment list including a specified camera and film, field forms to be used in each photograph, any needed measuring or calculating equipment, and fence-posts and equipment to permanently mark photo locations. Specify whether a tripod is required and why.
7. Specific, detailed diagrams and instructions for installing and maintaining photographic equipment. This is particularly important with remotely operated camera systems to assure their proper functioning.
8. A comprehensive filing system (app. D; Johnson 1991, Nader and others 1995) with a container for each study to hold all information: monitoring objectives, site descriptions, maps, color slides, and black-and-white pictures with their negatives or digital memory cards with a copy of the images. All color slides, black-and-white pictures plus their negatives, and digital images and their memory cards need to be labeled immediately after processing. A note on the outside of the file of the last monitoring date is helpful.

Cameras and Film

The purpose of photo monitoring is to document change in a landscape or topic over time. Measuring change requires photographs of good to excellent resolution and color, both of which are influenced by camera and film.

Two kinds of cameras are available: film and digital. Each has specified formats, such as a film camera with 35-mm film with a 50-mm lens, which is similar to a digital camera with a 13-mm lens. Some photographers suggest that changing from one kind of camera format to another poses serious problems in matching photographs. This is not insurmountable, however, as discussed under “Camera Format,” below. Another concern is quality of image. Switching from one brand of color film to another tends to change tones, particularly green and blue. And changing from film to digital usually influences image resolution and color.

Film and digital camera characteristics—Both types of cameras come in two configurations: (1) viewfinder and (2) view-through-the-lens or single lens reflex (SLR). Many digital cameras use SLR principles with a liquid crystal display (LCD). An LCD is a miniature (about 25 by 37 mm) computer monitor screen that displays the image as seen through the lens (Kodak 1999b). Viewfinders show an image that is parallel with the lens and have an outlined box in the viewer to show what the image will cover when a picture is taken at close range (parallax correction). The image will always appear sharp. With SLR systems, the image is viewed exactly as it will appear: there is no parallax correction and the image will appear fuzzy when out of focus, but SLR cameras are more expensive.

Both film and digital cameras provide for a strobe flash system. Less expensive cameras often have built-in flash that fires straight ahead and is effective within 2 m for direct light and within 6 m for fill-in. More expensive cameras provide a “hot shoe” for attaching a more powerful and adjustable flash system. Additional flash systems add cost to the camera. Some cameras provide both an internal flash and a hot shoe.

Zoom lenses have become popular, particularly with the point-and-shoot automatic 35-mm cameras. They also seem to be common on many digital cameras. These lenses have two main attributes: they add flexibility to the camera and they tend to be less sharp than a fixed lens. Zoom lenses may pose problems in photo monitoring because of the need to set a precise focal length to reproduce the original image coverage. For an SLR lens, this isn't too difficult because the lens will have focal lengths marked. But a point-and-shoot 35-mm camera will zoom from 35-mm focal length to 100 mm or greater, a threefold difference in photo coverage, with no indication of the precise focal length used. The equivalent in digital cameras would be 9.2 mm to 28 mm. See "Camera Format" for details.

Lens quality and speed vary. Lens speed is given in f-stops. The "f" indicates how large a hole is open to admit light into the camera. Small f-stops admit much light and large f-stops admit little: for example, at f-3.5, two times more light is admitted than at f-5.6, and f-5.6 admits twice the light of f-8. Depth of field also increases with an increase in f-stop. A slow lens of moderate sharpness is often characterized by f-stops of 3.5 to 4.8 and fast lenses of good sharpness by f-stops of 1.2 to 2.4. A film camera with an f-3.5 lens that's wide open and shooting at 1/60 of a second will create an underexposed image if the light meter says f-2.4 is needed, but a camera with an f-1.2 lens can easily capture the image. Faster lenses are more expensive. The processing unit in the camera computer usually provides digital camera speed; faster speed costs more.

Resolution (sharpness of the image) in film cameras is a function first of lens quality and second of film speed, which translates to graininess in the final picture. The difference in cost for films between ISO 100 and 400 is minimal, but good lenses do cost more. In digital cameras, resolution is determined by maximum dpi (dots per inch) of the camera. As of January 2000, most digital cameras started at about 0.7 megapixels, suitable for 4- by 6-in snapshots, and go up to 3.6, appropriate for 11- by 14-in pictures. Do not use less than a 2-megapixel camera. Good quality optical lenses also enhance resolution. Most digital cameras offer a choice of three to five resolution levels. For example a 1.3-megapixel camera might offer its best resolution at 1280 by 1020, midresolution at 900 by 700, and lowest at 600 by 400. Finer resolution results in fewer images on a digital storage card and slower processing. Quality also is influenced by the kind of compression, if any, used to store the image, and compression influences how many images may be placed in a memory card.

Film and digital concepts—One might consider the digital camera a special purpose computer designed to take photographs (Kodak 1999b). Digital images are captured on an electronic storage, or memory, card that must be processed to produce an image. The camera can alter an image with different settings. Images are made up of dots called pixels, each composed of three colors: red, green, and blue. Intensity of each color can be adjusted. Film and digital storage cards are discussed shortly.

A camera using slide film exposes an image on film—*period*. Once the exposure is made, there is no recourse with correction. There is some recourse with black-and-white and color negative film by changing print exposure time, selection of paper, and dodging or burning items to be enhanced.

With digital cameras, the image is only one link in the chain to a photograph (Kodak 1999a): This chain is (1) the camera with its dpi or pixel resolution, lens quality that captures the image, and the camera's ability to modify pixel characteristics; (2) CPU (the computer) that processes the image with its ability to make major changes in the pixels and thus the image; (3) monitor with its color projection of the image on the screen, which is used as a basis for changing the image characteristics; and (4) the output device that either prints the image (printer) or projects it (projector). The camera, CPU, and output device affect the resolution (dpi), color quality, and contrast. Matching the camera resolution with that of the CPU and output device attains best image quality. They are **not** all the same.

Film speed, the amount of light required to expose the film, is characterized by an ISO rating. Film resolution (graininess of an image) also is a product of film speed: faster film has more grain. Common ISO ratings are 100 for slow speed and fine-grain film (for example 1/60th second at f-5.6); ISO 200, which can be shot at twice the shutter speed (1/120th second at f-5.6) and has medium graininess; and ISO 400, which can be shot at four times the shutter speed (1/250th second at f-5.6) but is rather coarse grained.

Digital camera equivalents are approximately 1640 by 1400 dpi for ISO 400 (2.4-megapixel camera), 1960 by 1600 dpi for ISO 200 (3.2-megapixel camera), and 2280 by 1800 dpi for ISO 100 (4.1-megapixel camera). To determine the camera rating, multiply the two pixel numbers: $1280 \times 1020 = 1.3$ megapixels.

Output (pictures) differs between film and digital cameras. The prints are similar because they are all images printed on paper. Prints from color and black-and-white film and from digital images all share the same result: a picture one can hold in their hand or mount on a monitoring form.

Slides made from film and digital images share few common traits, however. A film image is determined at exposure and can be shown in presentations through a slide projector. A digital image cannot. Generally, the digital image first must be downloaded from the camera and placed into memory of a laptop computer. Then the laptop must be connected to a digital projector for presentation. Recently, cameras have been programmed for download directly to a projector; however, this projects only slides in the camera. It does not provide for a presentation using title, data, and instructional slides. Here are some things to consider when projecting digital images for a presentation (Kodak 1999a):

1. Know the native resolution (dpi) of the laptop and the camera. Select the resolution that will support "high color" (16 bit) color depth (1280 by 1024 dpi; a 1.3-megapixel camera) or higher. Settings of the laptop computer above or below the camera settings will result in reduced image quality.

2. Match the resolution of the laptop with the resolution of the digital projector. If the laptop uses 1280 by 1020 dpi and the projector only 800 by 600, image quality will be at the projector resolution.
3. Understand that colors on the computer monitor used to modify image characteristics are not the same as those projected. The projector gives the more accurate color.

Film—Film is another consideration in photo monitoring, particularly the use of color slide film compared to negative films when prints are the desired outcome. Prints can be modified many ways by using different kinds of printing paper, exposure timing, dodging, burning, and different filters to make good comparison pictures. An advantage of black and white film is its long life. Most color films or prints tend to fade over the years, even if they are kept in dark, cool, dry locations.

Tones in color film differ according to the chemicals used in manufacturing and processing the film: Kodachrome has warmer, more vivid colors than Elite Chrome (Ektachrome), yet Elite Chrome (Ektachrome) tends to produce a truer reproduction of the greens and browns in a natural landscape.¹ Repeat photography done with different brands of film therefore produce some significant differences in appearance of vegetation conditions in the scene, whether real or not (Magill 1989). The photo monitoring protocol should prescribe the brand of film, speed of film, and light (weather) conditions for the project.

Film processing will influence how well photos can be compared. Most film is sent to a commercial processor where either slides are produced or pictures are printed at a standard size, such as 3½ by 5 or 4 by 6 in. Quality of processing differs. Do not cheapen your product by cutting costs and quality at the final step (Johnson 1991).

Weather should be related to film. How does current weather compare to conditions of previous photographs (Magill 1989, Maxwell and Ward 1980a)? A dense, heavy cloud layer will produce different colors and tones compared to a high, thin overcast, which in turn will be different from full sunlight that causes deep shadows. Maxwell and Ward (1980a) suggest overcast skies to reduce shadows and taking at least three different exposures to bracket light conditions for comparable colors between photos. Weather conditions of original photographs should be duplicated.

Digital storage cards—Digital cameras do not use film, but rather electronic storage cards (Kodak 1999a). Storage cards are not developed but are processed by computer. Any or all images can be erased and the card reused. The color quality, contrast, and depth can be manipulated. Either all images or selected ones can be copied from one card to another, greatly facilitating storage and retrieval of images. Different brands of cameras use different storage cards. Storage cards also come in several sizes and makes.

¹ The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or services.

Storage cards vary in their megabyte (MB) capacity, which directly limits the number of images that can be stored. A general conversion from number of pixels in an image to number of images per storage card is a 1-to-1.2 ratio: a 1-megapixel photo requires about 1.2-MB of storage card capacity. For example, an image at 1280 by 1024 pixels (1.3-megapixels) would require an entire 2-MB card, or 24 photos could be placed on a 32-MB card. The same 32 MB card would hold 66 photos at 800 by 600 pixels (0.48-megapixel).

Digital storage cards can be reused. The deleted images, of course, are lost.

Processing of storage cards is quite different from film, with two alternatives: commercial or home processing. Commercial means the storage card is sent to a digital processing laboratory for prints similar to film. Home processing requires use of a CPU, with a download system from the camera, and a printer. For best image quality, the dpi of the camera and computer should be compatible, and the dpi of the computer and printer also should be compatible. Image quality is sacrificed if either the computer or printer cannot process the dpi of the camera, or image quality may be sacrificed by color rendition of the printer.

Digital images may be stored in three ways: (1) in the memory card used with the camera, (2) transferred to a compact disk (CD) and the memory card reused, or (3) transferred to a computer hard drive with essential information in its file and the memory card reused. If stored in a computer, assure that instructions for locating the folder or file are placed in the photo monitoring filing system.

Color prints are similar in cost between film and digital systems; however, slides made from digital memory cards tend to cost more. The use of two steps, from card to negative and from negative to slide, tends to reduce quality of the image.

Camera Format

Camera format is the combination of camera body image size and focal length of a lens. Format concepts apply to both film and digital cameras. Exact duplication of camera format is not of critical concern (Rogers and others 1983) when evaluating change in the subject photographed. Images may be enlarged or reduced to a constant area of coverage, printed, and compared.

When using slide film, however, images taken with different camera formats will project differently on the screen. This is a major concern discussed by Magill (1989) in his analysis of change in campgrounds. He projected slides onto a screen with a grid and adjusted size of the image according to specified criteria prior to analysis.

Some examples of common film camera formats that cover about the same area of a landscape are (1) 1- by 1.5-in image size (35-mm camera) using a 50-mm focal length lens, (2) 2- by 2-in (50- by 50-mm) image size using a 70-mm lens, or (3) a 4- by 5-in (100- by 125-mm) image using 128-mm lens. All are equivalent to a digital camera at 13-mm focal length. The advent of good quality zoom lenses permits a great variety of camera formats having both desirable and undesirable features.

A desirable feature is increased flexibility in choosing photograph formats without the need to change lenses. Undesirable features include higher f-stops and no constant focal length when rephotographing monitoring sequences.

The effects of camera format and distance from camera to subject are shown and discussed in figures 1 through 7. Camera position concerns are illustrated in figures 8 through 10. Change in emphasis on a topic by distance is discussed in "Camera Techniques," below.

Figure 1 shows a testing landscape where six objects are positioned, photographed, and outlined to compare size and location of the objects with change in distance, focal length, and camera position. Three lenses were used with a 35-mm camera body: (1) 35-mm wide angle, (2) 50-mm as a standard for comparison, and (3) 70-mm telephoto; these are equivalent to digital cameras of 9, 13, and 18 mm. They were used in conjunction with three distances from camera to meter board: (1) 7 m, (2) 10 m as a standard for comparison, and (3) 14 m. The effect of camera position was evaluated at 10 m with a 50-mm lens. The standard for comparison was 1.4 m above the ground (breast height) centered over the camera location fencepost. Camera position was moved upward 4 dm to 1.8 m (eye level) and sideways 4 dm.

The first evaluation (fig. 2) is a standard camera format of 50-mm lens on a 35-mm camera positioned 7, 10, and 14 m from a meter board. All photographs in figure 2 are clearly different. Outlines of objects, adjusted in size to the meter board at 10 m are shown in figure 3. All objects are different in both size and location.

Next, both camera format and distance to meter board were adjusted. The objective was to photograph the meter board at a constant size where the 35-mm lens at 7 m gave the same size meter board as 50-mm at 10 m and 70-mm at 14 m (fig. 4). Notice the difference in backgrounds. Comparison of object outlines in figure 5 shows that all objects are different in both size and location, almost identical with figure 3.

Finally, focal lengths (35, 50, and 70-mm) were changed at a fixed distance, 10 m (figs. 6 and 7). Figure 6 appears to show very different scenes insofar as what is included within each photo. But when the images are adjusted to size of the meter board at 50 mm shown in figure 7, each object is almost exactly the same size and location. This effect is what Rogers and others (1983) discuss. Figures 2 through 7 clearly indicate that distance from camera to meter board is critical; whereas focal length is not.

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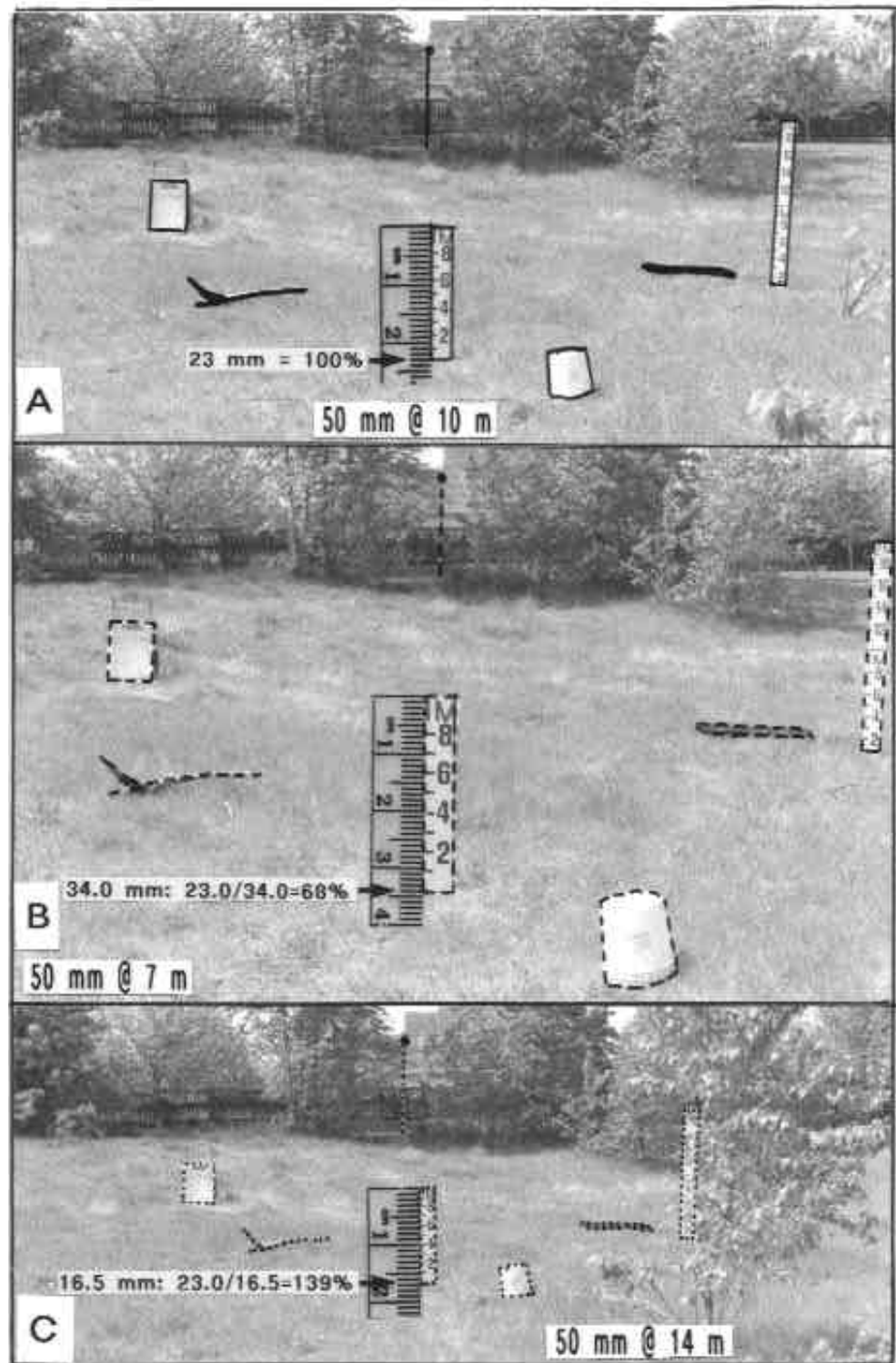


Figure 2—Effect of distance from camera to meter board on location and size of outlined objects when using the same camera format. Camera format is a 50-mm length lens on a 35-mm camera at 7, 10, and 14 m from the meter board. Objects were outlined on clear plastic overlay sheets as follows: 10 m in a solid line, 7 m in dashes, and 14 m in dots. Each outline was adjusted in size to match the meter board at 10 m as follows: measure in millimeters from the top of the board to bottom; this measurement is divided into the measure for 10 m for a percentage of change; then enlarge or reduce the overlay by that percentage. (A) The 10-m board was 23.0 mm and 100 percent; (B) the 7-m board was 34.0 mm reduced to 68 percent, and (C) the 14-m board was 16.5 mm enlarged to 139 percent. Figure 3 compares the adjusted outlines.

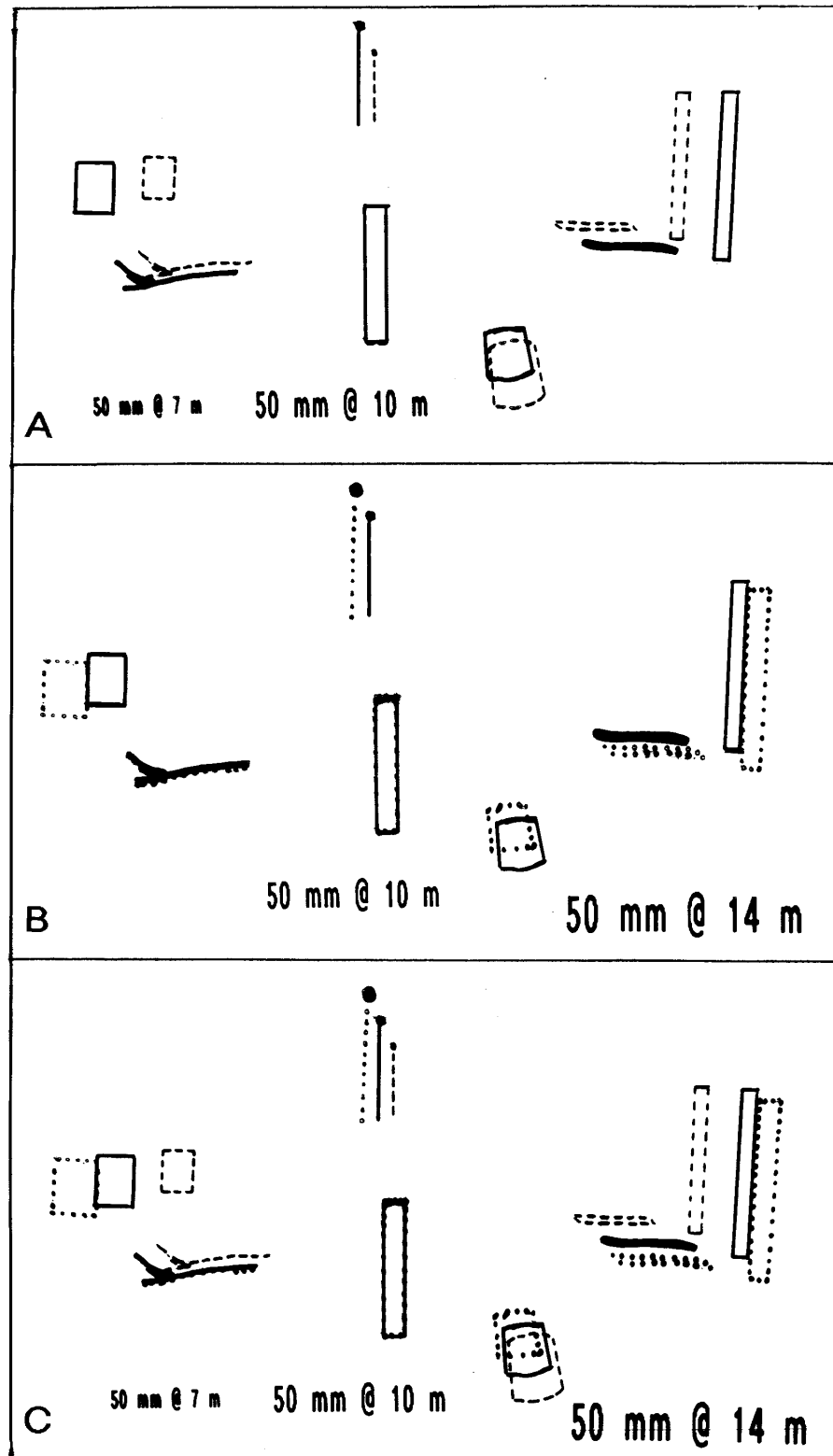


Figure 3—Overlays of object outlines from figure 2 adjusted in size to 10 m. The 10-m outline is solid, 7 m is dashes, and 14 m is dots. (A) Overlays of 7 m and 10 m shows objects of different size and location. (B) The 10-m and 14-m overlays also show different sizes and locations. (C) All three overlaid show that all objects are different in both size and location. Distance from camera to meter board is critical if objects in photographs are to be compared.

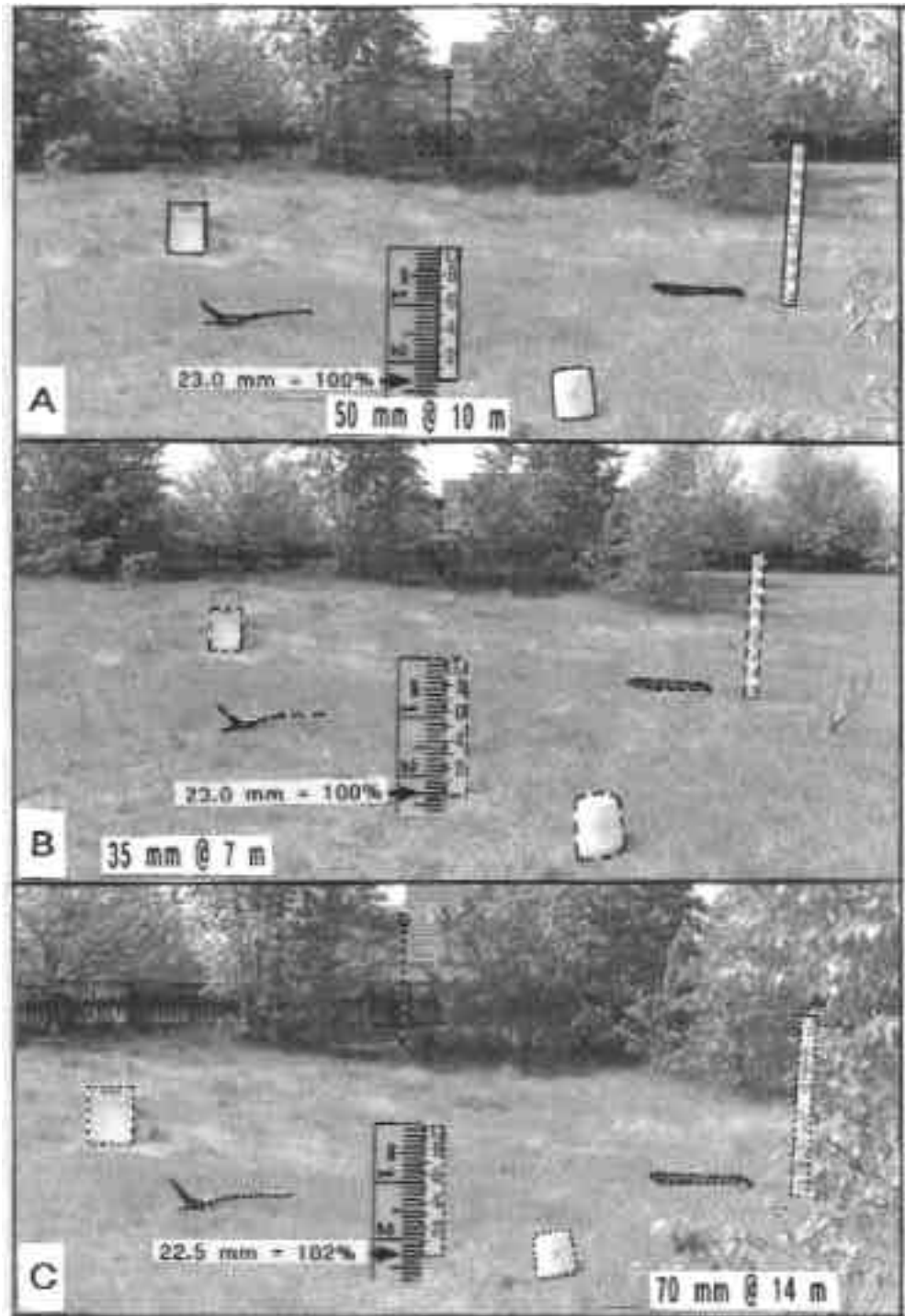


Figure 4—Both focal length and distance to meter board are adjusted to make the meter board the same size in each photograph: (A) 50-mm at 10 m, (B) 35-mm at 7 m, and (C) 70-mm at 14 m. Meter boards are measured to show similarity, and outlines were adjusted by the percentages shown. Objects are outlined on clear plastic overlays as follows: 50-mm with a solid line, 35-mm in dashes, and 70-mm in dots. Notice how the backgrounds change with a constant size meter board. Figure 5 compares the object outlines.

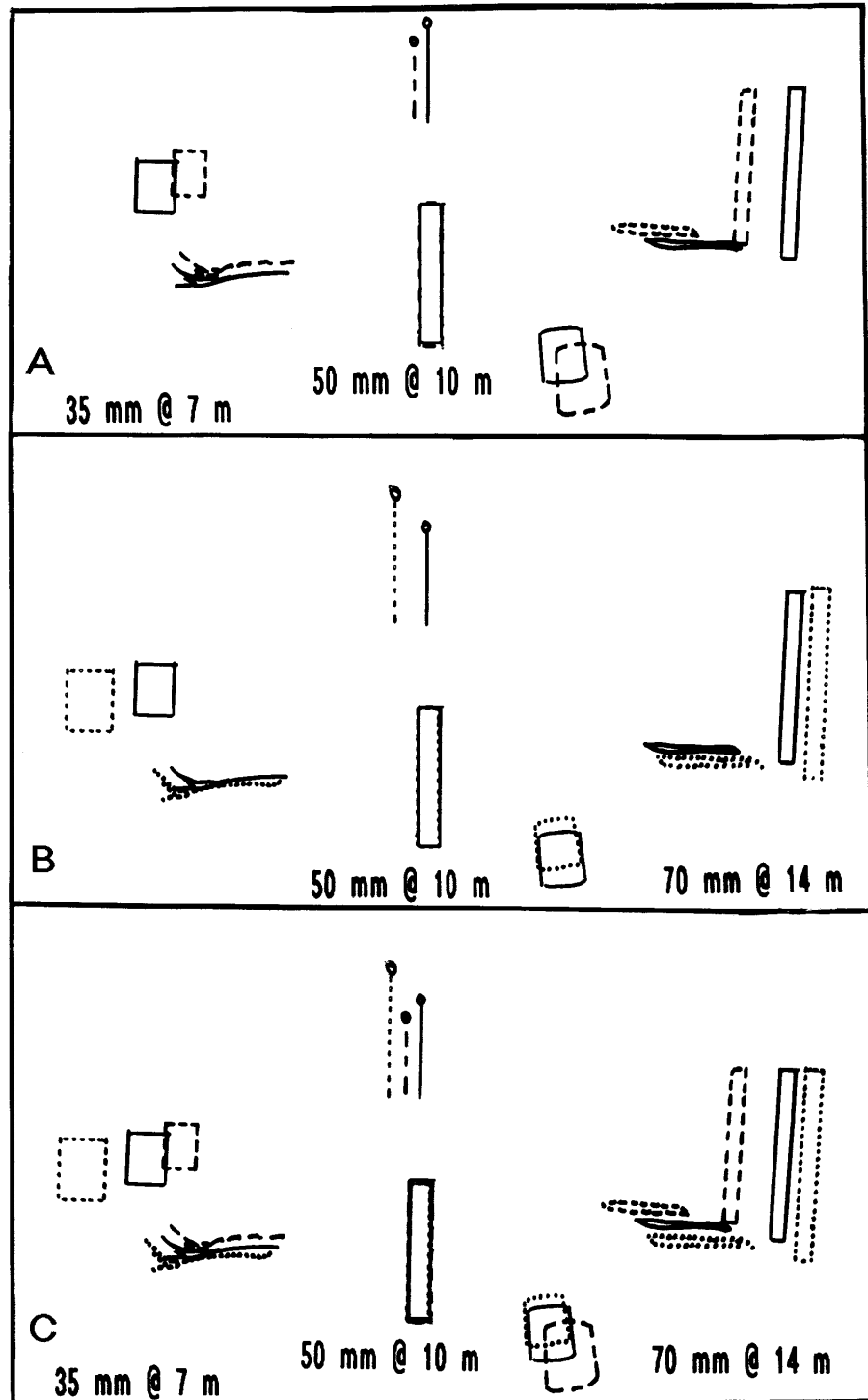


Figure 5—Object outlines from figure 4 overlaid to evaluate effects of camera focal length and distance from camera to meter board on size and location of objects. Photos were taken to keep the meter board at the same size. (A) The overlays for 35-mm at 7 m and for 50-mm at 10 m show different sizes and locations of items. A similar situation occurs with B. (C) All three overlaid shows a striking similarity to figure 3 because distance from camera to meter board is critical and focal length is not, as will be shown in figures 6 and 7.

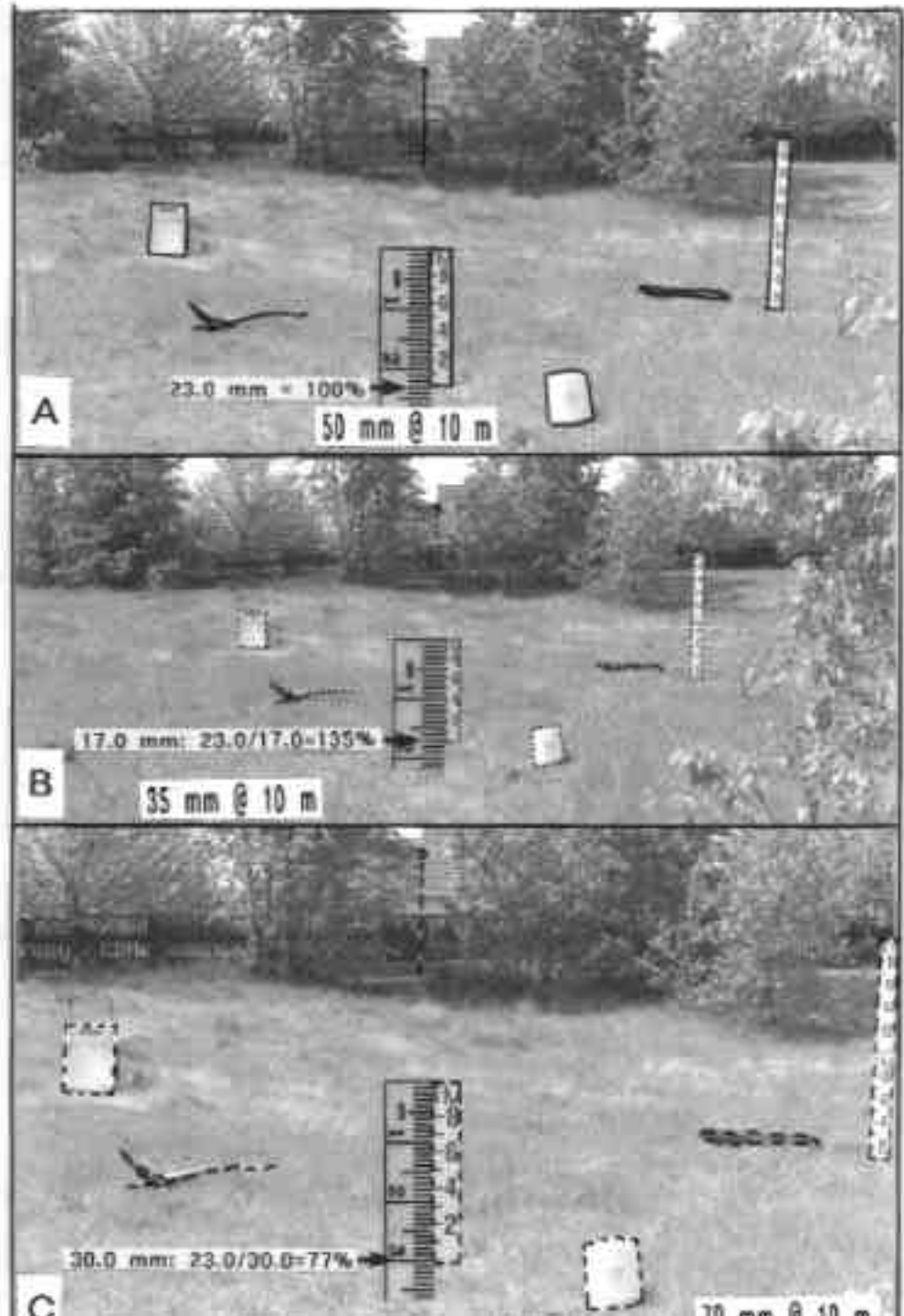


Figure 6—Effects of change in camera focal length of 35-mm, 50-mm, and 70-mm, at 10-m distance from camera to meter board using 50-mm at 10 m for comparison. Objects in each photograph were outlined on clear plastic overlays and were adjusted in size to the 50-mm at 10 m from the meter board as follows: (A) 50-mm was measured at 23.0 mm for 100 percent, solid outline; (B) 35-mm focal length was 17.0 mm, enlarged to 135 percent, outlined in dots; and (C) 70-mm was 30.0 mm, reduced to 77 percent, outlined in dashes. They are compared in figure 7.

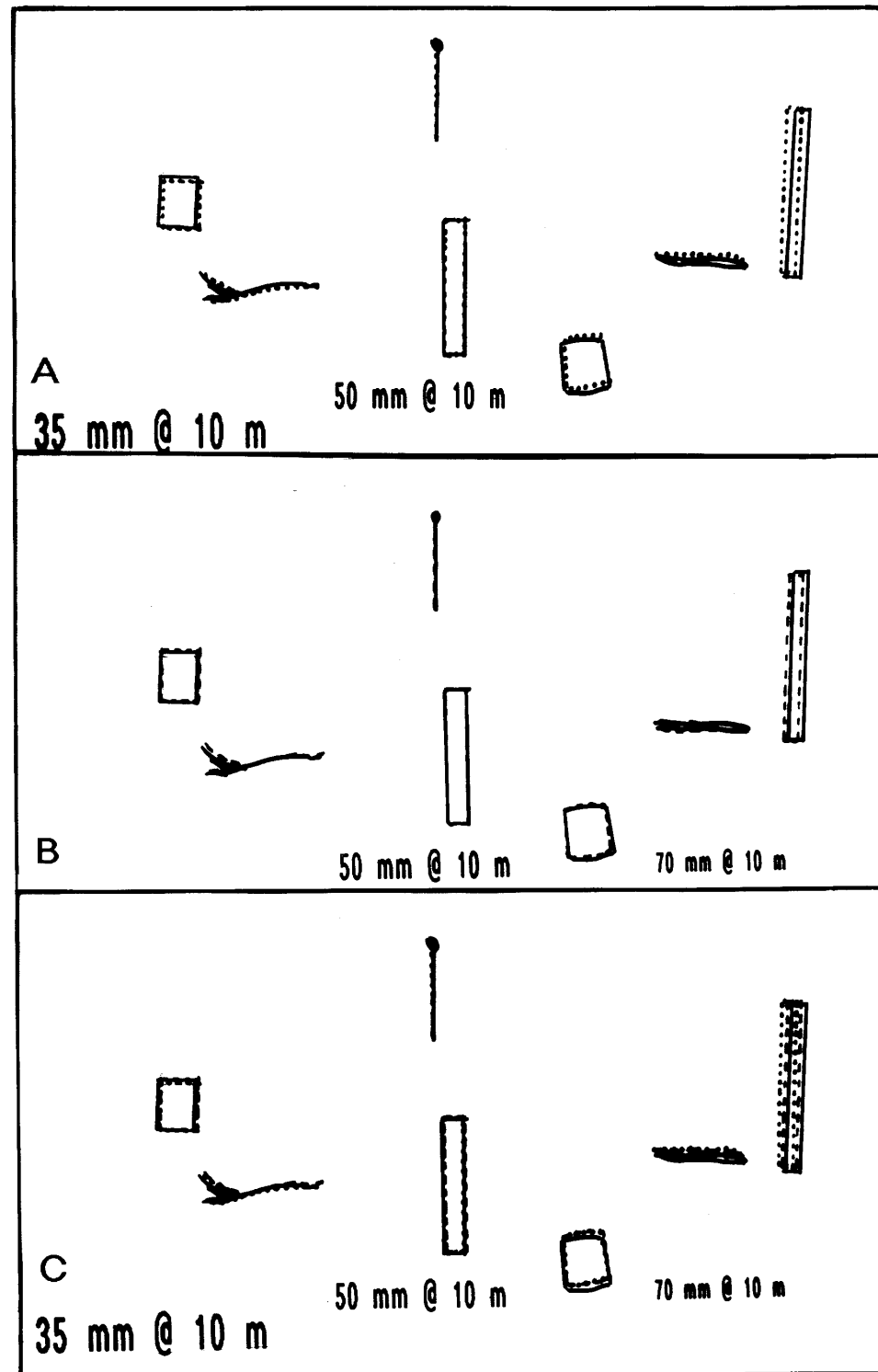


Figure 7—Object outlines for three camera focal lengths taken at 10 m from the meter board shown in figure 6. (A) Overlaying 35-mm and 50-mm shows almost no difference in object size or location. (B) Similarly, overlaying 50-mm and 70-mm shows little difference. (C) When all three are overlaid, there is almost no difference in object size or location. Camera focal length may differ without affecting analysis of photographic items when images are adjusted to a common size. A major disadvantage of using various focal lengths is the loss of background coverage in each photograph (shown in fig. 6, B and C). Comparison with figures 3 and 5 clearly demonstrates that distance from camera to meter board must remain the same.

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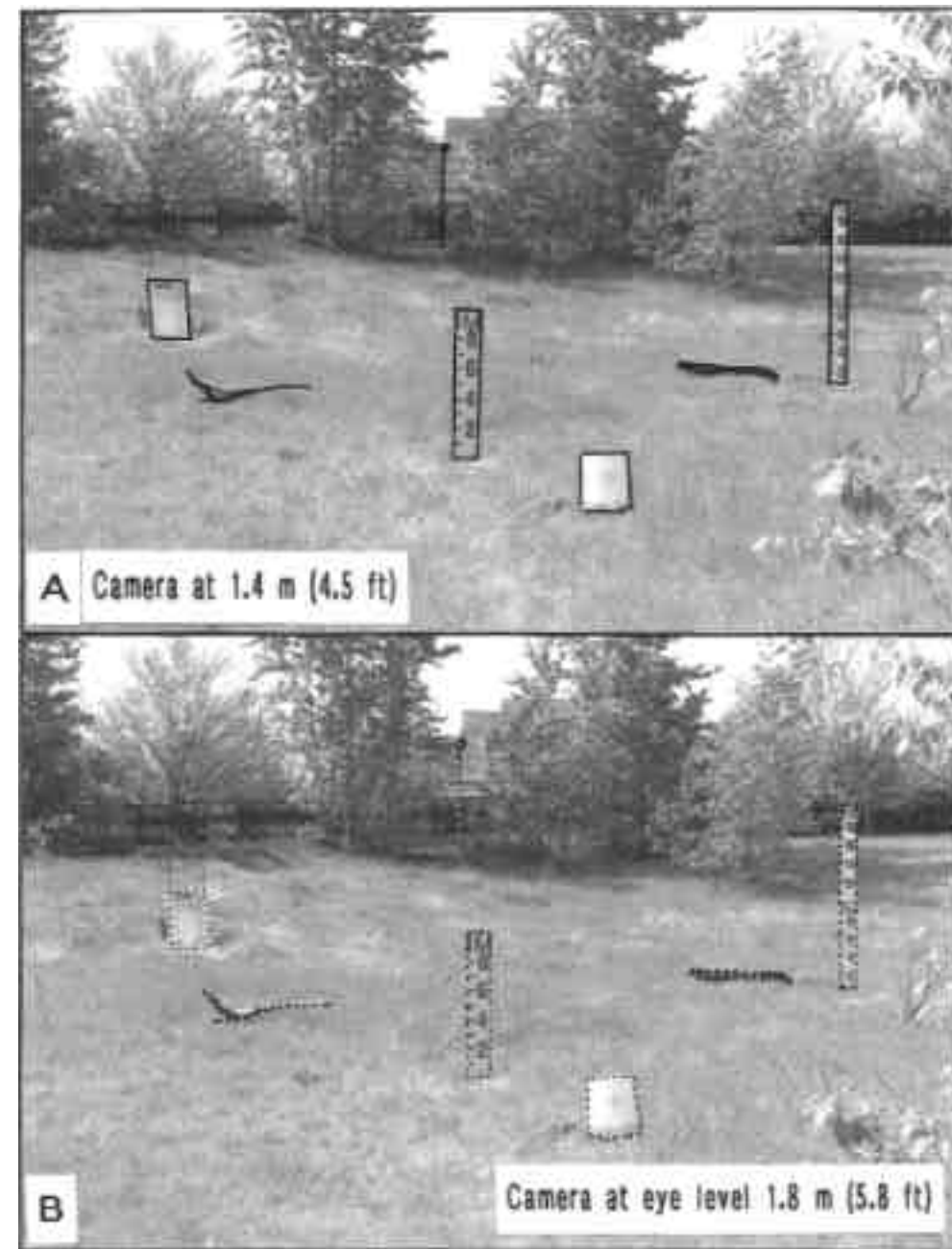


Figure 8—Effects of camera height aboveground on size and location of outlined objects. (A) Height of 1.4 m (4.5 ft, breast height) outlined in solid lines, is compared with (B) eye level of 1.8 m (5.8 ft) outlined in dots. The difference of 4 dm (16 in) is shown in figure 10A.

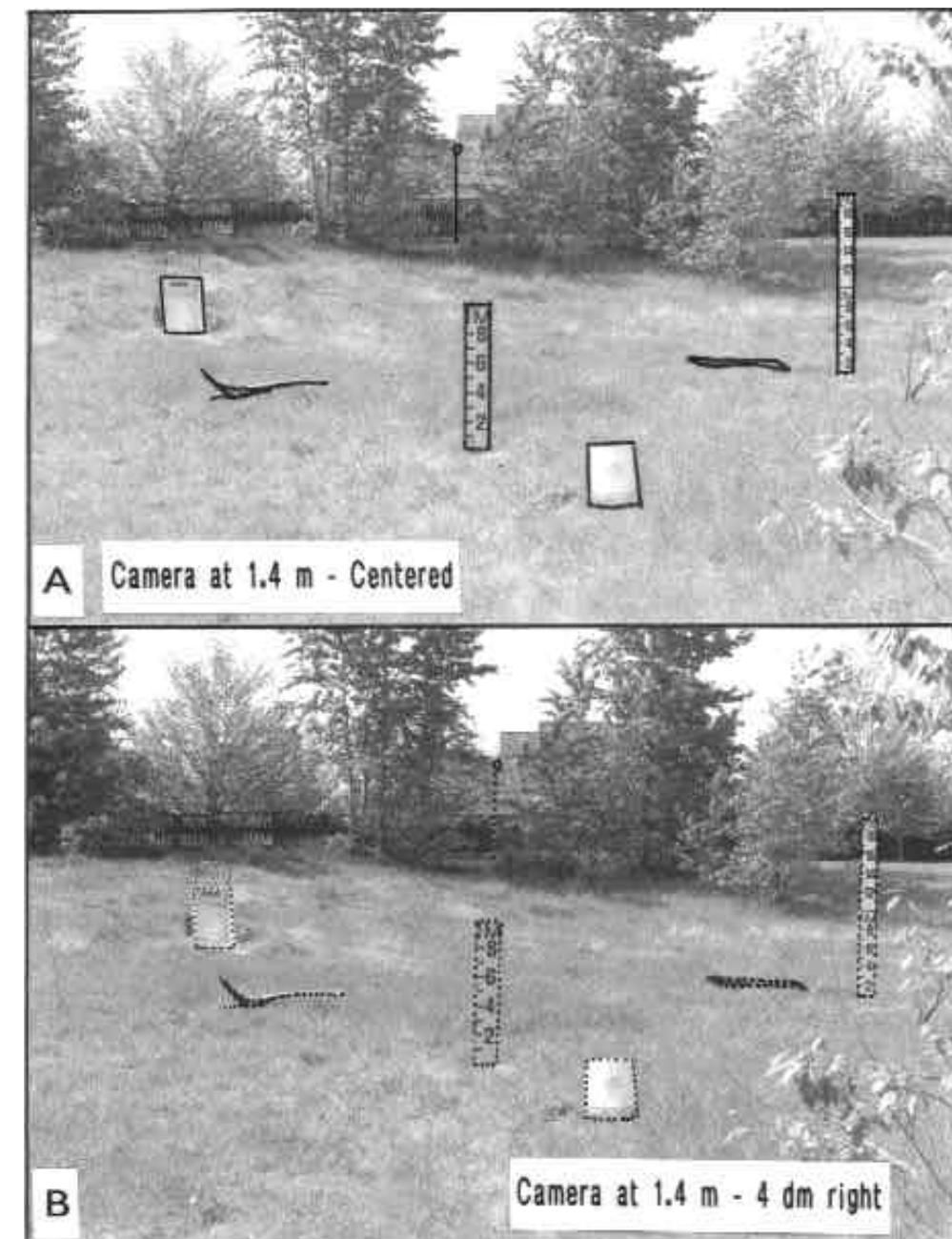


Figure 9—Effects of horizontal offset of the camera 4 dm (16 in) from center. (A) Center position is outlined in solid lines and (B) camera position to the right is outlined in dots. Difference in object size and location is shown in figure 10B.

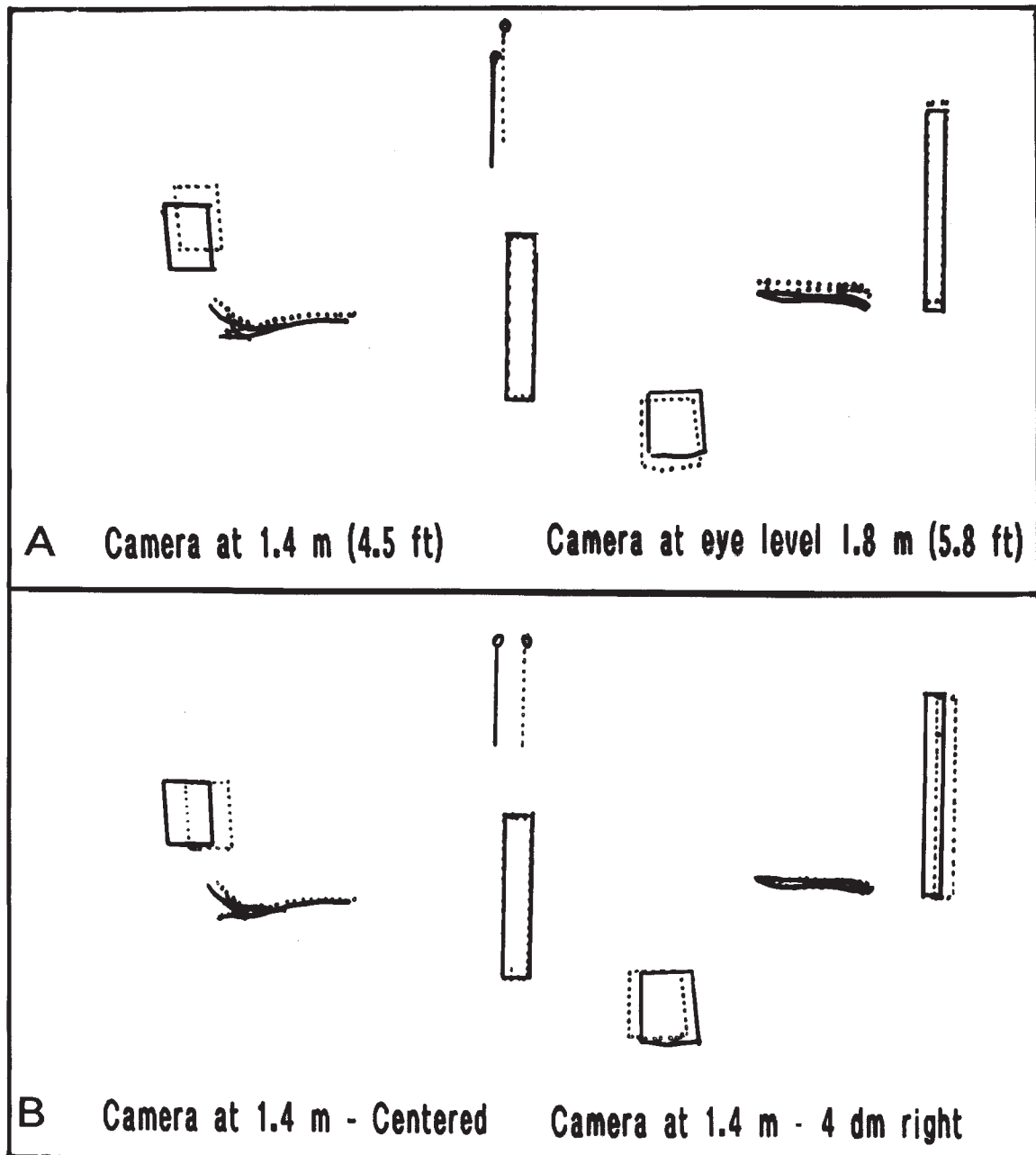


Figure 10—Effects of altering camera position by 4 dm (16 in) vertically and horizontally on size and location of outlined objects in figures 8 and 9. The reference position is 1.4 m (4.5 ft) centered over the camera location fencepost and outlined in solid lines. (A) Vertical movement of camera position, outlined in dots, to 1.8 m results in no change in object size but significant change in location on the photograph. (B) Horizontal movement of 4 dm (16 in) to the right, outlined in dots, results in no change in object size but significant change in position with the shift in a different direction from A. Position of the camera over the camera location fencepost affects location of objects but not size of objects.

Effects of camera position on object size and location are illustrated in figures 8 through 10. The photographs in figures 8 and 9 do not look different because 4-dm movement of the camera is difficult to detect. Figure 10, however, illustrates how much movement of objects occurs with only 4 dm (16 in) of change in camera position up or sideways. Although there is substantial change in object position, there is no change in size because the distance from camera to meter board was the same. Camera position is critical if location of objects is an objective of photographic monitoring; it is not critical if change in size of object is the objective.

Few restrictions and many opportunities exist in camera selection. The objective of photo monitoring suggests the appropriate style of camera and economics dictate the sophistication.

Filing System

A filing system must be developed for repeat photography. Place each photo study in a folder complete with purposes for the monitoring, site descriptions, notes, maps, color slides, and black-and-white prints with negatives or digital memory cards with prints (Johnson 1991, Nader and others 1995). The purpose of the file is to contain everything that other people will need for rephotography. Appendix D covers filing systems in detail.

Special note—It cannot be overemphasized to label and date all slides, black-and-white and color photographs, and the negatives as they are processed. Date and study location should be recorded on slides and negatives or digital memory cards by use of photo identification forms placed in the picture view at time of photography. Too often, negatives cannot be positively identified with their prints or date of photograph. I have found this a particular problem with negatives over 5 years old that document gradual change in conditions.

With these common characteristics in mind, two kinds of photo monitoring will be discussed: comparison photos and repeat photos.

Comparison Photo Monitoring

Comparison photo monitoring means comparing on-the-ground circumstances to a set of photographs depicting various known conditions and assigning a value or rating to the field situation. This deals primarily with effectiveness monitoring and asking the question, “Did we do what we said we would?” Three examples are illustrated: (1) appraisal of fuel loading, (2) estimation of herbage utilization, and (3) monitoring of public concern.

Forest Residue Estimation

An example of comparison photo monitoring is appraisal of fuel loading (fig. 11). Maxwell and Ward produced photo series for quantifying forest residues in the coastal Douglas-fir—hemlock type (*Pseudotsuga menziesii* (Mirb.) Franco-*Tsuga heterophylla* (Raf. Sarg.) (1976a), ponderosa pine type (*Pinus ponderosa* P. & C. Lawson) (1976b), Sierra mixed conifer type (*Abies* spp.) (1979), and natural forest residues in several Pacific Northwest forest types (1980b). Other examples are Koski and Fischer (1979) using photo series for appraising thinning slash in northern Idaho, Wade and others' (1993) photo series for estimating posthurricane residue in southern pine, and Ottmar and others' (1990) sophisticated stereophoto series for quantifying forest residues in the Willamette National Forest in Oregon.

Maxwell and Ward (1980a) and Fischer (1981) present detailed instructions for developing photo series for forest residues. Their procedures were very similar except that Fischer placed the size control marker 20 ft (6 m) from the camera and Maxwell and Ward placed it 30 ft (9 m). Color was preferred by both to enhance recognition of dry and green fuel. The procedure of Maxwell and Ward follows:

1. Find very high and very low fuel loadings in the proposed forest type and size class, and then intermediate loadings. A forest type is the dominant tree species, and size class is the diameter at breast height (dbh) of the stand; for example, Douglas-fir pole size 5 to 9 in (12 to 22 cm) dbh. Their publications showed three to five different fuel loadings per forest type and size class.
2. Select slightly concave topography so that residue within 180 ft (54.5 m), a desired sampling distance, is visible.
3. Take photographs on overcast days because bright sunlight streaming through canopies creates sharp contrasts (see app. E).
4. Use a quality 35-mm camera with 50-mm lens.
5. Take the photograph in landscape format (long dimension of the photo will be horizontal.)
6. Use a reasonably fast, fine-grained color film (for example, Kodachrome 64).



1-DF-4-PC

LOADING			OTHER MEASUREMENTS	
Size class (inches)	Weight (tons/acre)	Volume (ft ³ /acre)		
0.25-1.0	1.1	61	Average residue depth (feet)	<u>0.1</u>
1.1-3.0	2.3	143	Ground area covered by residue 1/4-inch diameter and larger (percent)	<u>40</u>
3.1-9.0	2.3	174	Average duff and litter depth (inches)	<u>0.7</u>
9.1-20.0	1.0	65	Sound residue 3.1-inch diameter and larger <u>Douglas-fir</u> (percent)	<u>79</u>
20.1+	0	0		(percent)
Total	6.7	443	Rotted residue 3.1-inch diameter and larger (percent)	<u>21</u>
HARVEST INFORMATION			PRECOMMERCIAL THINNING INFORMATION	FUEL RATING
Gross volume cruised (M fbm/acre)	<u>51</u>		Stems cut/acre	U.S. Forest Service Region 6
Net volume cruised (M fbm/acre)	<u>39</u>		Stems remaining/acre	fuel type identification <u>LL</u>
Average stems/acre cut	<u>52</u>		Basal area/acre before	REMARKS
Average d.b.h. of stems cut (inches)	<u>27</u>		Basal area/acre after	
Stand age (years)	<u>300</u>		Average d.b.h. before (inches)	
Cutting prescription <u>Shelterwood</u>			Average d.b.h. after (inches)	
Yarding method <u>Tractor</u>			Thinning method	
Slash treatment <u>Machine piled & burned</u>			Slash treatment	
Period since cut or treatment (months)	<u>12</u>			

Figure 11—Fuel loading comparison photograph from Maxwell and Ward (1976a, p. 32), originally produced in color. Conditions in the field are compared to a series of photographs to estimate fuel loading. This is one of a nine-report series showing residue after commercial thinning in Douglas-fir—western hemlock, size class 9 to 20 in dbh. The data table lists fuel loading weight and volume by size class, residue depth, percentage of ground cover by residue, average duff and litter depth, sound residue larger than 3.1 in by species, rotted residue larger than 3.1 in, harvest and precommercial thinning data, and the USDA Forest Service fuel rating.

7. Shoot between f-8 and f-16 for a long depth of field.
8. Always use a tripod because low light under tree canopies may require exposures below $1/30^{\text{th}}$ of a second.
9. Use the standard national field system marker placed 30 ft (9 m) from the camera; it is a pole 6 ft (1.8 m) tall with a 1-ft² (3 by 3 dm) marker at the top and alternate foot distances painted black and white (fig. 11).
10. Take a minimum of three exposures so that all fuel loadings from different locations can be presented in the same color mode.
11. To sample fuel loading, establish five base lines radiating from the camera and equidistant apart, with five sample points on each line in view of the camera. Sample the down material from each of the 25 sample points.
12. Sample standing live and dead material from six sample points distributed over the 25 fuel loading points.
13. Compute down fuels, standing fuel (live and dead trees, shrubs, grasses, and forbs) by size class, anticipated rate of spread, and flame length under selected moisture content and wind speed.

Maxwell and Ward's format shows a color picture of fuel loading with all data contained in that picture as computed by their instructions (fig. 11). The product is a pocket-sized booklet, about 5 by 9 in (12 by 22 cm), listing the forest type, such as west-side Douglas-fir or east-side pine associated, size class of the forest type, and within each forest type and size class, three to five fuel loadings.

To use their system, a person goes to the field, identifies the forest type and size class, then turns to appropriate photographs in the booklet and compares the fuel loading at the site with pictures in the booklet. The fuel loading is then estimated by comparing the existing conditions to those described for the photograph most nearly approximating field conditions. Jensen and others (1999) applied the concept for estimating fuel loading to a fire hazard to do a watershed analysis for the parks department of British Columbia.

Herbage Utilization

Another comparison photo monitoring system deals with utilization of grasses and forbs by livestock. Schmutz (1971) and Schmutz and others (1963) pioneered a series of photographs for grasses in the Southwest. Kinney and Clary (1994) developed a series depicting various kinds of utilization on riparian graminoids (fig. 12). On a single page, the latter depict six degrees of utilization: 0, 10, 30, 50, 70, and 90 percent. To use their guide, the species in question must be identified, its stubble height determined, and the height compared to photographs in the guide to estimate the percentage of utilization.

Kinney and Clary's procedure for developing a guide is rather simple and straightforward, as follows:

1. A height-weight curve was developed for each species to be photographed. A height-weight curve is the relation of the percentage of total height of the plant with seed heads to percentage of utilization. For example, a plant 5 dm tall might have 10 percent of its weight in the top 20 percent of its height (fig. 12). Thus, a plant 80 percent as tall as an ungrazed plant would represent 10-percent utilization.
2. A plant with seed heads of the desired species is selected, vegetation removed from around that individual, and a black backdrop placed behind the plant (fig. 12).
3. The plant is photographed in its full stature. Then it is clipped at heights that represent 10, 30, 50, 70, and 90 percent utilization. At each clipping, the plant is rephotographed.
4. These six photographs are then assembled onto a single page and accompanied with a height-weight graph showing the relation between plant height and percentage of utilization (fig. 12).

Guenther (1998), working in annual grass rangeland in California, developed a photo-monitoring guide dealing with residual dry matter. He used a Robel pole² (Robel and others 1970) photographed from 10 and 20 ft. Eight photographs depict increments of annual grass biomass from over 1,000 lb/acre to less than 125 lb/acre. The Robel pole is supplemented with a 0.96-ft² hoop placed at its base with four golf balls to help appraise grass density.

His procedure is to place the pole and take a photograph. Then the vegetation is clipped within the 0.96-ft² hoop to document the herbage production.

² The Robel pole is discussed in appendix A.

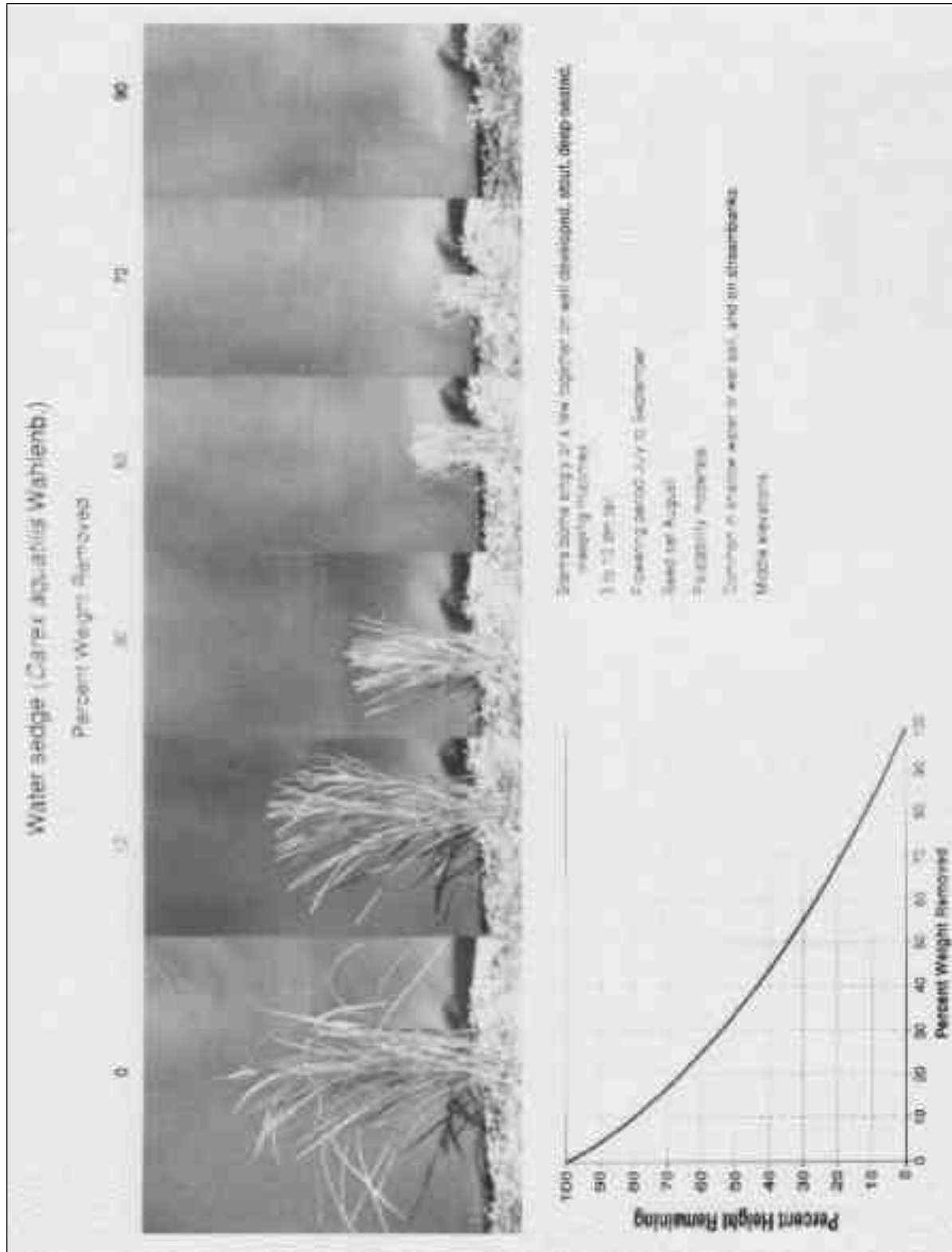


Figure 12—Sedge utilization comparison from Kinney and Cleary (1994, p. 7) for water sedge. Stubble height is shown for six levels of utilization. The photograph is compared to sedge utilization found in the field to appraise the amount of use.

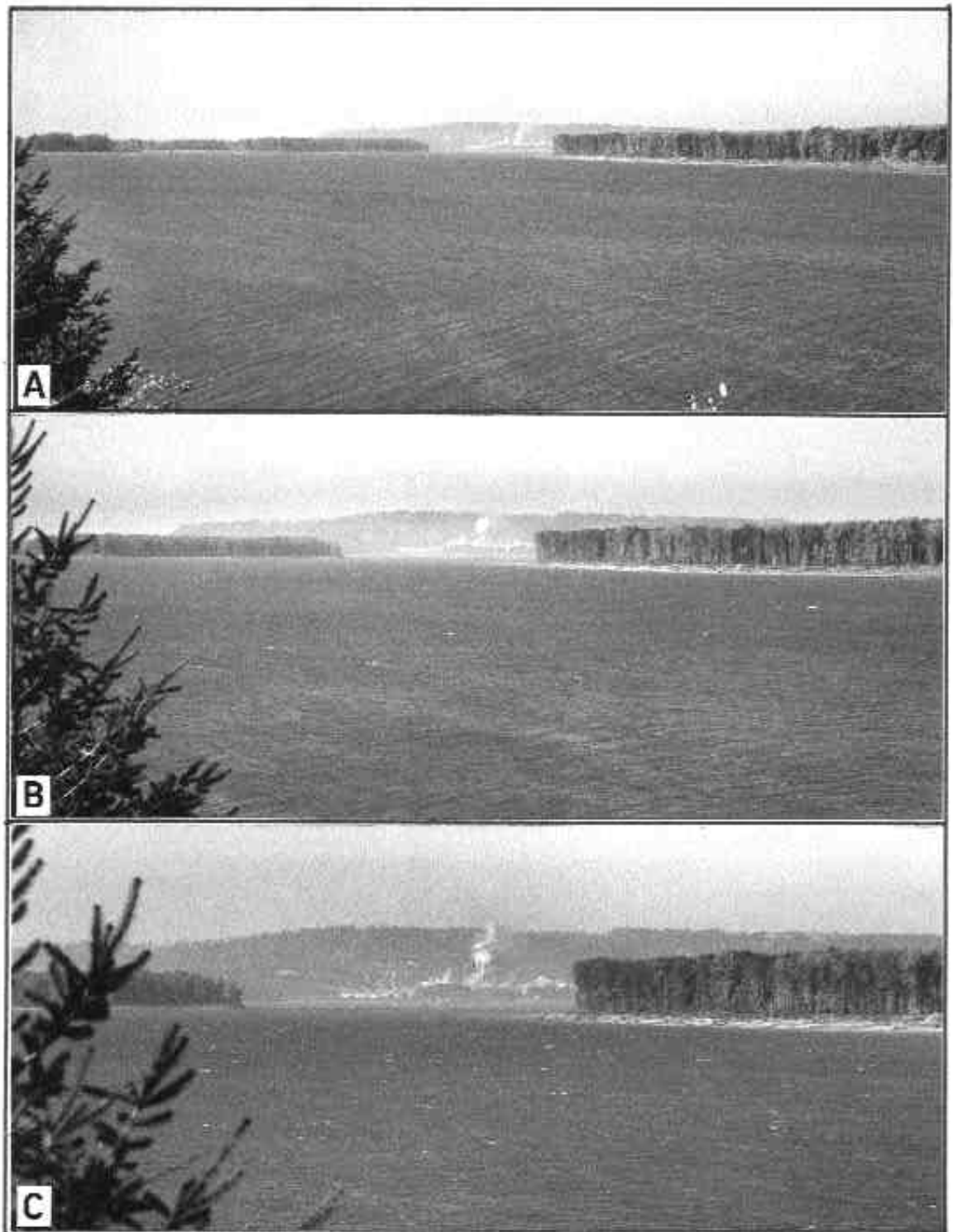


Figure 13—Comparison photographs of smoke from a pulpwood mill along the Columbia River taken from a turnout on Interstate 84: (A) 35-mm focal length simulating 20 mi distant, (B) 70-mm simulating 10 mi distant, and (C) 140-mm simulating 5 mi distant. Similar sets of photographs were used by Magill (1990), Benson (1983), and Ribe (1999) to appraise viewer's reactions to landscape scenes.

Monitoring Public Concern

Monitoring of public concern for landscape quality also uses a comparison photographic technique as discussed by Benson (1983), Magill (1990), and Ribe (1999). Their objectives were to test public awareness and concern for various landscape items, particularly effects of logging. Magill (1990) used a set of three to five photographs of the same landscape viewed at different distances (fig. 13). These were shown to people and their reaction or concern about the view documented. He tried to develop a threshold definition of various landscape features. The technique was as follows:

1. A landscape feature was selected as viewed from a suitable vantage point, such as a road or viewpoint.
2. This landscape was photographed with a 35-mm camera using color film and a zoom lens. Pictures were taken at 50, 70, 100, and 150 mm (fig. 13). This was done to simulate different distances from the landscape object, for example, 4.8, 3.2, 2.1, and 1.6 mi for each focal length, respectively.
3. No effort was made to select good visibility or particular weather conditions (fig. 13).

Benson (1983) discusses scenic beauty estimation and visual quality objective analysis through methods similar to those of Magill (1990). He also uses comparison photos to rate elk habitat characteristics and recreational impacts as part of forest planning. Ribe (1999) used photographs to test public response to 15-percent retention of green trees in clearcuts as a research method for appraising acceptance of alternatives in the Northwest Forest Plan.

Repeat Photography

As the name implies, repeat photography means retaking photographs from the same spot and of the same subject several times. To be effective, most repeat photography requires precise replacement of the camera and composition of the subject, be it a sample plot, view of a particular subject such as a streambank, or rephotographing a distant landscape.

Repeat photography is used for many purposes and, thus, can take on many different forms. It may be landscape rephotography covering 50 to more than 100 years of change (Skovlin and Thomas 1995); documenting animal activity at a specific site, such as ospreys (*Pandion haliaetus*) rearing young (Kristen and others 1996) or livestock distribution in a meadow (Kinney and Clary 1998); assessing air quality (Fox and others 1987); sampling change in vegetation using both general and closeup views (Hall 1976, Nader and others 1995); and appraising effects of management such as livestock utilization or logging (Gary and Currie 1977, Kay 1999, Kay and others 1999, Smith and Arno 1999). Hart and Laycock (1996) and Rogers and others (1984) present bibliographies on repeat photography. In this paper, a riparian setting, Pole Camp in eastern Oregon, will be used to illustrate various aspects of repeat photography.

Three things must be done for repeat photography to be successful: (1) map the site and the system layout, (2) document the system, and (3) permanently mark camera locations and photo points.

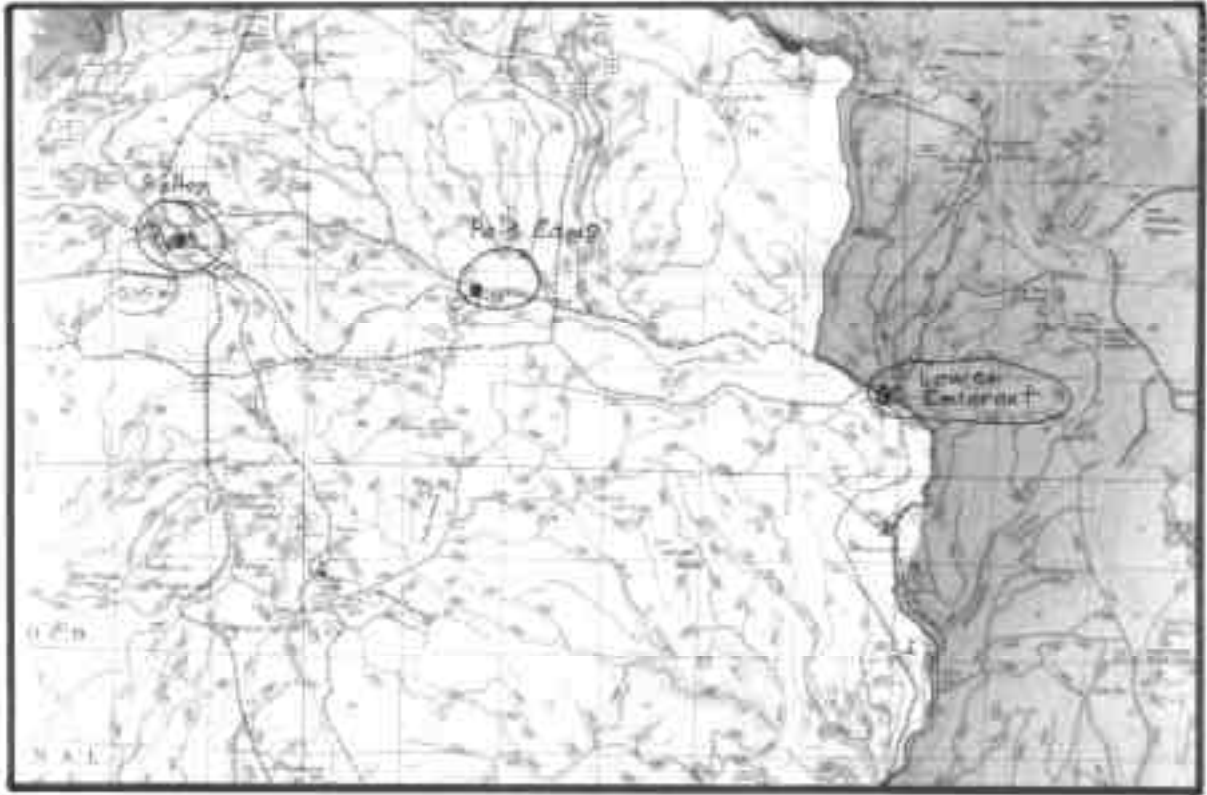


Figure 14—USDA Forest Service Ranger District map showing locations of the Button Meadow, Pole Camp, and Lower Emigrant riparian study sites in northeastern Oregon. Road numbers, mileage from road junctions, and directions to the witness sites (a tree or fencepost with an orange tag identifying the monitoring area) are given in the study writeup.

Maps of Location and Monitoring Layout

Maps are essential for relocating and rephotographing topics as discussed by Bauer and Burton (1993), Borman (1995), Governor's Watershed Enhancement Board (1993), Hall (1976), Nader and others (1995), National Park Service (1992), USDA Forest Service (1982), and USDI Bureau of Land Management (1996). Two maps are important:

1. Map of the monitoring site location so that those other than the installers can find it. Figure 14, a USDA Forest Service ranger district map, identifies the road on which the site is located. Establish a witness marker along the road by placing an orange tag on a tree or fencepost. Inscribe on the tag the identity of the monitoring site.
2. A map of the photo monitoring system layout so that others can duplicate the original photography (fig. 15). From the witness marker identified on the general map, record directions and measured distances to each camera location and photo point (fig. 15). Measure on the ground; do not attempt conversion to horizontal distance.

The emphasis on *others* (other people) refers to a problem discovered by many (Borman 1995; Gruel 1980, 1983; Johnson 1984; Magill 1989; Nader and others 1995; Parker and Harris 1959; Phillips and Shantz 1963; Progulske and Sowel 1974; Puchbauer and Carrol 1993; Reppert and Francis 1973; Strickler and Hall 1980; USDA Forest Service 1982; USDI Bureau of Land Management 1996).

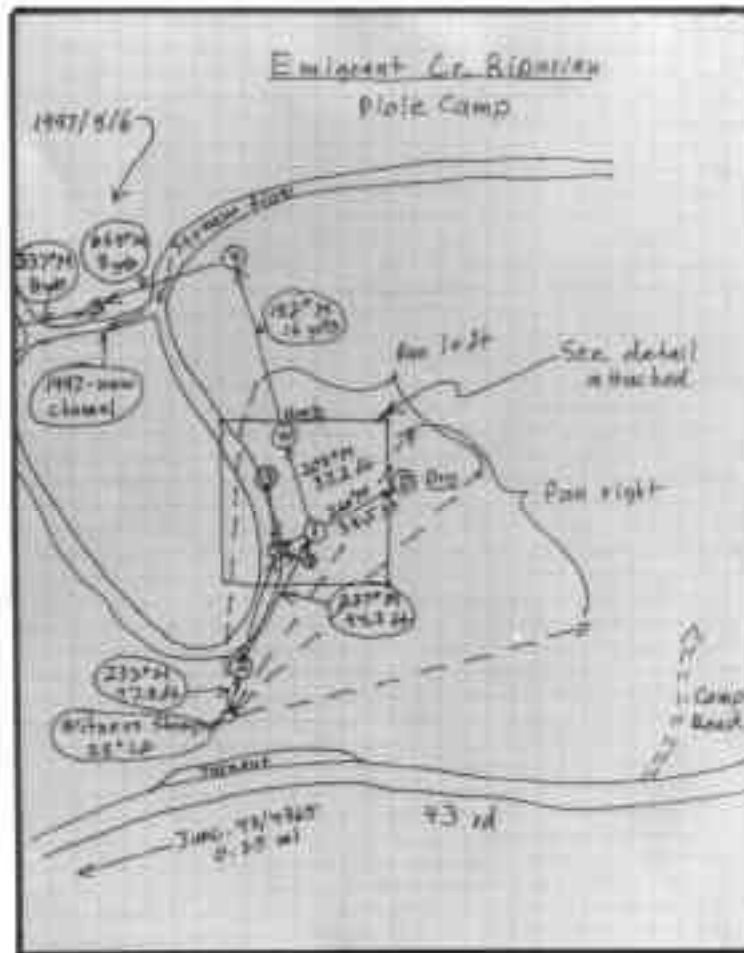


Figure 15—Study layout of the Pole Camp riparian site. Notice that all compass headings are shown as magnetic (M) to reduce confusion with the 21-degree deviation from true north in the Pacific Northwest. When distance is shown with a decimal point, it indicates a measured rather than a paced distance. Notice the two photo points from camera location 1—dry and wet. The boxed map is shown later in figure 27, which details location of the instream photo point.

Compass deviation is one item of particular importance in laying out the site map and relocating sites for repeat photography. In the Pacific Northwest, deviation is about 21 degrees east. The problem is, What does this mean? Does one add or subtract 21 degrees from the magnetic compass heading? Most people traveling by water, air, or land use magnetic headings for their direction; land survey, on the other hand, uses true direction. When providing direction on any map, specify true or magnetic. Notice in figure 15 that direction is listed first and distance second to provide easily followed instructions: You have to know what direction you are going before you can start moving.

Documentation of the Photo System

Each repeat-photography monitoring system must be documented in writing (in other words, a protocol for operation is created). It should include the following items:

1. The original size and focal length of camera such as a 35-mm camera with 50-mm lens or a 2- by 2-in (50- by 50-mm) square format camera with 70-mm lens.
2. The film to be used: speed and type of film such as Kodachrome 64 versus Elite Chrome (Ektachrome) 200, color or black and white negative film. Using both may require two different cameras or one camera with two backs. Digital cameras do not use film.

3. Definition of methods for repeatability of photographs. Specify how to aim the camera to repeat the field of view; for example, "site on the 1M of a meter board." The field of view must be held constant so changes in the subject matter, such as stream stability, vegetation change, or management activities, can be clearly documented.
4. Time of day, season of year, air quality for landscape rephotography, and lighting conditions, such as overcast sky to reduce shadows or backlighting to highlight vegetation (app. E).
5. A list of all equipment required.
6. Instructions for using mechanical or electronic aids for rephotography.

Permanent Marking

Witness sites, camera locations, and photo points or transects must be permanently marked for efficient photo monitoring. Steel stakes or fenceposts can be used. Each has advantages and disadvantages:

1. Steel stakes are difficult to find if vegetation overtops them.
2. Steel stakes protruding above the ground may be stepped on by animals or people, or run over by vehicles causing foot or tire damage. Stakes can be driven flush with the ground but then will require a metal detector to be relocated (White's Electronics, Inc. 1996).
3. Fenceposts are clearly visible and thus subject to theft.
4. Cheap fenceposts made of stamped steel are useful and durable (including against theft) when purchased in 5-ft (1.5-m) lengths and pounded 2 ft (0.6 m) into the ground. The 3 ft (0.8 m) above the ground is easily seen, and the flimsy construction deters theft because the stamped steel posts are as difficult to remove as strong T-bar posts.
5. Any fencepost aboveground is subject to destruction by equipment when an area is disturbed. When disturbance monitoring is contemplated, stakes driven flush with the ground are appropriate. Most inexpensive metal detectors will locate a 3/8-in (1-cm) diameter steel stake driven flush with the ground within a radius of 12 in (3 dm) (White's Electronics, Inc. 1996).

With this background, three kinds of repeat photography will be discussed: (1) landscape photography, (2) remote photo monitoring, and (3) site-specific monitoring.

Landscape Photography

Repeat landscape photography seems to have been devised by Professor S. Finsterwalder, who photographed and mapped glacial changes in the eastern Alps starting in 1888 (Hattersley-Smith 1966). In the United States, after the Civil War, photographers were invited to participate in exploring the Western United States. Some of these historical landscape pictures have been rephotographed 100 or more years later; for example, Progulske and Sowel (1974) rephotographed the area of Colonel Custer's 1874 exploration of the Black Hills to show changes in 100 years,

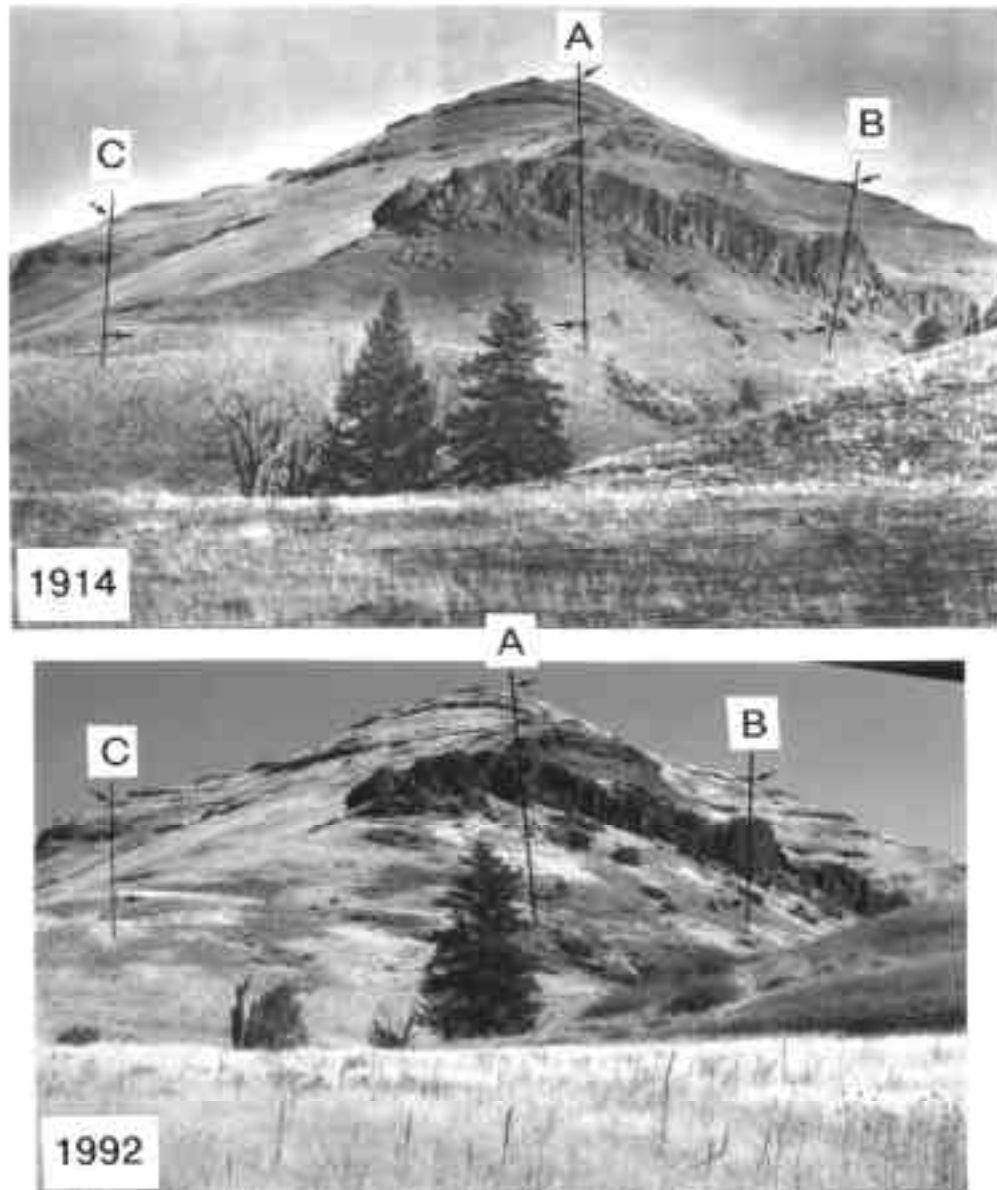


Figure 16—Relocation of historical photographs showing a view (1992) by Skovlin and Thomas (1995, p. 22-23) of Branson Creek, Wallowa County, Oregon, originally photographed in 1914 (top picture). The letter "A" identifies centerline orientation. Once the photographer was centered as on the original photograph, objects on the edges of the picture, such as "B" and "C", were chosen to refine location of the original camera. The photographer has to move forward or back until the angles of "B" and "C" are similar to the original photograph. Slight differences in orientation lines between 1914 and 1992 suggest the camera in 1992 was a few yards left of the original location. The usefulness of black-and-white photographs is illustrated here by triangulation lines placed directly on the picture.

and Skovlin and Thomas (1995) illustrated changes over 70 to 90 years in eastern Oregon (fig. 16). Landscape photography of small areas (10 to 100 ha) is discussed later and will be shown in figures 26 and 38. Appendix E illustrates some photographic techniques.

Johnson (1984), whose purpose was to evaluate change in sagebrush (*Artemisia* spp.) over 100 years or more, retok pictures taken by William H. Jackson during the 1860s to 1870s as part of the Hayden Expedition in Wyoming. Johnson concluded

that sagebrush is highly site-specific, some changes have occurred but they differ among sites, and there has been no major shift in sagebrush distribution, although densities have changed. He felt the landscape today is a fair representation of the 1870s.

Phillips and Shantz (1963), who compared photographs taken by Dr. Shantz 50 to 60 years previously, report on another historical photo series of vegetation changes in the northern Great Plains. Dr. Shantz also photographed in eastern Colorado in 1904. Many of the locations for his pictures were rephotographed in 1986 after 82 years (McGinnies and others 1991).

Branson (1985), Gary and Currie (1977), Gruell (1980, 1983), Johnson (1987), Puchbauer and Carroll (1993), Rogers (1982), and Veblen and Lorenz (1991) discuss additional landscape rephotography.

Purpose

Purposes other than historical documentation have prompted long-term retaking of landscape photographs. Long-term, in this context, refers to retaking photographs taken by another person, usually more than 20 years previously. Some have evaluated effects of livestock grazing and change in western rangelands (Branson 1985; Chaney and others 1991; Johnson 1984, 1987; McGinnies and others 1991; Phillips and Shantz 1963, Skovlin and Thomas 1995).

Changes in rangeland vegetation from 1902 to 1988 were documented by Medina (1996) in his history of the Santa Rita Experimental Range in southern Arizona. Fifty years of secondary succession under sheep grazing in green fescue (*Festuca viridula* Vasey) grasslands were rephotographed in the Wallowa Mountains (Reid and others 1991), and effects of revegetation in green fescue grasslands depleted by sheep grazing in the Wallowa Mountains were shown by Strickler and Hall (1980). They documented Dr. Arthur Samson's pioneer range work in rehabilitation, which helped to formulate the first textbook on range management.

Other uses for long-term landscape photography have been to appraise the historical effects of fire on wildlife habitat in the Bridger-Teton National Forest, Wyoming (Gruell 1980, 1983); forest health concerns in the Boise National Forest, Idaho (Puchbauer and Carroll 1993), which used photography from as early as 1870; changes in wildlife habitat in north Yellowstone (Houston 1982); causes for mule deer (*Odocoileus hemionus* Zimm) population eruptions in the intermountain West (Gruell 1986); long-term successional changes in Blue Mountain ecosystems (Skovlin and Thomas 1995) as it affects forest health, range condition, and wildlife habitat; and to illustrate change in research natural areas (Herring and Greene 1997).

Considerations in long-term repeat landscape photography include three important factors:

1. Relocating photographs done 50 to 100 years previously.
2. Duplicating photographs taken by cameras that are no longer manufactured or available.
3. Dealing with photographic conditions such as season, weather, light, and air quality.

Relocation

Most authors say that finding the camera location was their most difficult problem. Without precise camera relocation, duplicating the scene photographed by original cameras and duplicating weather conditions were unimportant (Gruell 1980, 1983; Hart and Laycock 1996; Johnson 1984; Phillips and Shantz 1963; Progulske and Sowel 1974; Puchbauer and Carroll 1993; Skovlin and Thomas 1995).

Johnson (1984) notes that each: "...photosite was relocated over a 12 year period through time-consuming search in the field aided by knowledge of the countryside and comparison of expedition maps and reports with modern references." He was referring to the Hayden Expedition. He also says that: "...the exact photo point was relocated by detailed inspection of photo features" (see fig. 16 and app. E).

A summary follows of comments by authors who have had to relocate landscape photography camera locations after 50 or more intervening years:

1. Study the travel log books, trail routes, and other descriptions of travel, not overlooking the slow rate of movement by horses and wagons, to locate a geographical area in which the old photograph might have been taken (Progulske and Sowel 1974).
2. Show the old photographs and descriptions to local residents for their ideas about location. In many cases, original photographers did not know local names of buttes; however, shape of the buttes and landforms are clues current residents can use to suggest camera locations (Progulske and Sowel 1974). If no travel logs are available, study of historic travel routes and railroads can provide clues as to where the photographers traveled and where they might have photographed (Phillips and Shantz 1963).
3. Identify unique landscape features such as hills, drainage ways, and their inter-relationships. Phillips (in Phillips and Shantz 1963) comments that Dr. Shantz always seemed to find a prominent landmark to include in his photos, even on the Great Plains, which greatly aided in relocation. Many of Shantz's photos were taken from the first railroads into an area where he would take photographs from a siding, town, or coaling station that could be readily relocated.
4. Orient the camera location by lining up near and distant objects in a triangulation system (fig. 16). For example, Progulske and Sowel (1974) point out that mountain profiles, abundance of rocks, thickness of soil, escarpments, and stream configuration were used. A search then can be made for rocks or dead trees, which lead to the target camera location. As Puchbauer and Carroll (1993) note, objects in the original photo often are overlooked during first examination; they suggest using a hand lens to locate subtle objects, such as old monarch trees (or their remains), on black-and-white photos.³

³ In my experience, black-and-white prints are superior to color slides in relocation because prints can be easily examined by hand lens, and triangulation lines, shown in fig. 16, may be placed directly on the photograph.

5. Problems with relocation:

- A. Historic travel routes, roads, or railroads may have been obliterated by modern activities, thereby making identification of camera locations difficult.
- B. Intervention by other objects is one of the most common problems encountered. These objects can be trees, buildings, or other obstructions to the view from the original camera location.
- C. No clear, identifiable landscape feature by which to locate even the general area of a photograph.

Considerations

Camera—The original cameras and films cannot be duplicated by equipment available today in nearly all cases of photography before 1930. Duplication of the original scene, therefore, requires matching negative size with focal length to replicate the original photographs as nearly as possible. For example a 4- by 5-in press camera with 128-mm lens is roughly similar to a 35-mm camera with 50-mm lens. Most authors of historic landscape rephotography comment on this situation and recommend solutions. Rogers and others (1983) deal specifically with this problem and demonstrate that camera format is not critical; camera location and distance to featured objects are the critical factors. They discuss adjustment of print size to original prints and some problems with loss of items on the periphery of photographs; for example, some detail is lost when using a 35-mm camera format (a 2-to-3 ratio) to duplicate a 4- by 5-in format (a 2-to-2.5 ratio).

Film—Film, of course, also is different; one would hardly expect to use a wet plate glass negative in today's world. And even if an early camera is still in working condition, compatible films no longer are made.

Season and weather—The season and weather (lighting conditions, time of day, and air quality) are a third important consideration in long-term landscape rephotography. Many authors note that not all the original photographs could be used because of poor quality due to air conditions, deterioration, processing, or inadequate photographic technique. When a photo site was found, Johnson (1984) points out that "subsequently, one or more visits were made to the site to duplicate as closely as possible the light, time of day, and date of originals."

These problems and conditions lead to rejection of many photographed landscapes as subjects for rephotography (Gruell 1980, 1983; Johnson 1984; Phillips and Shantz 1963; Progulske and Sowel 1974; Puchbauer and Carroll 1993; Skovlin and Thomas 1995).

Panoramic cameras—Panoramic cameras also have been used in landscape photography (Arnst 1985, Hanemann 1989). Hanemann describes the Osborn photo-recording transit, which is a unique camera once built in Portland, Oregon. The lens rotates through an arc of 120 degrees and focuses through a narrow slit onto a negative held in a semicircular position. This camera was used to rephotograph some of the scenes taken by Arnst (1985) in the Cascade Range of Oregon.

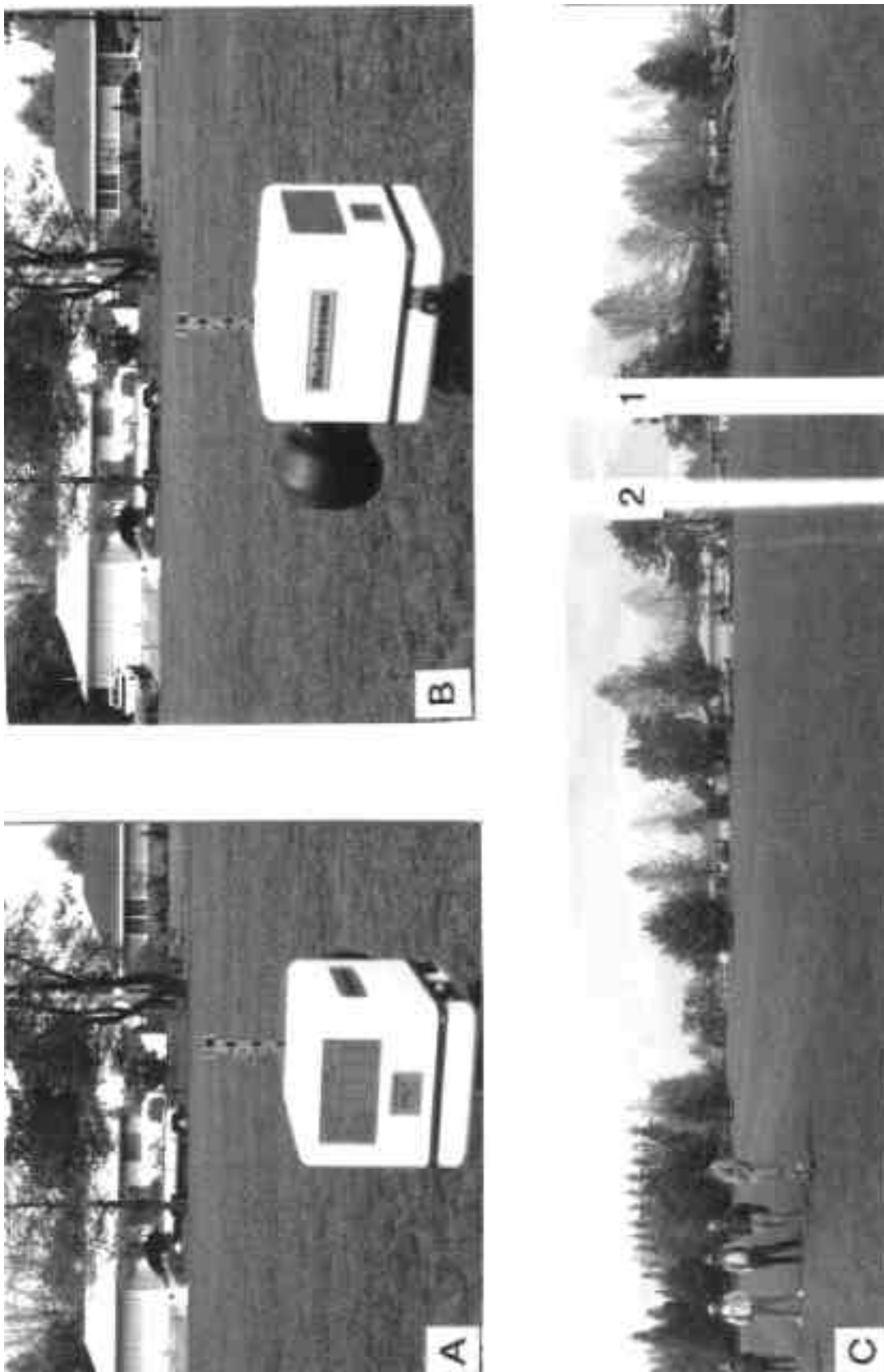


Figure 17—Panoramic photography using the rotating Hulcherama® Model 120 camera. The camera has no shutter. Instead, light is admitted through a vertical slit shown by the solid white bar (1) on the right in C. Amount of light is governed by a lens f-stop and by speed of camera rotation. (A) The camera begins its 360-degree rotation with the white line in C, then (B) continues past 360 degrees a few degrees to overlap the image. (C) Once started, the camera must continue to rotate at a specified speed. Should it be stopped, a fuzzy white strip will occur as shown by the white line (2) left of line (1) in C. A meter board has been used as a reference for the start of the rotation.

Today, panoramic cameras are built such that the camera itself rotates on a 360-degree arc while the film moves at the same rate of speed. The image passes through the lens and is constrained by a thin slit. The film rotates past the thin slit. An example is the Hulcherama[®] model 120 camera (Hulcher, n.d.; fig. 17).

Panoramic cameras have a singularly important requirement: they must be very accurately leveled so that rotation of the camera will photograph a constant horizon and this photograph can be retaken at a later date. Modern cameras can use both color and black-and-white film, commonly in 120 size, 12-exposure rolls. Exposure is determined by f-stop, slit width, and speed of camera rotation (Hulcher, n.d.).

Figure 18 illustrates problems using the meter board to orient general photographs instead of keeping a panoramic camera level. Camera location 1 at Pole Camp was chosen as the center of a 360-degree panoramic view of the area. Camera format was a 50-mm lens on a 35-mm camera body. The meter board was placed 10 m from the camera. For each successive photo, it was moved 8 m in a 10-m radius around the camera. On a flat flood plain, a meter board could be used to focus and orient the camera. However, camera orientation on the meter board in the stream of figure 18B lowered the view 1.3 m at the board, thereby causing displacement of the photos. Arrows point to a rock at top and a shrub in the center for orientation. An ideal panoramic view would have the camera level in all views to show changes in topography; thus the meter board would be lower in figure 18B and unusable for photo orientation.

Jensen and others (1999) used a camera rotated on a tripod similar to figure 17. In a test of observer variability, they found that 72 percent of the repeat photographs did not attain 20 percent overlap with originals. The causes were swapping cameras during rotation (to change film), thus causing misalignment of the view; inconsistent placement of the photo identification card, which should be placed at the same distance and location in the photo; and significant inconsistencies in exposure, which rendered some photos unacceptable for comparison because sun angle changed during 360 degrees of view.

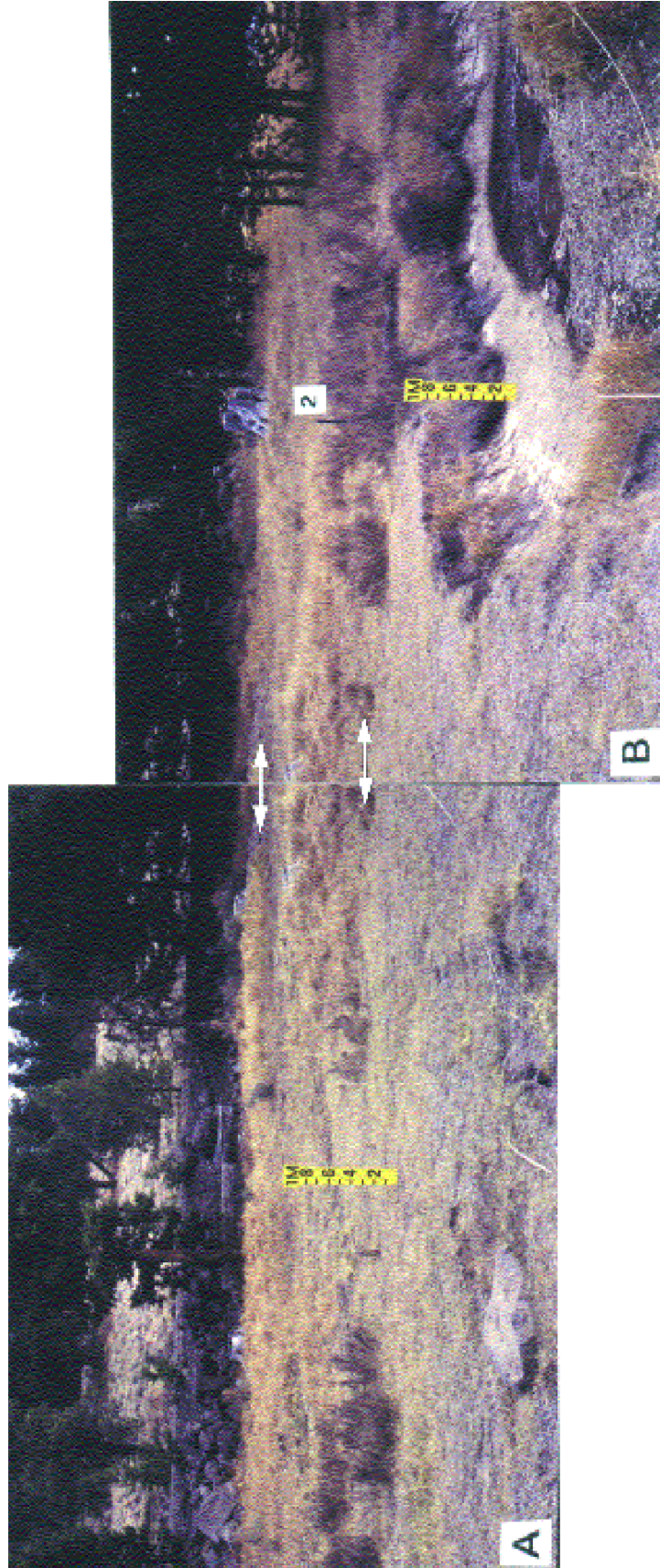


Figure 18—Two photographs of a 360-degree panoramic view of Pole Camp from camera location 1. The camera was focused on the “1M” of the meter board, similar to topic photographs, as a means for exact reorientation of subsequent pictures. As a result, view **B** is significantly displaced because the meter board is about 1.3 m lower than in view **A**. Overlap items are shown at arrows that cross from **A** to **B**. The number (2) identifies camera location 2. Above the (2) is the lodgepole pine witness stump. Figure 15 is a map of this site.



Figure 19—Mechanically triggered camera system used by Bull and others (1992) to monitor presence of marten (*Martes americana* Turton). Bait (arrow, lower right) was suspended on the tree to the right under a cover as one modification for winter operation. Camera was a 110 size with flashcube.

Remote Photo Monitoring

Remote photo monitoring uses unattended camera or video systems. Repeat photos are taken of a specific view, which may be a landscape (Fox and others 1987) or a specific activity such as a nest of ospreys (*Pandion haliaetus* Linn.) (Kristen and others 1996). Zielinski and Kucera (1995) deal with photo detection of animal presence in detail (fig. 19). Because remote photo monitoring is a topic unto itself, only a few examples will be presented.

Time-lapse systems have been described by Bryant,^{4 5} Bull and Meslow (1988), Fox and others (1987), Kinney and Clary (1998), Kristen and others (1996), and Temple (1972). They all used timing systems to trigger the camera at specified intervals ranging from fractions of a second to several hours. Movie cameras, 35-mm cameras, and video cameras were used. Bull and Meslow (1988) monitored pileated woodpecker (*Dryocopus pileatus* Linn.) chick feeding with a super 8-mm camera set to expose a frame every 8 to 12 seconds (Temple 1972).

Bryant (see footnote 4) used a time-lapse super 8-mm movie camera (Temple 1972) to monitor winter ice floods on Meadow Creek in eastern Oregon. The location was a research study site testing various livestock grazing effects on riparian ecosystems. The 45-minute flood lasted about 4 minutes at standard speed in a movie projector. Super 8-mm movie cameras have been replaced by camcorders.

⁴ Personal communication. 1990. Larry D. Bryant, wildlife biologist, on Meadow Creek flood. USDA Forest Service, Pacific Northwest Research Station, 1401 Gekeler Lane, La Grande, OR 97850-3368.

⁵ Personal communication. 1990. Larry D. Bryant, wildlife biologist, on remote video camera. USDA Forest Service, Pacific Northwest Research Station, 1401 Gekeler Lane, La Grande, OR 97850-3368.

In another study (see footnote 5), Bryant used time-lapse remote video to document livestock use of riparian areas. He found that video "film" is less expensive than camera film, instant viewing and transmission were advantages, and cost of camcorders and deterioration of video film were disadvantages.

Kinney and Clary (1998) monitored livestock distribution patterns over several grazing seasons in meadows through repeat 35-mm camera photography. The camera took a picture every 20 minutes during daylight hours during a 15- to 20-day grazing period on three meadows over 2 to 4 years. Dry graminoid locations were preferred even though forage production was not the highest. They emphasized several things: The sun must be behind the camera for all exposures. The camera must be set to expose for the desired kind of vegetation; for example, on grass and not on the surrounding evergreen forest. And, animals are curious and often affect the camera location by pushing on it, which modifies the camera aim or destroys the installation.

Fox and others (1987) discussed monitoring of air quality with a 35-mm camera. Their equipment was a 35-mm camera body with a 135-mm lens, automatic winder, automatic exposure designed to be on only during the exposure (not continuously), an ultraviolet filter, a data back capable of imprinting the date and time, and a battery-powered programmable timer capable of triggering the camera at least three times per day in a housing for the complete system capable of standing alone and operating in temperatures from -34 to $+54$ °C while being unattended for at least 10 days. Their criteria state that the site must contain at least one horizon-visibility target with as many of these characteristics as possible: (1) large, (2) identifiable on a topographic map, (3) dark vegetation (such as conifers), (4) 32 to 80 km in distance, (5) two or three targets at various distances, (6) camera and target at about the same elevation, (7) target centered in the camera viewfinder, (8) site path not affected by local sources of air pollution, (9) target as free of snow in winter as possible for contrast, (10) exceptionally bright or dark foreground objects avoided, and (11) camera oriented to avoid sun on the lens for pictures taken any time during the day. They provide a diagram and a system for evaluating film by using microdensitometric analysis of color slides.

Kristen and others (1996) monitored osprey nest activity over a season by using a video camera set to expose one frame every six-tenths to one second. The images were then transmitted by a directional antenna to a receiving station up to 8 km distant and viewed on a monitor. The lapse in time could be adjusted at the monitor receiving station. A deep cycle battery supplemented by a solar panel supplied the power to the system.



Figure 20—Pole Camp “wet” sample location showing three dates of the same year. June 15 is before scheduled grazing, August 1 is at change in rotation pastures, and October 1 is after grazing. This pasture was rested from June 15 to August 1. October 1 illustrates the degree of livestock use of Kentucky bluegrass at the meter board, aquatic sedge behind the board, and willows in the distance.

Site-Specific Repeat Photography

Site-specific means that a camera location and photo point or transect are permanently marked to document a specific topic on a limited tract of ground (not a landscape view) (Jensen and others 1999, Smith and Arno 1999). Directions and measured distances from witness site to camera locations and from camera to photo points or transects are required for precise relocation. For example, figure 20 is Pole Camp photo point "wet" (the wet meadow view). Topics were animal affects on willow shrubs (*Salix* spp.) and herbaceous stubble height remaining after grazing along the stream and adjacent meadow. A different kind of topic, planned disturbance and plant community development, is illustrated in figure 21.

Site-specific repeat photography may be divided into two kinds: topic and transect systems.

Topic Photographs

Topic photographs are shown in figures 20, 21, 22, and 23, where specific topics were monitored. This system uses a general photograph and may be supplemented by closeup photos of the meter board, a single plot frame (fig. 24), or overhead tree cover (fig. 25). Cole (1993) points out some limitations of topic photography when documenting damage to soils and vegetation from wilderness recreation. He indicates that measuring change from the photographs was difficult.

Transect identification using topic photography is used in the three-step method (Parker 1954, Parker and Harris 1959). In this method, Reppert and Francis (1973) could appraise species identification and their change in density and could verify correct replacement of the transect.

In British Columbia, Jensen and others (1999) applied topic photography to monitor recreational impacts, fuel loading, riparian vegetation and stream channels, disturbance recovery, and quantitative measurements of change in soil and vegetation. In an appraisal of observer variability, they found that a topic photopoint system could attain 80 to 100 percent overlap 95 times out of 100 (95-percent probability).

French and Mitchell (1983) used the single-topic approach to photograph change in shrubby vegetation in southern Idaho over 21 years. Pond (1971) evaluated an increase in chaparral (*Quercus* spp., *Ceanothus* spp., *Rhus* spp., *Arctostaphylos* spp.) for 47 years in an enclosure erected in 1920. Sharp and others (1990) show 40 years of change in a shadscale (*Atriplex confertifolia* (Torr. and Frem.) S. Wats.) stand in Idaho and correlate it with growing conditions to appraise effects of local weather on species dominance. In another study, Sharp and others (1992) document crested wheatgrass (*Agropyron desertorum* (Fisch. Ex Link) J. A. Schultes) production over 35 years and correlate it with growing conditions. Medina (1996) photo documented vegetation changes in the Santa Rita Experimental Range in southern Arizona at five locations: Burroweed (*Haplopappus tenuisectus*) increased and decreased with precipitation; jumping cholla (*Opuntia fulgida*) was absent in 1902, increased by the 1940s, then decreased; velvet mesquite (*Prosopis juliflora*) increased dramatically on mesic uplands but not on clayey, stony soils; and Lehman lovegrass (*Eragrostis lehmanniana*) increased and displaced many native species.

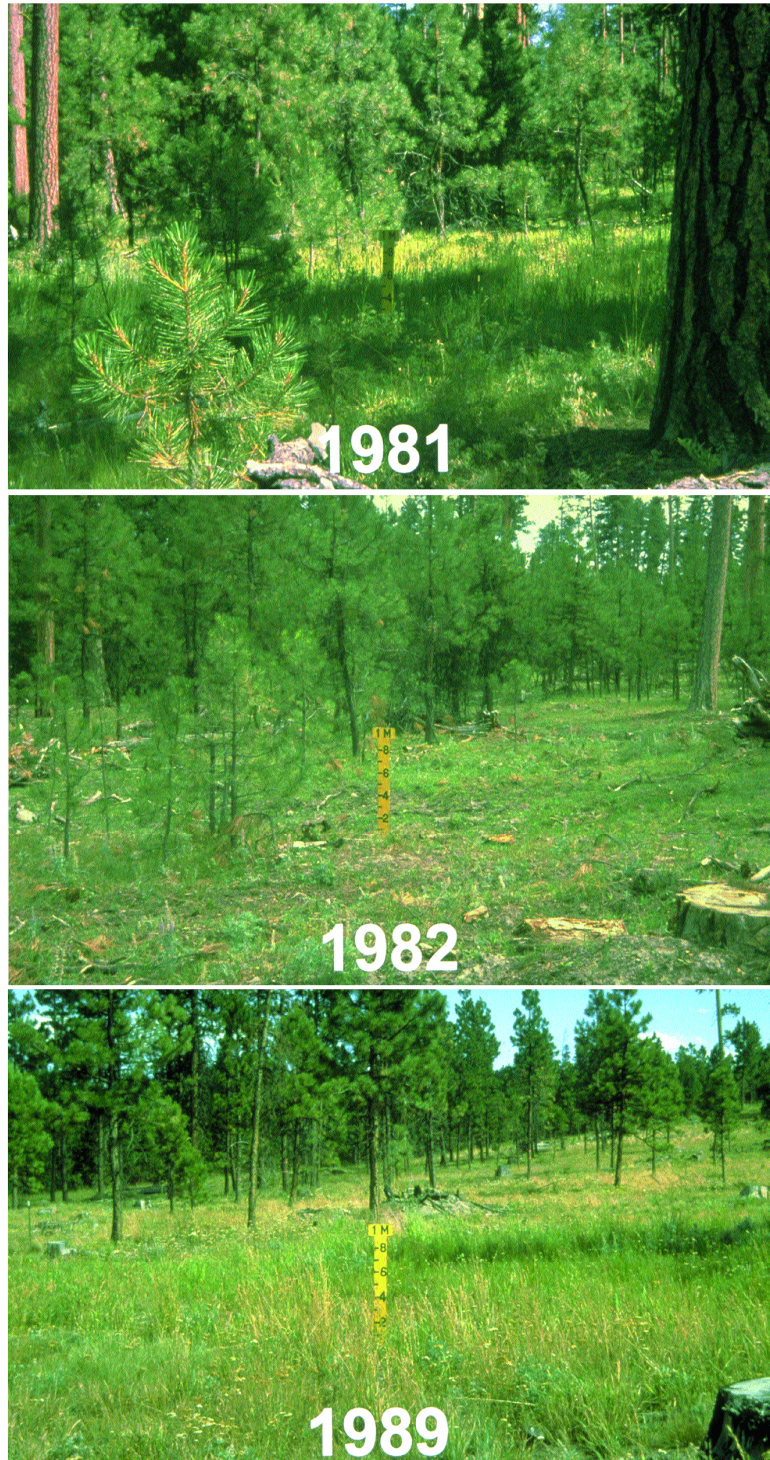


Figure 21—Aponderosa pine stand with pinegrass ground vegetation showing conditions after logging: undisturbed in 1981, after the first partial overstory removal in 1982, and in 1998 after the second overstory removal and precommercial thinning. These views, with their dramatic differences, emphasize the need for permanent marking of both camera locations and photo points. Exact reorientation of the picture uses the “1M” of the meter board as the photographic center (see fig. 29). All photographs were taken the first week of August.

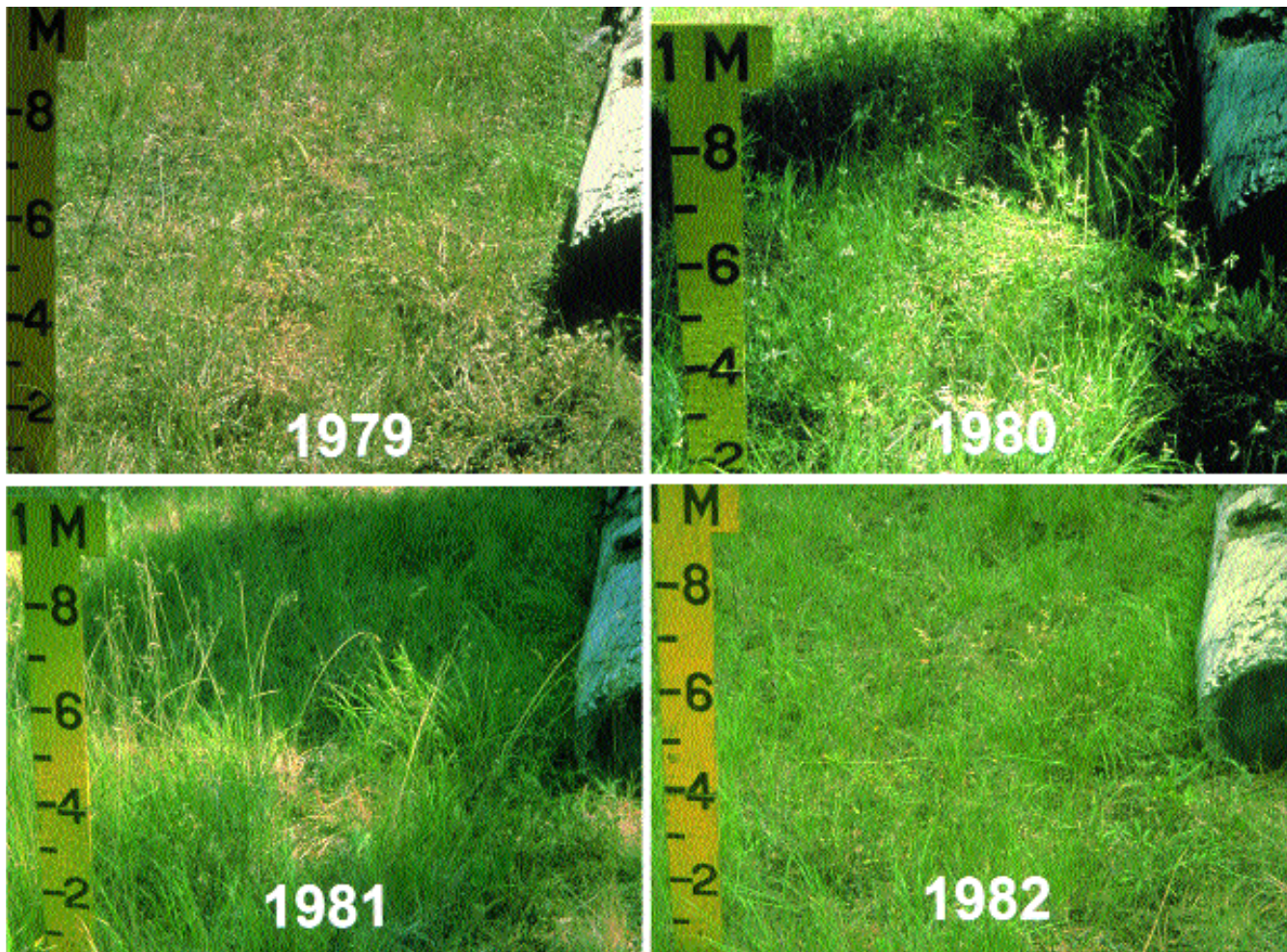


Figure 22—Photo monitoring each year at the same date (August 1) to document herbage production in a ponderosa pine stand with pinegrass. In 1979, drought occurred, which resulted in elk sedge (*Carex geyeri* Boott) dominance and only 400 lb of total herbage per acre. In 1980, lupine (*Lupinus caudatus* Kellog) was clearly important and pinegrass dominated over elk sedge with total herbage of 700 lb/acre. In 1981, Wheeler's bluegrass (*Poa nervosa* (Hook.) Vasey) was important, lupine was nearly absent, and pinegrass was common with total herbage of 750 lb, and in 1982, pinegrass was again clearly dominant without much bluegrass or lupine with total herbage about 600 lb/acre. Notice the lack of shadows under overcast skies in 1979 and 1982 compared to full sun in 1980 and 1981.

Effects on vegetation, soil, and streambanks from adjustment in livestock management are shown by Anderson and others (1990), Chaney and others (1991), Elmore and Beschta (1987), and Skovlin (1991). In Elk Creek, Oregon, a pair of repeat topic photographs was used to show riparian improvement (USDA Forest Service 1993).

Gary and Curry (1977) document changes in soil condition and erosion with a 40-year photographic record of plant recovery on an abused ponderosa pine watershed in Colorado. Skovlin (1991) shows changes in soil and vegetation on a forest zone bunchgrass type with a series of 1939, 1949, and 1989 photos that follow a shift in cattle grazing from season-long to deferred rotation.

Fire effects were followed by Lyon (1984), who presents 21 years of postfire change at the Sleeping Child burn, and Stickney (1986), who presents a similar series of photographs on succession for the first decade after the Sundance fire, both in northern Idaho. In another case, Lyon (1971) documented vegetation development



Figure 23—Streambank monitoring at the Pole Camp study site. In 1981 the camera location was 3 dm from the bank at a bend in the stream. An ice flood during early spring 1982 eroded the bend of the stream, increased its meander, and destroyed the camera location. In 1982, the camera was relocated 1.3 m to the left and 1 m back from the original location. The result was (1) apparent movement of the right bank, (2) the hole indicated by an arrow shows that only a portion of the bank fell into the stream, and (3) the angle between a rock in the stream bed and the camera to meter board was changed from 44 degrees to 39 degrees demonstrating the camera relocation. This kind of change in camera location or photo point should be avoided.



Figure 24—A1-m² plot frame marked at 2-dm intervals. Plot frames are quite useful in sparse vegetation such as the Crooked River National Grassland. The decimeter marks may be used to grid the plot frame (similar to fig. 28, below) to appraise vegetation change. However, riparian areas or other dense vegetation make plot frames questionable for photography, as suggested by figure 34.

after prescribed burning of Douglas-fir in south-central Idaho for 7 years; preburn and postburn vegetation was sampled, and photo points were established and recorded annually for the 7 years. His publication shows prefire vegetation and conditions 1, 3, and 7 years after burning. Blaisdell (1953) documented effects of prescribed burning on big sagebrush-wheatgrass. He shows one general two-photo series and a closeup six-photo series of before, immediately after, and 1, 2, 6, and 12 years after the burn. Johnson (1998) shows 5 years of response to fire by grassland and forest in eastern Oregon. The National Park Service (1992) provides detailed guides for documenting fire effects on vegetation.

Fire suppression effects in ponderosa pine stands are documented by Biswell (1963), Gruell and others (1982), and Weaver (1957, 1959). Smith and Arno (1999) provide repeat photos at 13 locations for an 88-year period. Gruell and others (1982) show 10 sets of repeat photographs of changes in ponderosa pine stands after logging and fire suppression. Shinn (1980) illustrates effects of fire suppression on western juniper (*Juniperus occidentalis* Hook.) sites.

Documentation of logging effects is shown in figure 21. In 1978, conditions were an undisturbed ponderosa pine overstory with pinegrass ground vegetation (*Calamagrostis rubescens* Buckl.) in the southern Blue Mountains of Oregon. The site was entered twice for selection cutting. The 1982 photo shows stand conditions after the first selection cut, and the 1988 one shows conditions after the second selection cut and precommercial thinning. Edgerton (1983) illustrates effects of logging on bitterbrush (*Purshia tridentata* (Pursh.) DC.) under lodgepole pine (*Pinus contorta* Doug. ex Laud.).

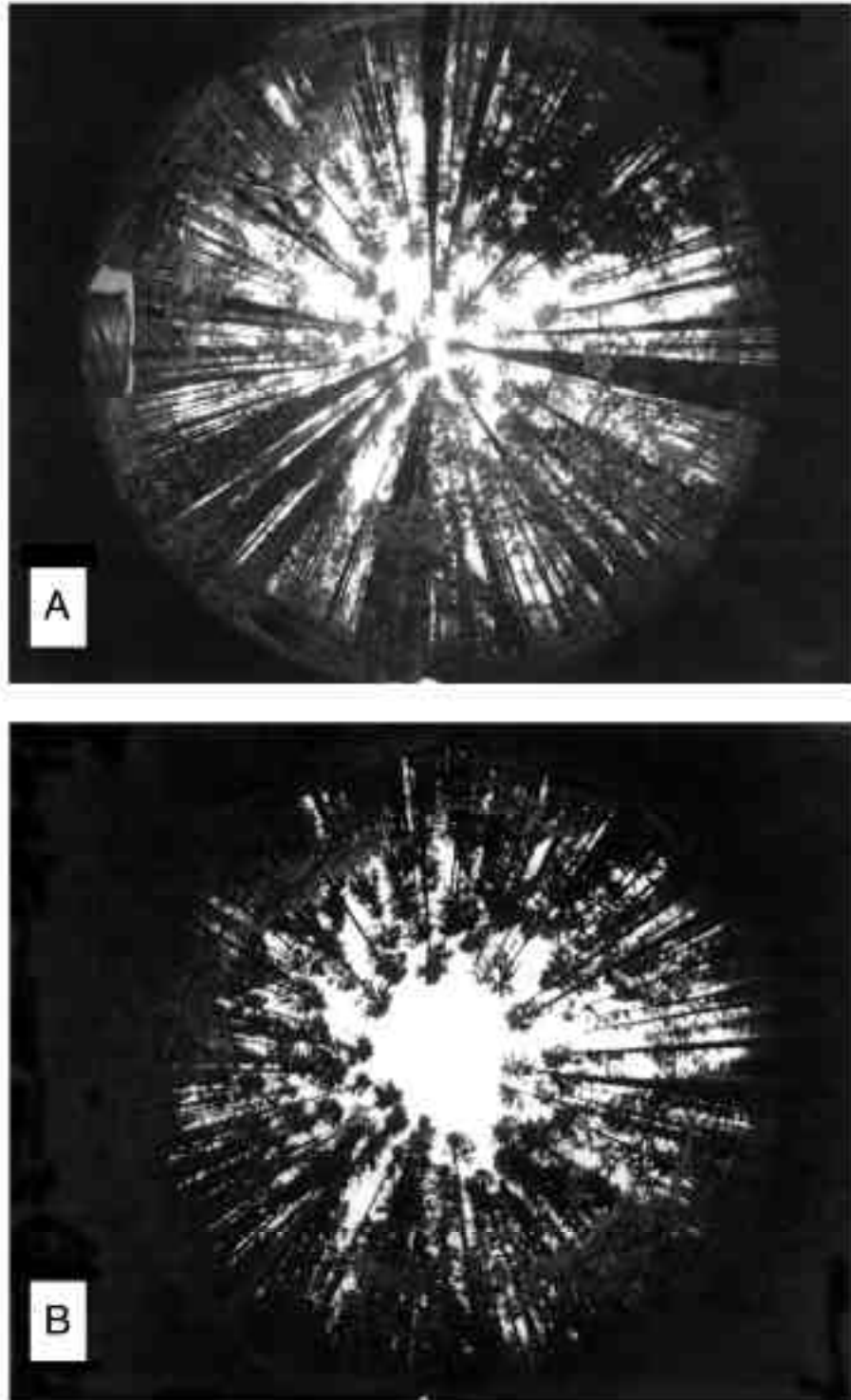


Figure 25—Photographs taken with a fisheye lens document change in forest canopy in a study of gap creation and effects on ground vegetation in 50-m-tall Douglas-fir (Easter and Spies 1993): (A) Canopy conditions before gap creation, and (B) canopy conditions after gap creation. Photographs cover a 180-degree vertical angle.

Another use of topic photo monitoring was documentation of harvester ant (*Pogonomyrmex owyheei* Cole) colonies over 9 years in southern Idaho (Porter and Jorgenson 1988).

In forested settings, tree cover often influences ground vegetation. Brown (1962) photographed tree canopy cover over a 180-degree arc using a special camera system. More recently, Chan and others (1986) applied electronic scanning and computer techniques to analysis of fisheye photographs under 50-m-tall Douglas-fir. Figure 25 illustrates use of fisheye photographs to monitor change in forest canopy following treatment to create small gaps (Easter and Spies 1993).

Topic photography does not have a fixed protocol similar to transect systems. Any topic that can be photographed is suitable; this is a very flexible concept.

Transect Photographs

Transect photo monitoring is a specialized activity dealt with in appendix A. Briefly, a general view of the transect is supplemented by closeup photographs taken of sample plots systematically along a line (fig. 25). Discussions are available in Bonham (1989), French and Mitchell (1983), Hall (1976), Lyon (1971), Nader and others (1995), National Park Service (1992), Owens and others (1985), Pierce and Eddleman (1970, 1973), Pond (1971), Ratliff and Westfall (1973), USDI Bureau of Land Management (1996), Wein and Rencz (1976), Wells (1971), and Wimbush and others (1967).

Winkworth and others (1962) supplemented their study of five measurement methods with systematic quadrant photographs taken from a stepladder. The photos gave an excellent representation of bunchgrass canopy coverage but were difficult to measure. Measurement required a simplification of the grass canopy outline, which introduced observer variability.

Transect photo monitoring may be summarized as follows:

1. Lay out the system and document it on a sitemap with directions and measured distances to camera locations and transect start and end (fig. 15).
2. Use the specified camera and focal length. Some recommend a 35-mm camera with a 28-mm lens. The 28-mm focal length will permit photographing a 1-m² plot with the camera held at eye level. Others recommend a 35-mm camera with 50-mm lens for small plots and oblique angles for larger plots (fig. 24).
3. Take two general photographs of the transect, one from each end, that include the photo identification form.
4. Use the required plot frame, such as 0.5 by 0.5 m or 1 by 1 m, placed at specified distances along the transect with a photo identification form (fig. 24).
5. To photograph and prevent shadows, stand on the north side of the plot frame, with toes touching the plot frame; make sure the photo identification form is visible.
6. Record data and information required by the system.



Figure 26—Landscape view of the Pole Camp riparian study flood plain. One problem with these landscape views is the lack of a fixed photo orientation spot, such as the meter board used in topic photographs (figs. 1, 20, 21, 23, and 28). Rephotographing the scene requires techniques similar to those shown in figure 17.

Pole Camp

Examples of site-specific repeat photography will use Pole Camp, a riparian meadow within a forested setting north of Burns, Oregon (fig. 26). In 1975 the cattle grazing system in Emigrant Creek watershed was changed from season-long use to a three-pasture, rest-rotation system wherein one pasture is spring grazed, a second is fall grazed, and a third is rested. This grazing is rotated over the following two years so that no pasture is used during the same time each year of a 3-year cycle. The purpose was to reduce livestock impacts on the riparian area and its stream. Monitoring was designed to appraise effectiveness of changed grazing. The five questions—why, where, what, when, and how—were addressed as follows.

Monitoring questions—*Why* to monitor dealt with the effectiveness of rest-rotation cattle grazing in improving riparian ecosystem function.

Where to monitor was determined by identifying critical or key livestock grazing areas. Pole Camp is one of three locations selected (figs. 14 and 26). Figure 14 is a road map locating the three areas, and figure 15 shows the Pole Camp monitoring layout.

What to monitor dealt with selecting specific sites at Pole Camp to record stream-bank stability (fig. 23), riparian shrub (*Salix* spp.) growth in height and crown width (fig. 20), herbaceous stubble height tall enough to trap sediments (fig. 20C), and herbaceous plant community stability, deterioration, or improvement (fig. 20).

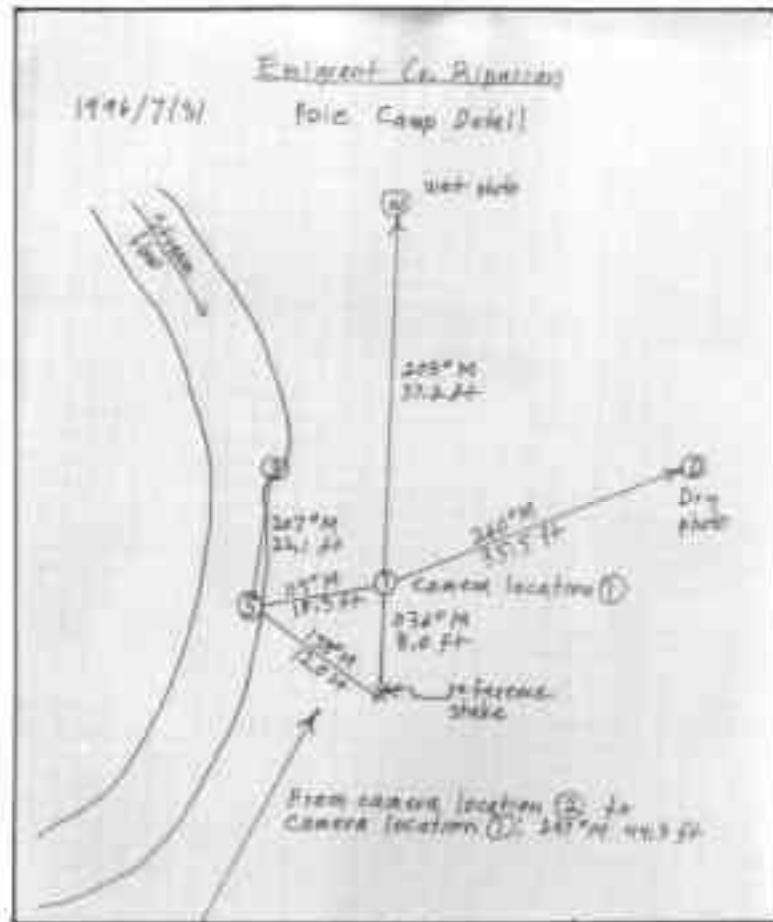


Figure 27—Triangulation location of the meter board (shown in figure 23) to document streambank erosion at Pole Camp. This map is the boxed area shown in figure 15. Any photo point or camera location in a tenuous spot should be referenced by two or more locator stakes.

When to monitor for livestock impacts was dictated by the grazing system, which required three monitoring times during the season: June 15 just before cattle grazing, August 1 as pastures were rotated, and October 1 after the grazing season ended (fig. 20). Pole Camp was used two years out of three: spring one year, fall another, and no use the third year.

How to monitor required developing a system of landscape, general, and closeup photos. A meter board in general photos is used for two closeup photos, one on each side of the board. A meter board generally was not used in the landscape pictures (fig. 26). An integral part of *how* was a map of the sampling layout (fig. 15) and any specific instructions, such as location of the instream meter board (fig. 23) shown in figure 27.

Exact Relocation

Exact relocation of photographs is one essential ingredient in site-specific photo monitoring (fig. 20). This is required if any comparison analysis of photographs is contemplated (Magill 1989, Rogers and others 1983; fig. 28 and app. A). Analysis

entails comparing or overlaying photographs so change in the subject matter, usually vegetation, can be analyzed. Analysis may be through the use of grids as shown in figure 28 (Magill 1989 and app. A) or by use of digitizing (Cunningham and others 1996).

Exact realignment of general photographs is greatly facilitated by use of a target as shown in figures 20, 21, 28, 29, and 30. A meter board is recommended to mark the topic of interest, which usually is located in the center of the photograph. Place the meter board at a distance such that it will be 25 to 33 percent of the height of the photograph. Using a 35-mm camera with 50-mm lens, 10 m from the camera will produce 25-percent meter board height (fig. 2) and 7 m will produce 33 percent (fig. 2). This 7 m also will produce a 25-percent meter board height with a 35-mm camera lens (fig. 4). Both the camera location and the meter board (photo point) are then permanently marked with fenceposts or steel stakes. The meter board is designed such that the numbers and letters can be read easily from a color slide or black-and-white photograph. Details of meter board construction are in appendix C.

A successfully used alternative employs a target board 0.5 m wide and 2.5 m tall set 10 m from the camera. The board is painted black and white alternately every 0.5 m (Van Horn and Van Horn 1996). It was designed to document riparian rehabilitation efforts in herb and shrub vegetation.

Camera Techniques

General photographs—Consistent rephotography requires a reference point to orient subsequent views. The objective is to have the view remain constant while items within the view change. A meter board serves this purpose. Figure 29 illustrates three repeat photographs of a ponderosa pine-elk sedge community that was selectively cut; figure 29A illustrates how the camera focus ring is placed over the “1M.” This accomplishes two things: (1) it provides a common orientation point for the first and subsequent photographs, and (2) it provides a locus for focusing the camera for maximum depth of field. When the meter board is placed at the topic of interest, the topic should be in sharp focus. Figure 30 illustrates effects of various camera orientations.

The meter board also provides a size control for indexing a grid. A grid can be overlaid on the photograph as suggested by Magill (1989), depicted in figure 28, and discussed in appendix A. Grid analysis entails outlining each topic of interest and counting the number of grid intersects within the outline. Figure 30D shows sloppy installation of the meter board because the board is not vertical. Vertical orientation is essential if grid analysis is contemplated. Appendix C has construction plans for a meter board that include attaching a line or pocket level to the top so that the board can be oriented vertically.

Text continues on page 54.

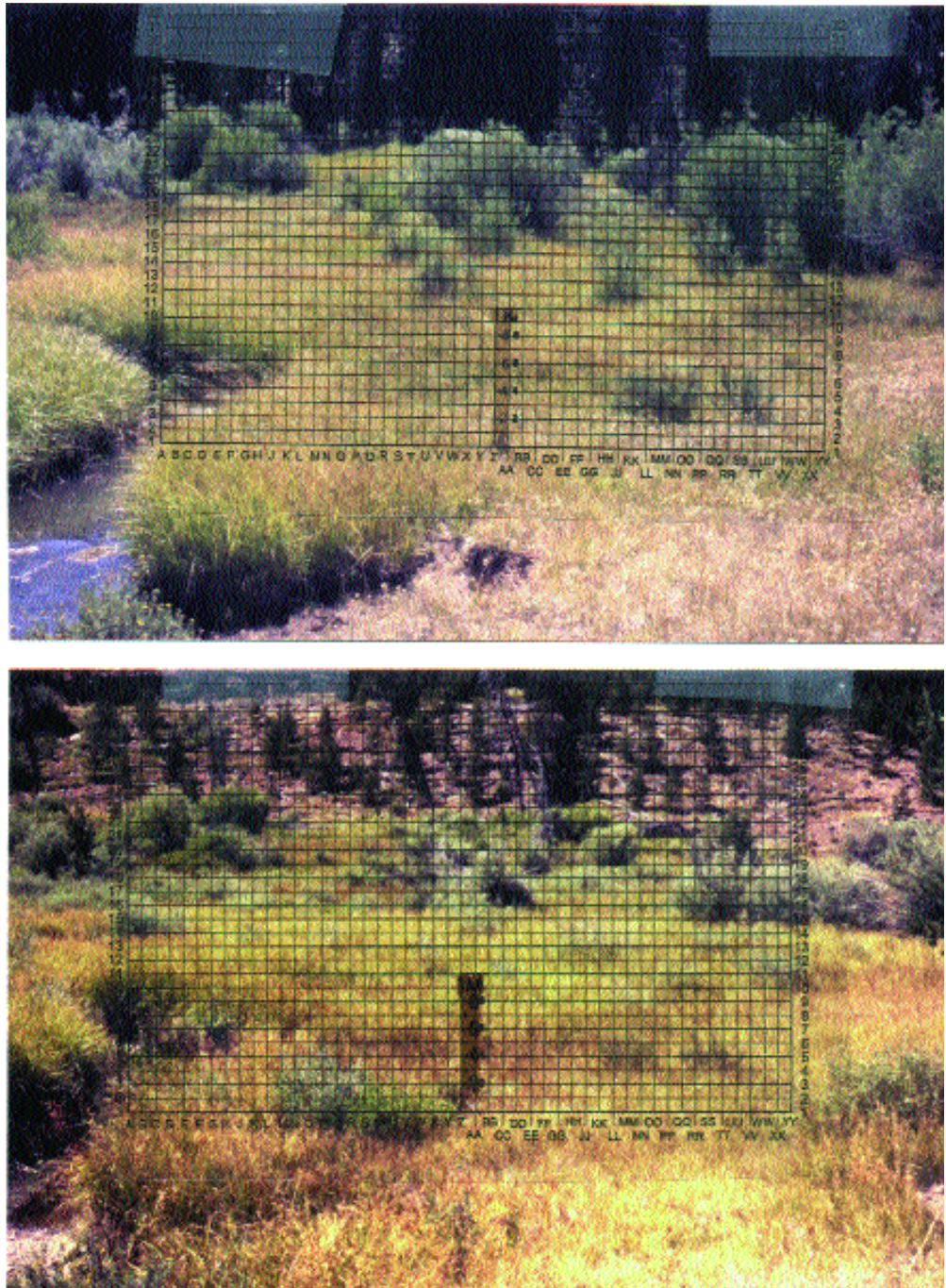


Figure 28—Grid intersect system used to outline and follow items with intersecting grid lines. This is Pole Camp wet (fig. 20) showing change in willow shrub profile area from 1981 to 1997 following 12 years of beaver (*Castor canadensis* Kuhl) utilization and high water tables caused by dams. In 1981, grid intersect U-13 identifies a young willow missing in 1997. Intersect RR-24 is at the top of a tall willow in 1981. The top is missing in 1997 owing to beaver cutting large stems for dam construction. Appendix A discusses grid analysis of photographs.



Figure 29—The meter board is used to aim the camera for consistent repeat photography. (A) Placement of the camera focus ring on the "1M", which puts the "1M" in the center of the picture (dashed lines). This orientation produces exact replication of repeat photographs as shown in B and C. The camera is focused on the "1M" placing it at the optimum sharpness for depth of field. With an f-stop of 8, everything in the picture will be in focus. This series is part of a study following logging effects on ground vegetation and stand structure (figs. 50 and 51): (A) 1977 just prior to a selection cut; (B) the summer after the cut and showing a two-turn skid trail crossing the meter board location; and (C) is 1995, 18 years later. Notice the color difference in A. The slide film was Ansacochrome compared to Ektachrome in B and C.

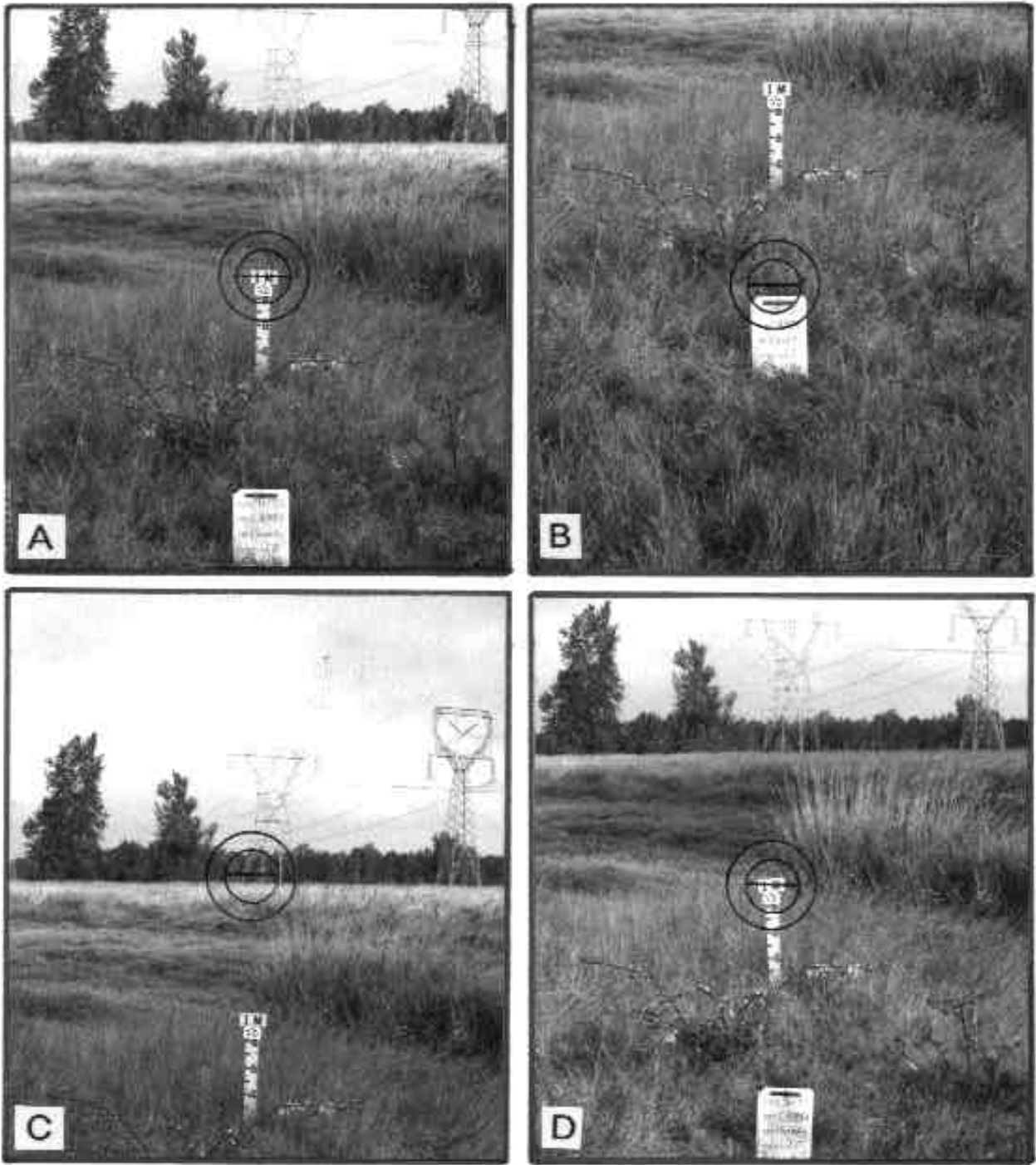


Figure 30—Photograph orientation using the camera focus system shown in **A** and placing it exactly on the “1M” of the meter board. **(B)** The focus is on the photograph identification sheet showing a maximum of ground vegetation. **(C)** The focus is on the distant horizon. **(D)** The meter board has not been set vertically, simply sloppy work. The tag on the meter board showing “2D” means this is photo point D at camera location 2. Five photo points are taken at this camera location. Notice the fadeout of the photo identification paper in B due to the light color. This will not happen with the medium blue shown in appendix C.

Use of double meter boards for identifying a topic of interest is illustrated in figure 31. The area is Lower Emigrant, one of three study areas on Emigrant Creek (fig. 14). When shrubs or other items exceed about 2 m in height, the double boards aid in following changes. Appendix C has plans for this double meter board, which folds in the center to provide a choice of either a 1-m or 2-m board.

Topic emphasis—Figure 32 illustrates four degrees of topic emphasis. A general topic, such as figure 21, may be represented by a 50-mm lens with meter board set at 14 m, a more limited topic is identified by the board set at 10 m, a closer view with the board set at 7 m, and a confined topic set at 5 m. The 5-m distance is recommended for shrub transect sampling discussed below.

Use of a 35-mm lens is illustrated in figure 33, a sagebrush-bunchgrass community. The meter board was placed 5, 7, and 10 m from the camera. The size of the meter board at these distances closely approximates a 50-mm lens at 7, 10, and 14 m, respectively.

Closeup photographs—Closeup photography is strongly recommended for topic monitoring locations. It is an integral part of transect systems. A view of ground conditions is taken with the meter board as a photo point locator and size control system. Figure 34 is a pair of closeup views from figure 20, Aug. '76, showing characteristics of the wet meadow at Pole Camp. Accompany each photograph with notes on the vegetation.

Some people might prefer a square target on the ground (fig. 24). In sparse vegetation this is satisfactory, but it may not be a suitable system in riparian areas such as that in figure 35. Figure 35A was taken 1 month after cows were removed, and figure 35B shows the same area 3 months later. The 4-dm-tall vegetation would completely obscure any kind of plot frame laid on the ground.

Figure 35 also illustrates the importance of standing 2 m away from the meter board and placing the "1M" of the meter board in the upper corners of photographs. In figure 35A, the bottom of the meter board can be determined whereas in figure 35B it cannot be seen. The entire meter board must fit in the frame if analysis of the images is to be possible. In figure 35C, the "1M" of the meter board is down almost 2 dm from the top of the frame; the bottom of the meter board, therefore is 2 dm below the bottom of the photograph, which makes accurate comparison between figures 35A and 35C difficult.

This concept of precise relocation of photo images can best be illustrated by use of lap dissolve 35-mm projection equipment. The objective is to hold the meter board absolutely still on the screen and show the vegetation change as each photograph is dissolved onto another.

Text continues on page 60.

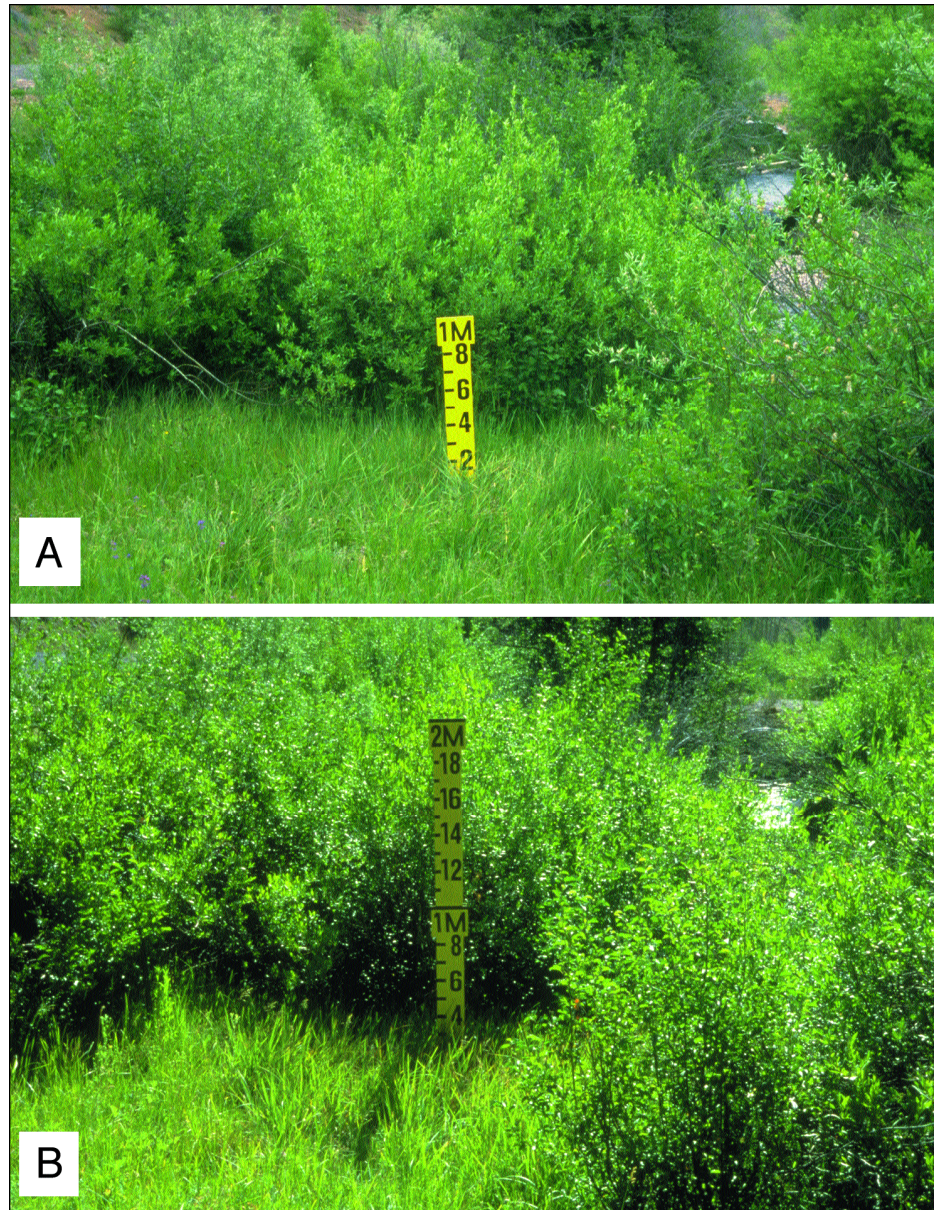


Figure 31—Use of double meter boards for topic identification (in this case, impacts on willows from grazing livestock) and monitoring: (A) a single meter board's effectiveness in appraising shrub impacts, and (B) a better system for documenting shrub reaction to grazing. The camera is focused on the "1M" for consistent photo orientation.

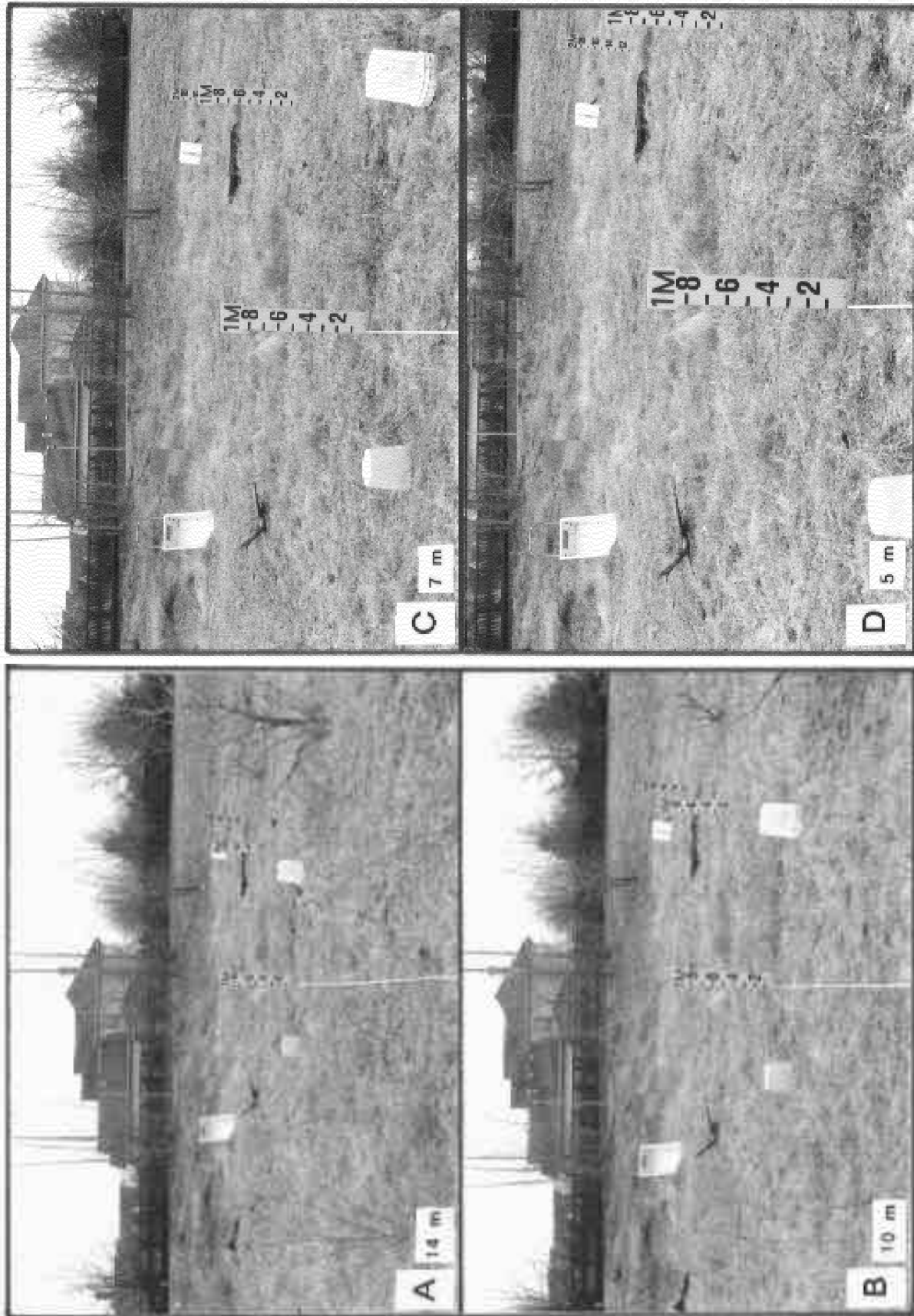


Figure 32—Emphasis on topic identification is shown by distance from camera to meter board using a 50-mm lens on a 35-mm camera: (A) 14 m from the camera illustrating a close landscape view, (B) 10 m from the camera (a distance I have used as a standard), (C) 7 m from the camera emphasizing a rather specific topic, and (D) 5 m from the camera (a distance recommended for individual shrub analysis). Size and nature of the topic being monitored determine distance from camera to photo point. This scene is a testing layout where distances from the camera to meter board were evaluated, camera focal lengths were tested, and combinations of focal length and distance were compared (figs. 1-10).

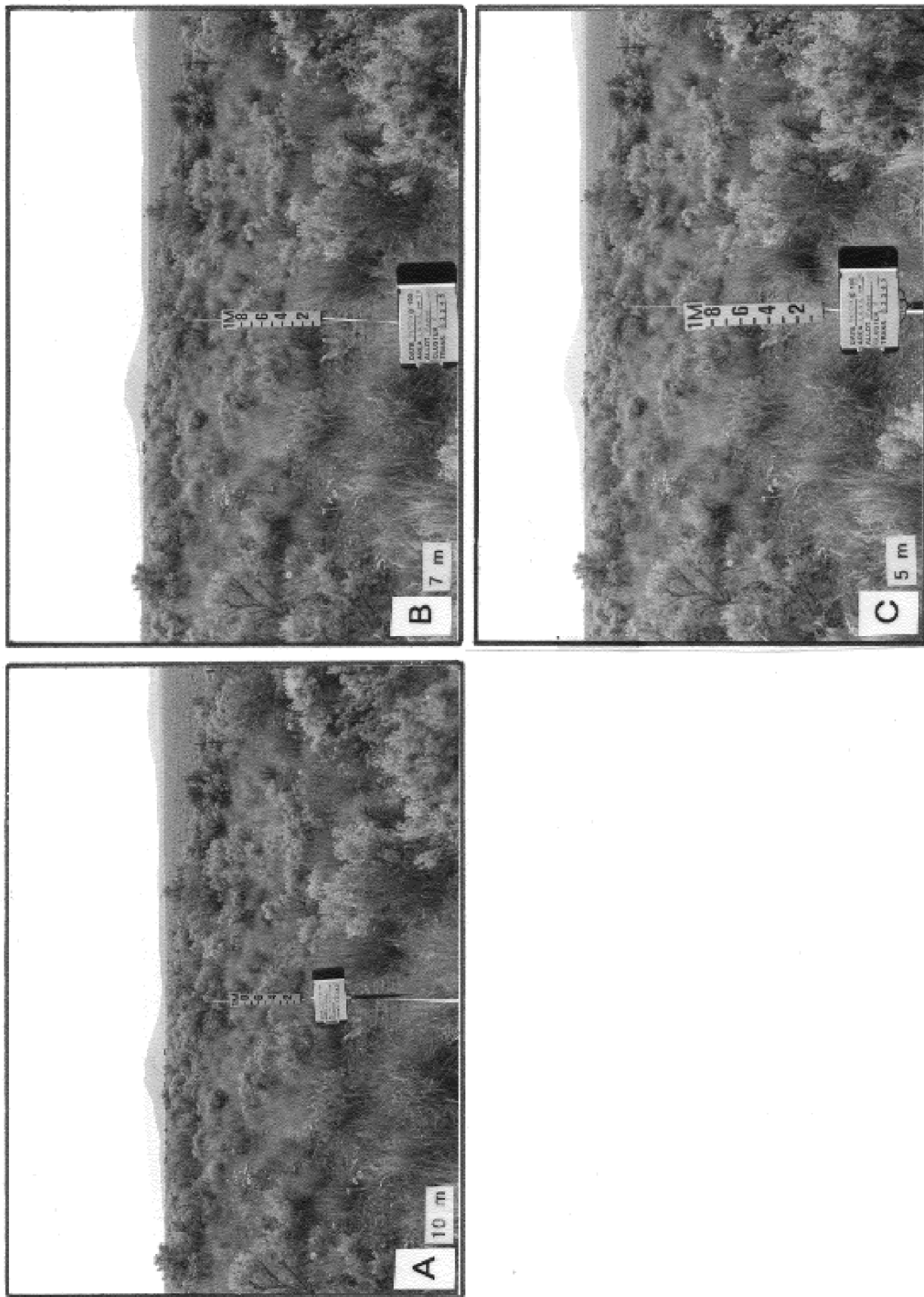


Figure 33—Evaluation of a 35-mm camera for placement of a meter board to emphasize a topic. This is a transect in the Crooked River National Grassland in eastern Oregon. (A) Placement of the meter board 10 m from the camera. It is essentially the same as the 14-m distance with a 50-mm lens (fig. 32A). (B) A distance of 7 m, essentially similar to 10 m and using a 50-mm lens (fig. 32B). (C) Distance of 5 m, equivalent to 7 m with a 50-mm lens (fig. 32C). Comparison between figure 32 and this figure suggest advantages of pocket-size, quality 35-mm focal length cameras.

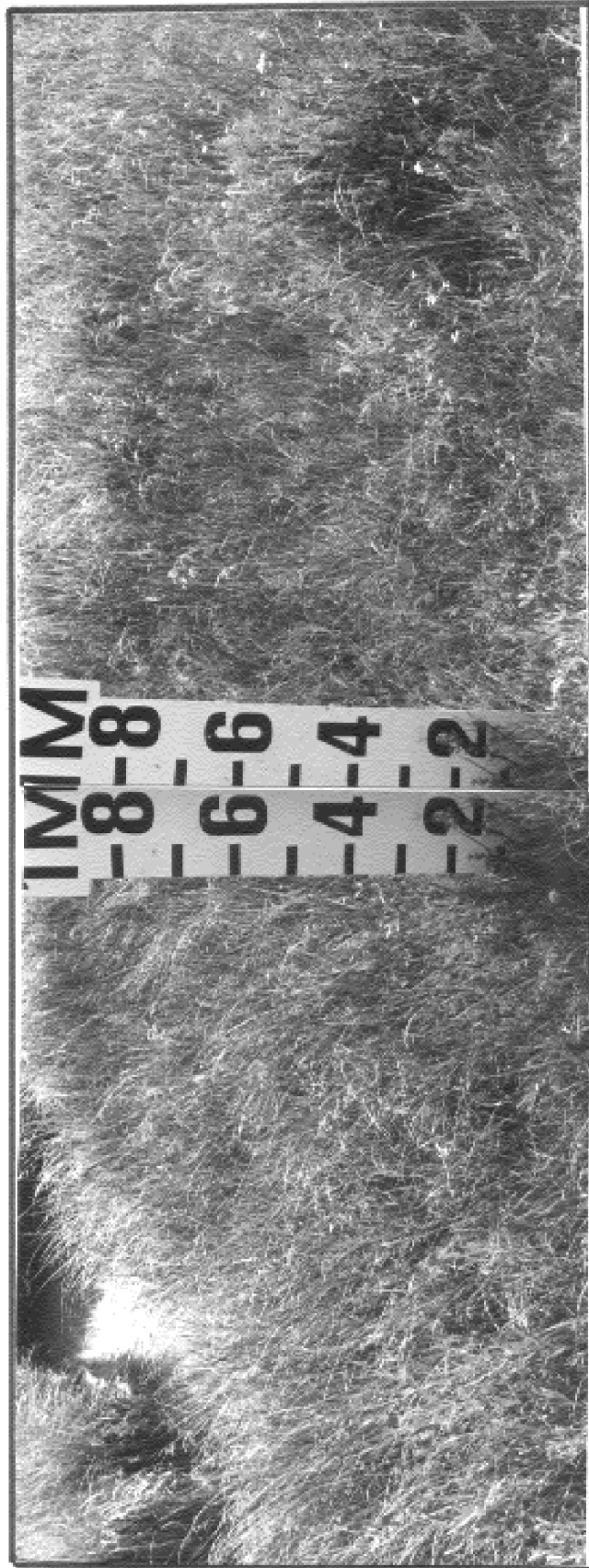


Figure 34—Technique for documenting ground vegetation using the meter board. Take one picture to the left and one to the right, keeping the meter board at the edge of the photograph. Stand 2 m from the board. Tilt the camera slightly off horizontal to make the meter board parallel with the side of the photograph. Place the "1M" top of the board in the upper corner of the view. The 2-m distance, using a 50-mm lens on a 35-mm camera, will assure that the bottom of the board is in the lower corner of the picture. When mounting the pictures, I overlap the meter boards so only one is showing. Set the camera to 3 m, which will put vegetation in focus from the bottom of the meter board to a distance of at least 2 m beyond the board. These are closeup views of figure 20, Aug. '76.

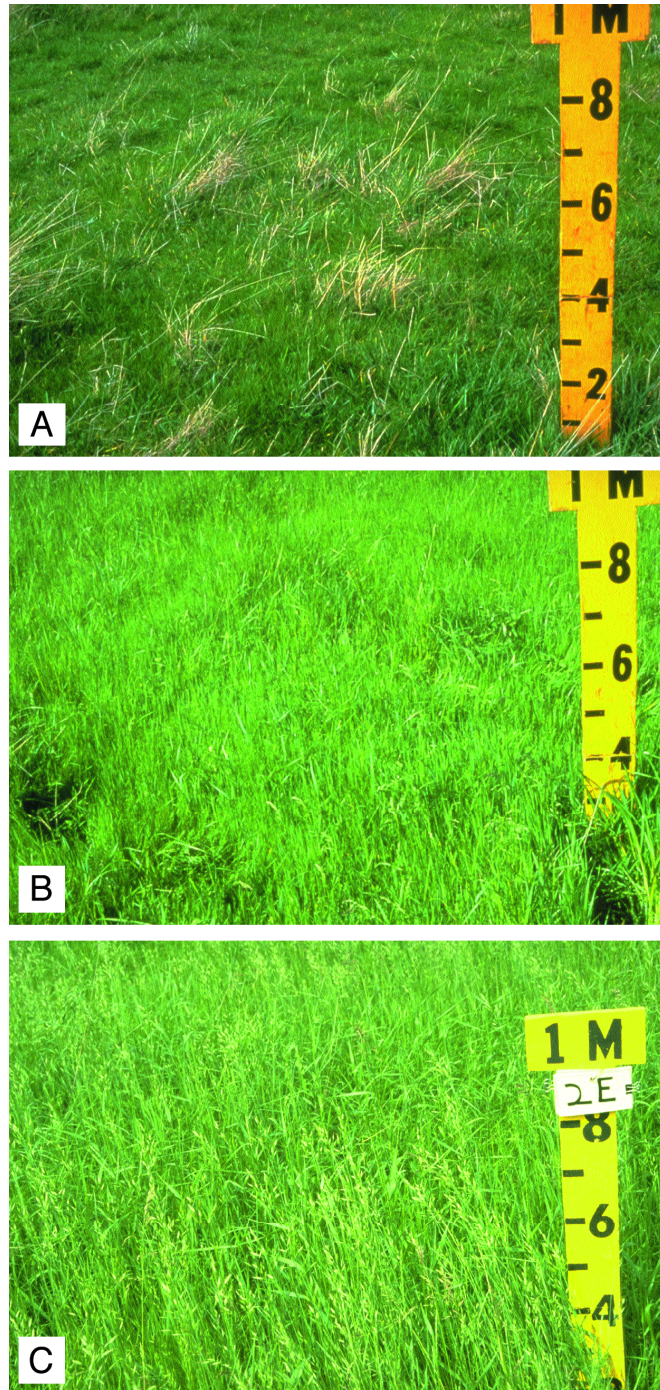


Figure 35—Riparian vegetation sampling on the Sandy Delta, south bank of the Columbia River, east of Portland, Oregon. A plot frame would be appropriate in photograph A with the 1-dm stubble height, which also permits visual estimation of the bottom of the meter board. The plot frame would not be visible in B or C. Exact reorientation of the photograph is essential: (1) The “1M” must be in the top corner of the view, (2) the bottom of the board must be in the lower corner, (3) the photograph must be taken from 2 m with a 50-mm lens on a 35-mm camera, and (4) the camera must be tilted slightly off horizontal to make the board parallel with the side of the view frame. In B, just 3 months later, grass is over 4 dm tall and effectively hiding the bottom of the meter board and any plot frame that might have been used. Problems with tall vegetation and exact photograph reorientation are shown in C, where the “1M” was not placed in the top corner of the view frame. Instead it is about 2 dm below the corner meaning the bottom of the board is about 2 dm below the bottom of the picture, an unacceptable rephotograph.

Photo Point Location

Photo point identifies the topic to be monitored (fig. 23); thus, it determines the camera location. One important factor is relocation of the meter board to orient later rephotography. In figure 27, the meter board was placed 10.3 ft from permanently marked camera location 1. The direction from the camera location to meter board was 115 degrees magnetic. The meter board location was marked with a fencepost, which severe flooding could remove; distance and direction to the meter board from a permanent location therefore are essential. The most foolproof method is a triangulation system using two permanent markers (fig. 27). The direction and distance from each marker are recorded. This triangulation method can replace the meter board within a decimeter of its original location. A diagram of the monitoring system should be part of the site map (fig. 15).

Camera Location

Selection of a camera location is determined by position of the topic (photo point) to be monitored. Consider how the distance from the camera to the meter board will influence topic emphasis (figs. 32 and 33). Both distance and photo point position are used to locate the camera for best documentation. Consider locating the camera where it will serve more than one photo point. This accomplishes three things: (1) efficiency is increased by using several photo points from a camera location, (2) the photo monitoring system is easier to relocate when one camera location will also locate two or more photo points, and (3) more information is obtained from the specific site being monitored.

Figure 35 shows "2E" on a meter board, meaning the fifth photo point at camera location 2. Using more than one photo point means careful location of the camera because it must be placed in a position to adequately depict several conditions specified in the monitoring objectives (appendix D). If a distance of about 10 m from camera to photo point is used, orient the camera location using a 10-m radius to encompass as many topics of interest as possible. The same distance from camera to photo point need not be the same for every photo point; for example, 8 m to photo point A, 10 m to B, and 12 m to C. However, the same distance to each photo point must be used for all subsequent photos: 8 m to A, 10 m to B, and 12 m to C.

Vegetation close to the camera location is another important consideration. Most authors who have rephotographed landscapes report vegetation grew up between the camera location and photo point, which obscured the view and rendered the rephotograph worthless. In many cases, the camera was moved to an unobstructed view (fig. 36).

Figure 26 illustrates a limited landscape photograph. The primary difference between this and a general site-specific view is the lack of a meter board for centering the camera view. Often, landscape views of an area must be reoriented in a manner similar to long-distance landscapes (fig. 16).

The need to map and stake both camera location and photo point is illustrated in figure 21. Treatment of the ponderosa pine-pinegrass community was so dramatic that relocation of photography without a map and permanent markings would be nearly impossible. Here stakes driven flush with the ground were relocated by use of a metal detector. Following treatment, fenceposts were placed at the stakes for easy relocation.

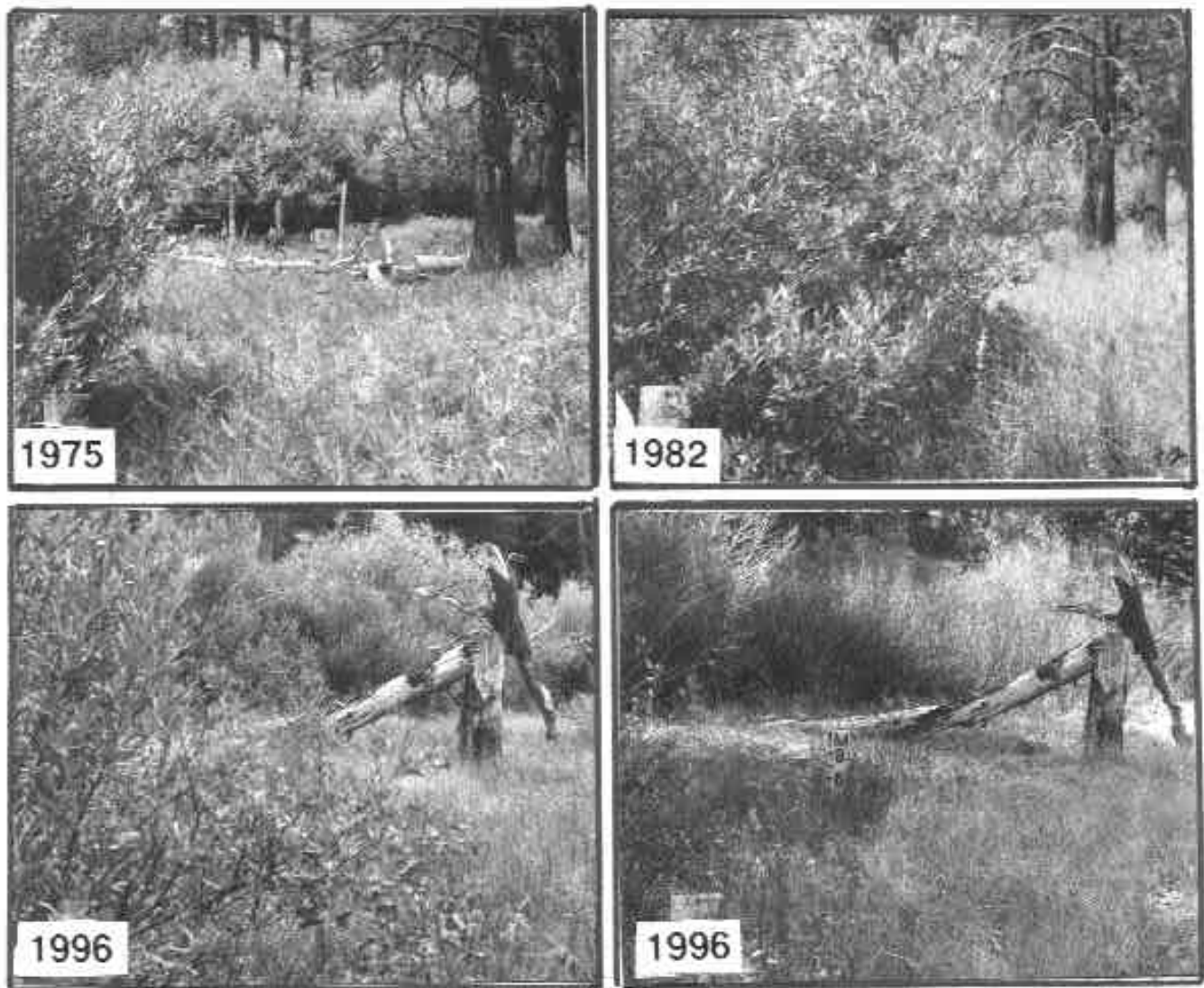


Figure 36—Effect of intervening vegetation between the camera and photo point. In 1975, the meter board was in full view at the start of the study to appraise effects of livestock on willow growth. By 1982, willows had grown between the camera and meter board requiring a change in the camera location. It was moved 1 m to the right. By 1996, willows had again obstructed the view so the camera location was moved 3 more meters to the right, a total of 4 m. This was a very poor camera location. Avoid locations where woody vegetation will obstruct the view and render future photographs difficult to interpret.

Riparian Areas

Riparian areas pose some particular problems in regard to camera location and photo points. Figure 23 documents streambank stability at Pole Camp. Figure 23A was the original camera location and photo point; however, the camera location was placed 2 dm from the bank. A winter ice episode eroded the bank, increased stream sinuosity, and destroyed the camera location. The camera had to be moved 1.2 m to the left and 1 m back from its original location. This resulted in a different view, as shown in figure 23B, which suggests that the streambank had moved 0.7 to 0.9 m to the right. But it had not moved to the right; the apparent movement was caused by a change in camera location—a situation to avoid.

**Relocation of
Repeat
Photography
Idiosyncrasies With
Compass Directions**

Riparian areas provide other challenges, particularly after floods. Deposition of silt is a valuable topic to document. Consider, when installing photo monitoring, pounding the fenceposts down to exactly the height of the meter board. When silt is deposited, the height of the meter board above the fencepost will be a measure of silt deposition.

Floods have other influences. Fenceposts may be torn out, thereby eliminating the photo point or camera location. Thus, documentation of fencepost position is essential (Governor's Watershed Enhancement Board 1993). Figure 27 illustrates a triangulation method for replacing washed out fenceposts.

Finding existing camera locations and photo points, whether landscape or site-specific, is sometimes difficult. Following are some suggestions for relocation.

In the Pacific Northwest, there is a 21-degree deviation from magnetic north. This can result in problems of two kinds:

1. The compass heading written on the map or layout instructions should be labeled as either true or magnetic. If it is a true heading, was the 21-degree deviation added or subtracted from the magnetic heading?
2. When searching for the camera location or photo point, be prepared to try four different headings.
 - A. Follow the heading and distance given. If the camera or photo point cannot be relocated, then . . .
 - B. Subtract 21 degrees from the recorded heading and look. If the locations still are not found, then . . .
 - C. Add 21 degrees to the given heading and follow that direction. If the camera location or photo point still has not been determined, presume that direction from the witness site to the camera location or photo point is reversed. In other words, a heading was taken from the photo point back to the camera location or camera location back to the witness site and recorded. Therefore . . .
 - D. Add 180 degrees to the compass heading and proceed with (A) through (C), above. This system has produced results for me 95 percent of the time.

**Field Book for
Rephotography**

A photo-monitoring field book is recommended for carrying the original and some intervening photographs into the field. If different people did previous photographs, you may discover some disorientation of subsequent views. For that reason, a copy of the original photograph is very important. Rephotograph the original and not the misoriented intervening photographs.

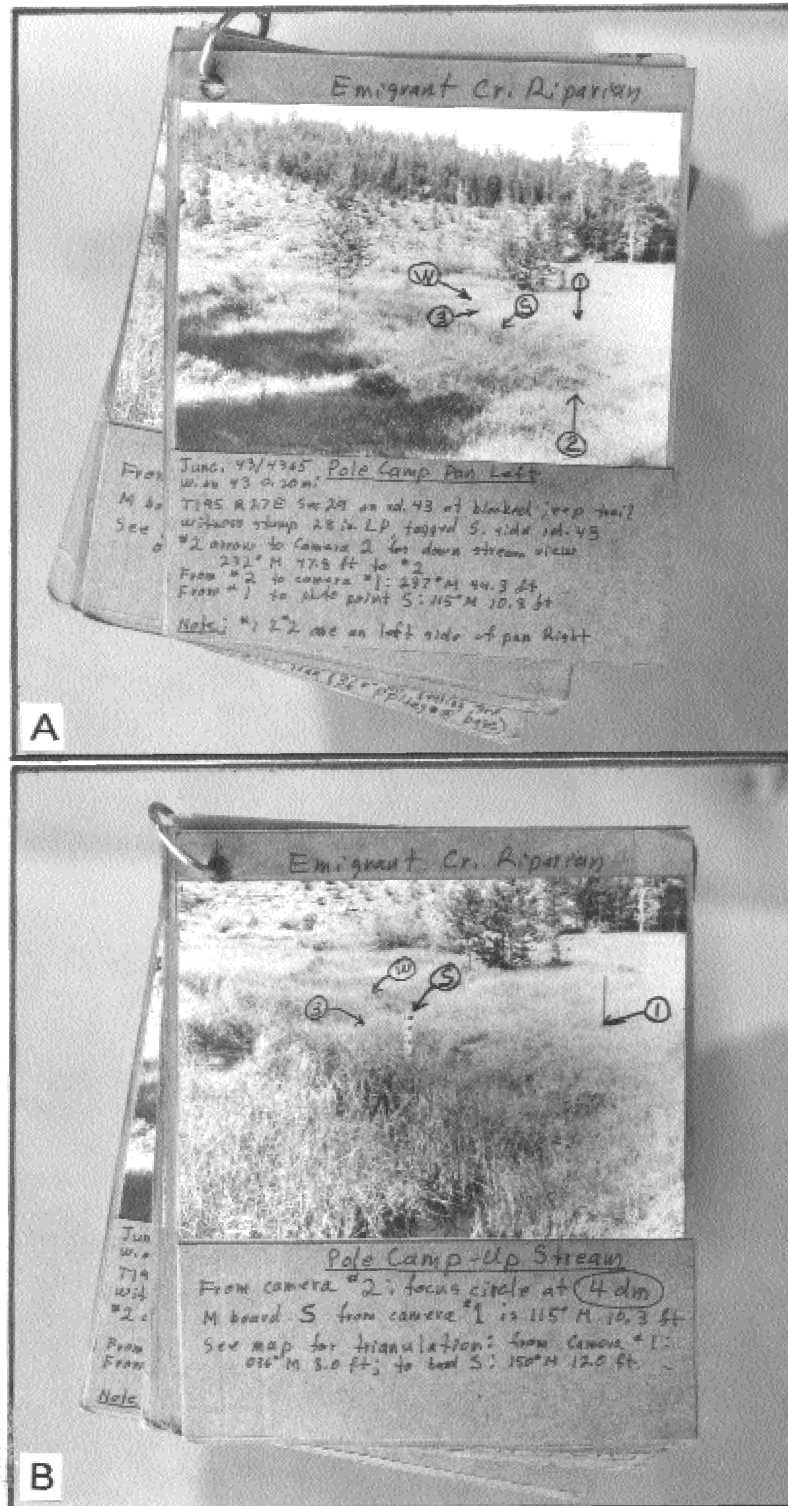


Figure 37—The author's system for finding camera locations and photo points. It is a pocket-sized set of photographs and directions mounted on cardboard (file separator thickness). (A) A left landscape view of the sampling area at Pole Camp; the right view is figure 26. A also locates camera locations 1 and 2. Camera location 1 has two photo points: D is Pole Camp dry and W is Pole Camp wet (fig. 20). (B) The upstream photo point taken from camera location 2 to S and illustrated in figure 23. Maps of this area are shown in figures 14, 15, and 27.

A system I devised is shown in figure 37 for the Pole Camp example. Figure 37A is a landscape view of the Pole Camp flood plain with camera locations and some photo points identified. It locates the left of two flood-plain scenes; the right is shown in figure 26. Both are mapped in figure 15. Figure 37B is a general view from camera location 2 to photo point S on the streambank, the scene in figure 23.

The pocket-size booklet has a picture of each camera location and photo point complete with directions from the witness site to camera location and orientation of the photo point. Cheap 5-ft fenceposts driven 2 ft into the ground are used to mark both camera locations and photo points.

Once at the area, review the photographs for changes in vegetation. Next, note the number of years since the last photograph, particularly if it was taken more than 3 years previously. The purpose is to evaluate changes in the vegetation that might make previous photographs difficult to interpret (figs. 21, 23, 36, and 38; app. E).

If camera locations and photo points are not marked, align items in the photographs as depicted in figures 16 and 38 and appendix E. Start in the center of the photograph to orient the direction of the picture as shown by line 1 (fig. 38). Then, orient items on the sides of the picture, shown by arrows 2 and 3, to triangulate the camera location. Move forward or back along the line to establish the distances shown at 2 and 3. This is the camera location and photo point direction. Mark them with fenceposts and add a meter board (photo point) location.

Multiple-Camera System

When both color and black-and-white photographs are to be taken, consider the camera system shown in figure 39. One camera is for black-and-white, the other for color. The cameras are the same make and model to simplify adjustment for lighting and distance. Appendix C has construction details.

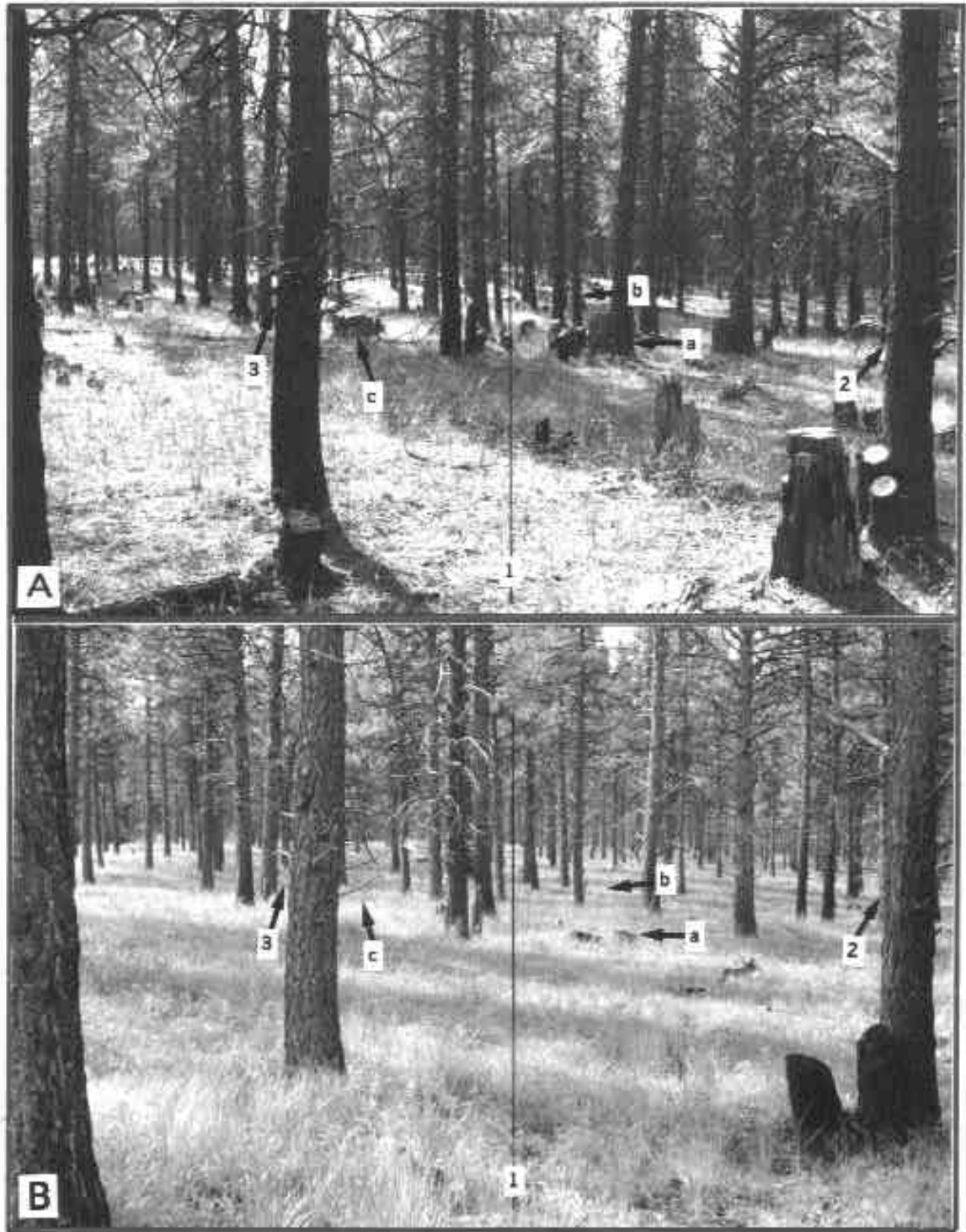


Figure 38—Photograph reorientation uses a black-and-white photo on which a triangulation system is diagrammed. A center line (1) is established on the original photograph (A) for direction. The center line is identified by position of trees in the background and framing the picture with trees in the foreground. Then positions of items 2 and 3 at the sides of the picture are used to triangulate the camera location. Looking to the right, note the position of trees at arrow 2 while also looking left for tree positions at arrow 3. (B) Move forward and backward along the center line until items at arrows 2 and 3 are lined up. Try to include some unusual object in the photograph, such as the pair of stumps in the lower right corner. Photograph A is a pre-underburn condition, and B is postburn and salvage of killed trees. In B, note missing trees at arrows a and b, and a burned-out stump at arrow c.



Figure 39—A system for combining color and black-and-white photography. Both cameras are connected by strap aluminum 1/8 inch thick and 1 inch wide bent into a U-shape with holes drilled for mounting screws to connect the cameras. The cameras operate independently. Please consider using identical cameras so all setting controls are adjusted in the same way, greatly avoiding mistakes.

Review

Ground-based photo monitoring may be divided into two systems: (1) comparison photos whereby a photograph is used to compare a known condition (shown in the photo) with field conditions to estimate some parameter of the field condition, and (2) repeat photographs where several photos are taken of the same tract of ground over a period of time. Comparison systems can evaluate fuel loading and herbage utilization and monitor public reaction to scenery. Repeat photography was categorized into landscape, remote, and site-specific systems. Critical attributes of repeat photography are (1) maps to find the sampling location and of the photo monitoring layout; (2) documentation of the monitoring system to include camera and film, weather, season, sampling technique, and equipment; and (3) precise replication of photographs.

Literature Cited

- Anderson, E.W.; Franzen, D.L.; Melland, J.E. 1990.** R_x grazing to benefit watershed-wildlife-livestock. *Rangelands*. 12: 105-111.
- Arnst, Albert. 1985.** We climbed the highest mountains. Portland, OR: Fernhopper Press. 22 p.
- Bauer, Stephen, B.; Burton, Timothy A. 1993.** Monitoring protocols to evaluate water quality effects of grazing management on western rangeland streams. I: Establishing permanent photo points. EPA 910/R-93-017. Seattle, WA: U.S. Environmental Protection Agency, Region 10: 145-149.
- Benson, Robert E. 1983.** Using photos to extend resource inventory data. In: Bell, John F.; Atterbury, Toby, eds. 1983. Renewable resource inventories for monitoring changes and trends. Proceedings: international conference; 1983 August 15-19; Corvallis, OR. Corvallis, OR: Oregon State University, College of Forestry: 349-352.
- Biswell, H.H. 1963.** Research in wildland fire ecology in California. In: Proceedings: Tall Timbers: fire ecology conference, 1963 [dates unknown]; [location unknown]. Tallahassee, FL: Tall Timbers Research Station: 63-97.
- Blaisdell, James P. 1953.** Ecological effects of planned burning of sagebrush-grass range on the upper Snake River plains. Tech. Bull. 1075. Washington, DC: U.S. Department of Agriculture. 39 p.
- Bonham, Charles D. 1989.** Measurements for terrestrial vegetation. New York City: John Wiley & Sons.
- Borman, Michael M. 1995.** Photo monitoring. The Grazier. Corvallis, OR: Oregon State Extension Service. 282(May): 2-6.
- Branson, Farrel A. 1985.** Vegetation changes on western rangelands. Range Monograph 2. Denver, CO: Society for Range Management. 76 p.
- Brown, Harry E. 1962.** The canopy camera. Sta. Pap. 72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.
- Bull, Evelyn L.; Holthausen, Richard S.; Bright, Larry R. 1992.** Comparison of 3 techniques to monitor marten. *Wildlife Society Bulletin*. 20: 406-410.
- Bull, Evelyn L.; Meslow, E. Charles. 1988.** Breeding biology of the pileated woodpecker—management implications. Res. Note PNW-RN-474. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 8 p.
- Chan, S.S.; McCreight, R.W.; Walstad, J.D.; Spies, T.A. 1986.** Evaluating forest vegetation with computerized analysis of fisheye photographs. *Forest Science*. 32(4): 1085-1091.

- Chaney, E.; Elmore, W.; Platts, W.S. 1991.** Livestock grazing on western riparian areas. Washington, DC: U.S. Government Printing Office.
- Cole, David N. 1993.** Campsites in three western wildernesses: proliferation and change in condition over 12 to 16 years. Res. Pap. INT-463. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 15 p.
- Cunningham, David J.; Anderson, William H.; Anthony, R. Michael. 1996.** An image-processing program for automated counting. Wildlife Society Bulletin. 24(2): 345-346.
- Easter, M.J.; Spies, T.A. 1993.** Using hemispherical photography for estimating photosynthetic photon flux density under canopies and in gaps in Douglas-fir forests of the Pacific Northwest. Canadian Journal of Forest Research. 24: 2050-2058.
- Edgerton, P.J. 1983.** Response of bitterbrush understory of a central Oregon lodge-pole pine forest to logging disturbance. In: Tiedemann, A.R.; Johnson, K.L., eds. Research and management of bitterbrush and cliffrose in western North America. Gen. Tech. Rep. INT-152. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 99-106.
- Elmore, W.; Beschta, R.L. 1987.** Riparian areas: perceptions in management. Rangelands. 9: 260-266.
- Fischer, William C. 1981.** Photo guides for appraising downed woody fuels in Montana forests: how they were made. Res. Note INT-299. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.
- Fox, Douglas G.; Bernabo, J. Christopher; Hood, Betsy. 1987.** Guidelines for measuring the physical, chemical, and biological conditions of wilderness ecosystems. Gen. Tech. Rep. RM-146. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 48 p.
- French, Norman R.; Mitchell, John E. 1983.** Long-term vegetation changes in permanent quadrants at the Idaho National Engineering Laboratory site. Bull. 36. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences. 42 p.
- Gary, Howard L.; Currie, Pat O. 1977.** The Front Range pine type: a 40-year photographic record of plant recovery on an abused watershed. Gen. Tech. Rep. RM-46. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 17 p.
- Governor's Watershed Enhancement Board. 1993.** Photo plots [Leaflet]. Salem, OR: State of Oregon. 16 p.

- Gruell, George E. 1980.** Fire's influence on wildlife habitat on the Bridger-Teton National Forest, Wyoming. Volume I: Photographic record and analysis. Res. Pap. INT-235. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 207 p.
- Gruell, George E. 1983.** Fire and vegetative trends in the northern Rockies: interpretations from 1871-1982 photographs. Gen. Tech. Rep. INT-158. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 117 p.
- Gruell, George E. 1986.** Post-1900 mule deer eruptions in the Intermountain West: principle causes and influences. Gen. Tech. Rep. INT-206. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 37 p.
- Gruell, George E.; Schmidt, Wyman C.; Arno, Steven F.; Reich, William J. 1982.** Seventy years of vegetative change in a managed ponderosa pine forest in western Montana: implication for resource management. Gen. Tech. Rep. INT-130. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 42 p.
- Guenther, Keith. 1998.** Residual dry matter (RDM) monitoring photo guide. Clyde, CA: Wildland Solutions [234 Park Street, 94520]. 16 p.
- Hall, Frederick C. 1976.** Range trend sampling by photographs. R-6 Regional Guide 2-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 50 p.
- Hanemann, Mike. 1989.** The Osborne photo recording transit. International Association of Panoramic Photographers: 6(1): 6-7, 9.
- Hart, Richard H.; Laycock, William A. 1996.** Repeat photography on range and forest lands in the Western United States. Journal of Range Management. 49: 60-67.
- Hattersley-Smith, G. 1966.** The symposium on glacier mapping. Canadian Journal of Earth Sciences. 3(6): 737-743.
- Hedgecoe, John. 1994.** John Hedgecoe's landscape photography. New York City: Sterling Publishing Co. 224 p.
- Herring, Margaret; Greene, Sarah, eds. 1997.** Natural Areas Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 9(1): 1-8.
- Houston, D.B. 1982.** The northern Yellowstone elk: ecology and management. New York City: MacMillan Publishing Co. 474 p.
- Hulcher, Charles A. [N.d.].** Instruction manual for Hulcherama model 120 panoramic camera. Hampton, VA: Charles A. Hulcher Co., Inc. 4 p.

- Jensen, D.; Smith, W.; Bodman, M. [and others] 1999.** Application of photopoint monitoring for the CRD Parks and Water Departments. [City unknown], BC: [Publisher unknown]. 114 p. Illustrated. [Water Department, Capital Regional District; Parks Department, Capital Regional District; Environmental Youth Team Program, Ministry of Environment, Lands and Parks].
- Johnson, C. 1991.** A photo point system: Eco-Area 3. Baker City, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest. 6 p.
- Johnson, Charles Grier, Jr. 1998.** Vegetation response after wildfires in National Forests of northeastern Oregon. R6-NR-ECOL-TP-O6-98. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 157 p.
- Johnson, Kendall L. 1984.** Sagebrush over time: a photographic study of range-land change. In: Proceedings: symposium on the biology of *Artemesia* and *Chrysothamnus*; 1984 July 9-13; [location of meeting unknown]. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 223-252.
- Johnson, K.L. 1987.** Rangeland through time: a photographic study of vegetation change in Wyoming, 1870-1986. Misc. Publ. 50. Laramie, WY: University of Wyoming, Agriculture Experiment Station. 188 p.
- Kay, Charles E. 1999.** Repeat photography and long-term vegetation change on the U.S. Sheep Experiment Station and other rangelands in the Centennial Mountains. Dubois, ID: Agricultural Research Service; final report to the U.S. Sheep Experiment Station. 281 p.
- Kay, Charles E.; White, Cliff A.; Pengelly, Ian R.; Patton, Brian. 1999.** Long-term ecosystem states and processes in Banff National Park and the central Canadian Rockies. Occas. Pap. 9. [Place of publication unknown]: Parks Canada, National Parks.
- Kinney, John W.; Clary, Warren P. 1994.** A photographic utilization guide for key riparian graminoids. Gen. Tech. Rep. INT-GTR-308. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.
- Kinney, John W., Clary, Warren P. 1998.** Time-lapse photography to monitor riparian meadow use. Res. Note RMRS-RN-5. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 5 p.
- Kodak. 1999a.** Digital learning center. <http://www.kodak.com/US/en/digital/dlc/>. (March 2000).
- Kodak. 1999b.** Learn about digital cameras. <http://www.kodak.com/US/en/digital/cameras>. (March 2000).

- Koski, Wayne H.; Fischer, William C. 1979.** Photo series for appraising thinning slash in north Idaho. Gen. Tech. Rep. INT-46. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 49 p.
- Kristan, Deborah M.; Golightly, Richard T., Jr.; Tomkiewicz, Stanley M., Jr. 1996.** A solar-powered transmitting video camera for monitoring raptor nests. Wildlife Society Bulletin. 24(2): 284-290.
- Lyon, L. Jack. 1971.** Vegetal development following prescribed burning of Douglas-fir in southcentral Idaho. Res. Pap. INT-105. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 30 p.
- Lyon, L. Jack. 1984.** The Sleeping Child burn: 21 years of postfire change. Res. Pap. INT-330. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 17 p.
- Magill, Arthur W. 1989.** Monitoring environment change with color slides. Gen. Tech. Rep. PSW-117. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 55 p.
- Magill, Arthur W. 1990.** Assessing public concern for landscape quality: a potential model to identify visual thresholds. Res. Pap. PSW-203. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 48 p.
- Maxwell, Wayne G.; Ward, Franklin R. 1976a.** Photo series for quantifying forest residues in the: coastal Douglas-fir-hemlock type; coastal Douglas-fir-hardwood type. Gen. Tech. Rep. PNW-51. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 103 p.
- Maxwell, Wayne G.; Ward, Franklin R. 1976b.** Photo series for quantifying forest residues in the: ponderosa pine type; ponderosa pine and associated species type; lodgepole pine type. Gen. Tech. Rep. PNW-52. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 73 p.
- Maxwell, Wayne G.; Ward, Franklin R. 1979.** Photo series for quantifying forest residues in the: Sierra mixed conifer type; Sierra true fir type. Gen. Tech. Rep. PNW-54. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 79 p.
- Maxwell, Wayne G.; Ward, Franklin R. 1980a.** Guidelines for developing or supplementing natural photo series. Res. Note PNW-358. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

- Maxwell, Wayne G.; Ward, Franklin R. 1980b.** Photo series for quantifying natural forest residues in common vegetation types of the Pacific Northwest. Gen. Tech. Rep. PNW-105. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 229 p.
- McGinnies, W.J.; Shantz, H.L.; McGinnies, W.G. 1991.** Changes in vegetation and land use in eastern Colorado: a photographic study, 1904-1986. ARS-85. Fort Collins, CO. U.S. Department of Agriculture, Agriculture Research Service. 165 p.
- Medina, Alvin L. 1996.** The Santa Rita Experimental Range: annotated bibliography (1903-1988). Gen. Tech. Rep. RM-GTR-276. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 67 p.
- Nader, Glenn; DeLasaux, Mike; Delms, Rick [and others]. 1995.** "How to" monitor rangelands. Handb. Level-1. Alturas, CA: University of California, Cooperative Extension Service, Modoc County. 44 p.
- National Park Service. 1992.** National Park Service Western Region fire monitoring handbook. Appendix D: Guidelines for establishing photopoints. San Francisco, CA: National Park Service.
- Ottmar, Roger D.; Hardy, Colin C.; Vihnanek, Robert E. 1990.** Stereo photo series for quantifying forest residues in the Douglas-fir-hemlock types of the Willamette National Forest. Gen. Tech. Rep. PNW-GTR-258. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 63 p.
- Owens, M.K.; Gardiner, H.G.; Norton, B.E. 1985.** A photographic technique for repeated mapping of rangeland plant populations in permanent plots. *Journal of Range Management*. 38: 231-232.
- Parker, K.W. 1954.** A method for measuring trend in range condition on National Forest ranges with supplemental instructions for measurement and observation of vigor, composition, and browse [Internal publication]. Washington, DC: U.S. Department of Agriculture, Forest Service. 37 p.
- Parker, K.W.; Harris, R.W. 1959.** The three-step method for measuring condition and trend of forest ranges: a resumé of its history, development, and use. In: *Techniques and methods of measuring understory vegetation: Proceedings of a symposium; 1958 October; Tifton, GA.* Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 55-69.
- Phillips, Walter S.; Shantz, Homer L. 1963.** Photographic documentation: vegetational changes in northern Great Plains. Rep. 214. Tucson, AZ: The University of Arizona, College of Agriculture, Agriculture Experiment Station. 185 p.

- Pierce, W.R.; Eddleman, L.E. 1973.** A test of stereophotographic sampling in grasslands. *Journal of Range Management*. 26: 148-150.
- Pierce, William R.; Eddleman, Lee E. 1970.** A field stereophotographic technique for range vegetation analysis. *Journal of Range Management*. 23: 218-220.
- Pond, Floyd W. 1971.** Chaparral 47 years later. Res. Pap. RM-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 11 p.
- Porter, S.D.; Jorgenson, C.D. 1988.** Longevity of harvester ant colonies in southern Idaho. *Journal of Range Management*. 41: 104-107.
- Progulske, Donald R.; Sowel, Richard H. 1974.** Yellow ore, yellow hair, yellow pine: a photographic study of a century of forest ecology. Bull. 616. Brookings, SD: South Dakota State University, Agricultural Experiment Station. 169 p.
- Puchbauer, Truman C.; Carroll, Franklin C. 1993.** Snapshot in time: repeat photography on the Boise National Forest 1870-1992. Boise, ID: U.S. Department of Agriculture, Forest Service, Boise National Forest. 239 p.
- Ratliff, Raymond D.; Westfall, Stanley E. 1973.** A simple stereophotographic technique for analyzing small plots. *Journal of Range Management*. 26(2): 147-148.
- Reid, Elbert H.; Johnson, Charles G., Jr.; Hall, Wade B. 1991.** Green fescue grassland: 50 years of secondary succession under sheep grazing. R6-F16-SO-0591. Baker City, OR: U.S. Department of Agriculture, Forest Service, Wallowa-Whitman National Forest. 37 p.
- Reppert, Jack N.; Francis, Richard E. 1973.** Interpretation of trend in range conditions from 3-step data. Res. Pap. RM-103. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 15 p.
- Ribe, R. 1999.** Regeneration harvest versus clearcuts: public views of the acceptability and aesthetics of Northwest Forest Plan harvests. *Northwest Science*. 73: 102-117.
- Robel, R.J.; Briggs, J.N.; Dayton, A.D.; Hulbert, L.C. 1970.** Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management*. 23: 295-297.
- Rogers, G.F. 1982.** Then and now: a photographic history of vegetation change in the central Great Basin Desert. Salt Lake City, UT: University of Utah Press. 152 p.
- Rogers, G.F.; Malde, H.E.; Turner, R.M. 1984.** Bibliography of repeat photography for evaluation of landscape change. Salt Lake City, UT: University of Utah Press. 179 p.

- Rogers, Garry F.; Turner, Raymond M.; Malde, Harold E. 1983.** Using matched photographs to monitor resource change. In: Bell, John F; Atterbury, Toby, eds. Renewable resource inventories for monitoring changes and trend: Proceedings of an international conference; 1983 August 15-19; Corvallis, OR. Corvallis, OR: College of Forestry, Oregon State University: 90-92.
- Schmutz, Ervin M. 1971.** Estimation of range use with grazed-class photo guides. Bull. A-73. Tucson, AZ: University of Arizona, Agricultural Experiment Station and Cooperative Extension Service. 16 p.
- Schmutz, Ervin M.; Holt, Gary A.; Michaels, Charles C. 1963.** Grazed-class method of estimating forage utilization. Journal of Range Management. 16: 54-60.
- Sharp, Lee E.; Sanders, Ken; Rimbey, Neil. 1990.** Forty years of change in a shadescale stand in Idaho. Rangelands. 12: 313-328.
- Sharp, Lee A.; Sanders, Ken; Rimbey, Neil. 1992.** Variability of crested wheat-grass production over 35 years. Rangelands. 14: 153-168.
- Shinn, Dean A. 1980.** Historical perspectives on range burning in the inland Pacific Northwest. Journal of Range Management. 33: 415-423.
- Skovlin, Jon M. 1991.** Fifty years of research progress: a historical document on the Starkey Experimental Forest and Range. Gen. Tech. Rep. PNW-GTR-266. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 58 p.
- Skovlin, Jon M.; Thomas, Jack Ward. 1995.** Interpreting long-term trends in Blue Mountain ecosystems from repeat photography. Res. Pap. PNW-GTR-315. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 102 p.
- Smith, Helen Y.; Arno, Steven F., eds. 1999.** Eighty-eight years of change in a managed ponderosa pine forest. Gen. Tech. Rep. RMRS-GTR-23. Ogden, UT: U.S. Department of Agriculture, Rocky Mountain Research Station. 55 p. + 14 foldout photopoint pages, 1 poster.
- Stickney, Peter F. 1986.** First decade plant succession following the Sundance forest fire, northern Idaho. Gen. Tech. Rep. INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 26 p.
- Strickler, Gerald S.; Hall, Wade B. 1980.** The Standley allotment: a history of range recovery. Res. Pap. PNW-278. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 35 p.
- Temple, Stanley A. 1972.** A portable time-lapse camera for recording wildlife activity. Wildlife Society Bulletin. 36(3): 944-947.

- U.S. Department of Agriculture, Forest Service. 1982.** Recording the changes: field guide to establishing and maintaining permanent camera point systems. R6-10095-1982. Portland, OR: Pacific Northwest Region. 13 p.
- U.S. Department of Agriculture, Forest Service. 1993.** Riparian revival: the story of Elk Creek [Leaflet]. Enterprise, OR: Wallowa-Whitman National Forest, Wallowa Valley Ranger District. 4 p.
- U.S. Department of the Interior, Bureau of Land Management. 1996.** Sampling vegetation attributes: interagency technical reference. BLM/RS/ST-96/002+1730. Denver, CO: Denver Service Center. 164 p.
- Van Horn, Mia; Van Horn, Kent. 1996.** Quantitative photomonitoring for restoration projects. Restoration and Management Notes. 14: 30-34.
- Veblen, T.T.; Lorenz, D.C. 1991.** The Colorado Front Range: a century of ecological change. Salt Lake City: University of Utah Press.
- Wade, Dale D.; Forbus, James K.; Saveland, James M. 1993.** Photo series for estimating post-hurricane residues and fire behavior in southern pine. Gen. Tech. Rep. SE-82. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 19 p.
- Weaver, Herald. 1957.** Effects of prescribed burning in ponderosa pine. Journal of Forestry. 55: 133-138.
- Weaver, Herald. 1959.** Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. Journal of Forestry. 57: 15-20.
- Wein, R.W.; Rencz, A.N. 1976.** Plant cover and standing crop sampling procedures for the Canadian High Arctic. Arctic Alpine Research. 8: 139-150.
- Wells, K.F. 1971.** Measuring vegetation changes on fixed quadrats by vertical ground stereophotography. Journal of Range Management. 24: 233-239.
- White's Electronics, Inc. 1996.** Classic II SL™. Sweet Home, OR: White's Electronics, Inc. [1011 Pleasant Valley Road, 97368].
- Wimbush, D.J.; Barrow, M.D.; Costin, A.B. 1967.** Color stereo-photography for the measurement of vegetation. Ecology. 48: 150-152.
- Winkworth, R.E.; Perry, R.A.; Rossetti, C.O. 1962.** A comparison of methods of estimating plant cover in an arid grassland community. Journal of Range Management. 15: 194-196.
- Zielinski, William J.; Kucera, Thomas E. 1995.** American otter, fisher, lynx, and wolverine: survey methods for their detection. Gen. Tech. Rep. PSW-GTR-157. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 163 p., enclosure.

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Appendix A: Methodology for Photo Monitoring of Change in Vegetation or Soil

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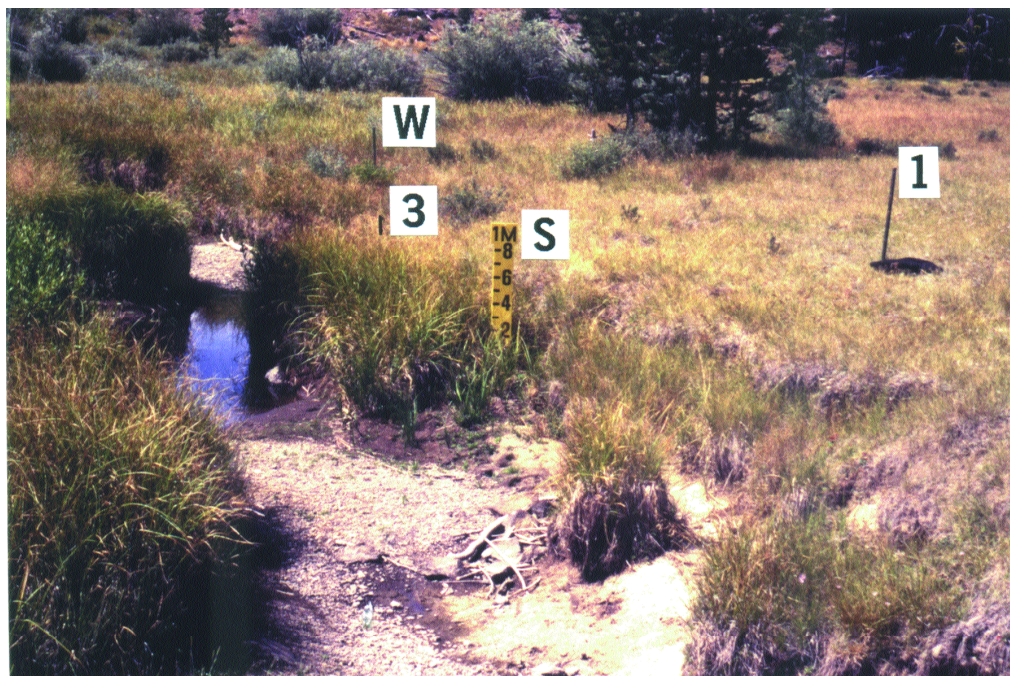


Figure 40—A general photograph taken in 1997 with the topic of streambank stability. It is part of a riparian study on Emigrant Creek, Snow Mountain District, Ochocho National Forest, near Burns, Oregon. The site is Pole Camp, a place livestock find highly attractive. The location of Pole Camp is shown on the map in figure 41. This streambank photo point is taken up stream from camera location 2 shown on the map in figure 42. Fencepost 1 is camera location 1, fencepost 3 is camera location 3 looking downstream at photo point S, S is photo point streambank, and fencepost W is photo point wet meadow. Other views of this streambank are shown in figures 23 and 49.



Figure 41—Local map showing location of the Emigrant Creek riparian study, Snow Mountain District, Ochocho National Forest, near Burns, Oregon. Three study areas are shown: Button Meadow at the head of Crowfoot Creek, Pole Camp shown in figures 20, 23, 26, 40, 44 and 49, and Lower Emigrant. This is one of two essential maps designed so people other than those installing the monitoring system can find the sampling sites. The other map is shown in figure 42.

Introduction

This appendix contains instructions on how to apply various photographic sampling methods designed to document changes in vegetation or soil on specific tracts of ground. It does not deal with general landscape photography or remotely operated cameras.

Nine photographic methods are discussed:

1. General photography where a scene is followed over time.
2. Topic photography dealing with a selected item, such as a streambank (fig. 40) or logging disturbance (fig. 21).
3. Grid analysis of photographs to document change in the selected topic or item.
4. Shrub sampling to record change in shrub profile area, usually accomplished by use of grid analysis.
5. Transect photography, in three dimensions, of square-foot plots.
6. Transect photo sampling of nested frequency plots.
7. Transect sampling of meter square (or 3-ft square) plots photographed at an oblique angle.
8. Photo documentation of tree canopy cover.
9. Photo records of herbage utilization using the Robel pole system.

All nine methods have several features in common, which are detailed in the following sections.

Selection of an Area

Selection of a monitoring area requires professional expertise liberally dosed with artistic finesse. The **purpose** for photographic monitoring is the most critical factor: Where in the landscape is the topic of concern, and once at the area, what kind of change should be documented? In some cases, *where* is straightforward; for example, documenting impacts of logging requires going to an area being logged (fig. 21) and documenting effects of beavers on a stream requires finding beaver dams. On the other hand, documenting impacts of livestock grazing requires understanding livestock distribution plus knowing the location of areas sensitive to grazing and the most critical season of use (figs. 20 and 40).

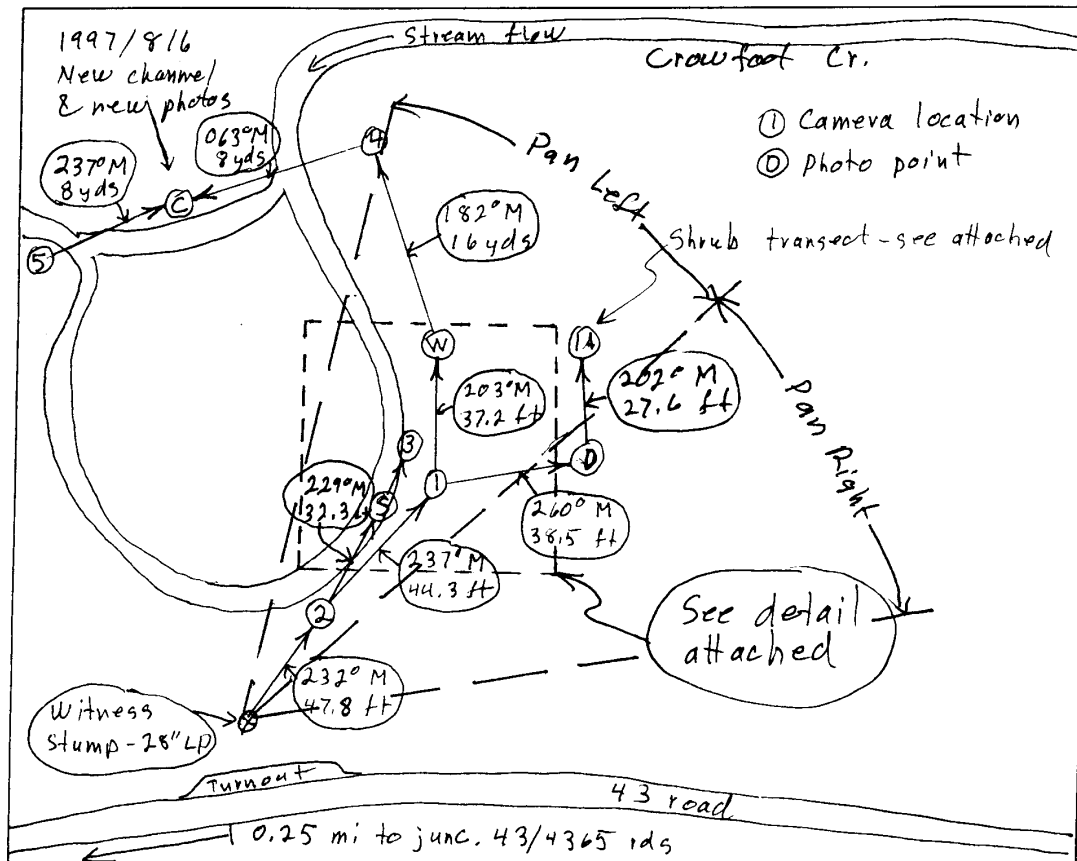
Once in an area, determine specifically what is to be documented for change. In figure 40 at Pole Camp, for example, the purpose was to document effects of livestock grazing on a riparian area. Pole Camp was selected because livestock preferred it. Specific objectives were to evaluate grazing effects on streambanks, willow shrub utilization, and differences in use between grass and sedge sites (Kentucky bluegrass by the fencepost on the right [1]) and sedge (at the fencepost in the background [W]). The topic in figure 40 is streambank stability.

Another example is the ponderosa pine stand shown in figure 21. In this case, the purpose for photo sampling was to document effects of a two-stage overstory removal and subsequent precommercial thinning on stand structure and ground vegetation. The site was selected based on the sale area. Stand conditions of open pine and clumped reproduction across an opening were chosen for the photo point. The opening was selected to avoid tree crown encroachment between the camera location and photo point and to appraise logging effects on livestock forage. It was photographed before and after each entry (fig. 21).

PHOTOGRAPHIC SITE DESCRIPTION AND LOCATION

Date 1974/10/5 Area Snow Mtn. Dist.
 Unit Pole Camp Observer: F. C. Hall
 No. of Camera locations: 5 No. of Photo points: 4
 Plant community Dry & wet meadow; willows
 Location: T. 19 S. R. 27 E. Sec. 29 SW of NE
 Location description S of rd 43; 0.25 mi W of junc. 43 & 4365 rds
off of turnout at E end of meadow
 Photo purpose: Document effects of change from season-long cattley
use to 3-pasture rest-rotation
 Discussion: Three photo points established in Oct 1974 documented
dry meadow (1), wet meadow with willows (W) and a fallen block of
wood at the stream edge (5) (1997) Flood of 2/96 washed out heavy
dams & created a new channel. Shrub sampling initiated 6/97.

MAP



Use back of sheet for additional details.

Figure 42—Filing system form "Photographic Site Description and Location" showing the monitoring layout for Pole Camp. Note in the lower left corner a reference to the junction of roads 43 and 4365 at 0.25 mi. Immediately opposite the road turnout is a 28-in-diameter lodgepole pine stump. An aluminum tag, orange for visibility, is attached to the stump with directions and distances to camera locations: a witness site. An additional map, noted by the square labeled "See detail attached," is shown in figure 27. It documents triangulation of the streambank photo point. Another note, "Shrub transect - see attached," installed in 1997, is shown in figures 64 and 65.

When to Photograph

When to photograph usually is determined by the activity being monitored. Pole Camp is part of a study evaluating effects of cattle grazing on a riparian area. Figure 20 includes photographs taken three times per year corresponding to livestock activity: June 15 before grazing, August 1 as cattle change pastures, and October 1 after animals leave the allotment. This three-season monitoring is repeated every year.

The ponderosa pine stand (fig. 21) illustrates a very different monitoring schedule. Photography was planned for the first week in August so that vegetation development would be consistent. Photographs were taken just before logging and in each of the two growing seasons afterward to document rapid changes in ground vegetation. Then a 5-year rephotographing cycle was established to follow slower changes in both stand structure and ground vegetation. The routine was repeated with the second logging and the precommercial thinning.

If vegetation is a primary topic, consider establishing a fixed date for rephotography. An established date has several advantages: (1) It offers an opportunity to evaluate seasonal differences in plant phenological development, (2) it provides a consistent reference for comparing change over several years, and (3) it establishes a consistent time interval over which change is documented.

Maps to Locate the Monitoring System

When the photo monitoring system has been established, prepare maps to locate the area and document the sampling layout. Assume that the person installing the monitoring program will **not** be the one to find and rephotograph the area. Provide maps and instructions accordingly. A local map showing roads and site locations is illustrated in figure 41 for Pole Camp, one of three locations for the Emigrant Creek riparian study.

After establishing the sampling system, establish a witness site or tree which marks the area. Identify it with a permanent marker, such as an orange aluminum tag, and determine direction and distance to camera locations or transects. Inscribe these on the identification tag. Next create a map of the camera locations and photo points or transects with directions and measured distances by using the filing system form "Photographic Site Description and Location" (fig. 42) found in appendix B. Note whether the direction is taken in magnetic or true degrees by indicating either "M" or "T." A 21-degree deviation in the Pacific Northwest must be accounted for. Measure distances between witness site, camera location, and photo points on the ground. Do not convert to horizontal distance.

Fenceposts or stakes—Monitoring, by definition, means repeated observation. Therefore, all camera locations, transects, and photo points must be permanently marked. The recommended method is with stamped metal fenceposts (fig. 40). These cost about \$2.25 each for a 5-ft size in 2000. Stamped metal has several advantages over strong T-bar posts: the former are flimsy and will bend if driven into by a vehicle or run over by an animal; they will bend flat and remain in the ground to mark the spot; they resist theft because they are just as difficult to pull out as a good fencepost but not worth the trouble; and they are easy to carry and pound. But the primary advantage of flimsy fenceposts is their visibility, as shown in figure 40. If visibility is not desired, steel stakes are a choice but require a metal detector to relocate.

DATE _____									
AREA _____									
UNIT _____									
CAMERA: 1 2 3 4 5									
PHOTO: A B C D									
E F G H I J									

Figure 43—An example of a photograph identification card to be placed in the camera view (fig. 44). This has been reduced to 60 percent. Appendix B has blank forms for reproduction onto dark blue paper. The best paper colors are Hammermill Brite Hue Blue® or Georgia Pacific Papers Hots Blue®. Light colored paper, common in the office environment, fades out under direct sun and should not be used.

Steel stakes often have been used and may be necessary in shallow soils or in areas that will be disturbed. If disturbance or shallow soils prevent use of fenceposts, the stakes should be driven flush with the ground. If left a few inches aboveground, stakes will damage tires, hooves, or feet and are often difficult to find. When driven flush with the ground, they require a metal detector for location (White's Electronics, Inc. 1996). Even then, the stakes must be of some mass for detection with a simple, \$250 machine. Angle iron should be 1 in on the angle and at least 8 in long. Cement reinforcing bar should be at least three-eighths of an inch in diameter and at least 8 in long.

One overriding consideration in photo monitoring is the requirement that the **same distance** be observed between the camera location and photo point for all subsequent photography of that sample. Any analysis of change depicted in the photographs can be done **only** when the distance remains the same. Therefore, always **measure** distance from camera location to photo point. A fixed distance for all photo monitoring is not required; this may differ from one photo point to another. Camera format also may change, such as first pictures with a 50-mm lens and next pictures with a 35-mm lens, but distance must remain the same. It can remain the same only if permanently marked.

Identification of Photographs

Identify each photograph by site name, photograph number, and date. Figure 43 is an example of a form for use in general or topic photographs (fig. 44). (Forms are in appendix B.) The critical factor is identification of **negatives** for color or black-and-white

CAMERA LOCATION AND PHOTO POINTS

Date 1997/6/17 Camera Location Witness Stump
 Area Snow Mtn. Dist. Number of Photo points: 2
 Unit Pole Camp Observer R. G. Hall
 Comments From rd junc. 43/4365, on rd 73 for 0.25 mi W. to
turnout on S. side road; witness stump 22" LP 20 yds. S
 slope 1 Aspect W Slope position bottom

Photo point A:
 Compass bearing: 237° M
 Distance:
Flood plain, left view
of Pole Camp study
site.
Mt. pine beetle killed
LP stand in background
1, 2, 3 are camera
locations; S & W are
photo points



Photo point B:
 Compass bearing: 270° M
 Distance:
Flood plain, right view
of Pole Camp study site.
1 & 2 are camera loca-
tions, D is dry meadow
photo point.

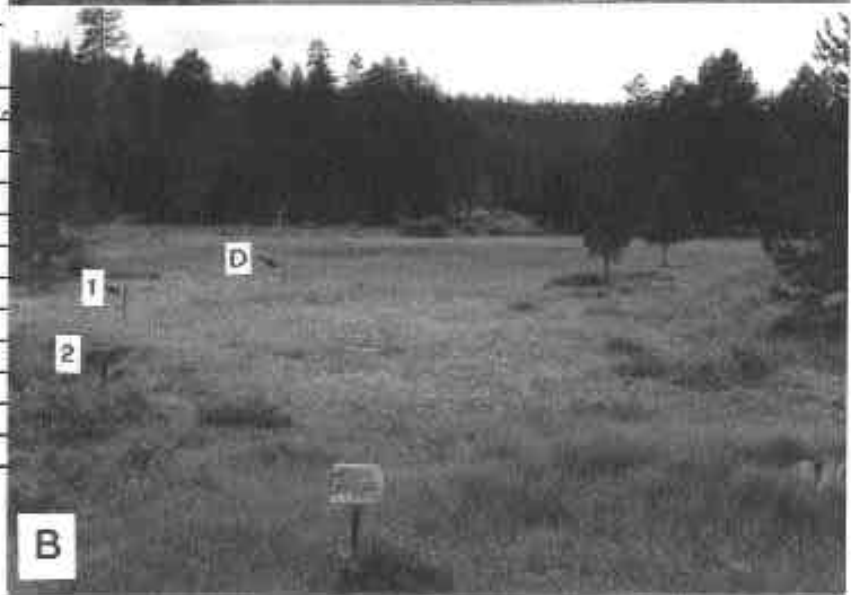


Figure 44—Filing system form "Camera Location and Photo Points" showing general photographs of Pole Camp taken from the witness stump: (A) left landscape and (B) right landscape noted in figure 42. Note repeat of fenceposts 1 and 2 in both pictures. Fenceposts identify camera locations 1, 2, and 3 and photo points D for the dry meadow, W for the wet meadow, and S for the streambank. Photo identification cards similar to figure 43, a form from appendix B, are at the bottom of each picture. The purpose of these photographs is twofold: (1) to illustrate the general sampling area and (2) to show location of the photo monitoring layout. Used in conjunction with the map in figure 42, someone other than the original sampling crew should be able to find and rephotograph this site.

pictures or digital images. Slides have borders to write on, but there is no similar space on negatives. Placing a photo identification card in each view as it is photographed assures a permanent record on the negative. Negative identification has been one my biggest problems!

Paper color is the next consideration. Plain white or light colors, common in the office environment, are not suitable because they are too light and will fade when photographed outdoors in full sunlight (fig. 30). The recommended paper color is either Hammermill Brite Hue Blue® or Georgia Pacific Papers Hots Blue® (app. B). Tests have shown these darker blue hues are superior to other vibrant colors such as green and yellow.

Description of the Topic

Describe what is in the scene to be photographed (fig. 44). This might include plant species, ground conditions, disturbances, or any other pertinent item. Appendix B contains forms with provision for recording these notes. For example, the filing system form, "Camera Location and Photo Points," is shown in figure 44 with two views of Pole Camp. Figures 46 to 48 (shown below), using the same form, illustrate mountain pine beetle effects on lodgepole pine over 13 years. And figure 50 (also shown below) is the "Photo Points and Close Photos" form for a general view and two closeup photographs of a ponderosa pine-elk sedge plant community in undisturbed condition. Recording of the percentage of cover for various items is recommended for good photo descriptions.

Filing System

Photo monitoring requires a way to file slides, prints, and negatives. My system is organized around each study with an expandable file used to contain everything (app. D).

The expandable files are placed in a file cabinet dedicated to sampling and organized first by geographic location and then by date for next photography. By filing studies geographically, generally around overnight facilities, travel planning is greatly facilitated. Noting the next photography date on each file helps with seasonal planning (app. D).

General Photography

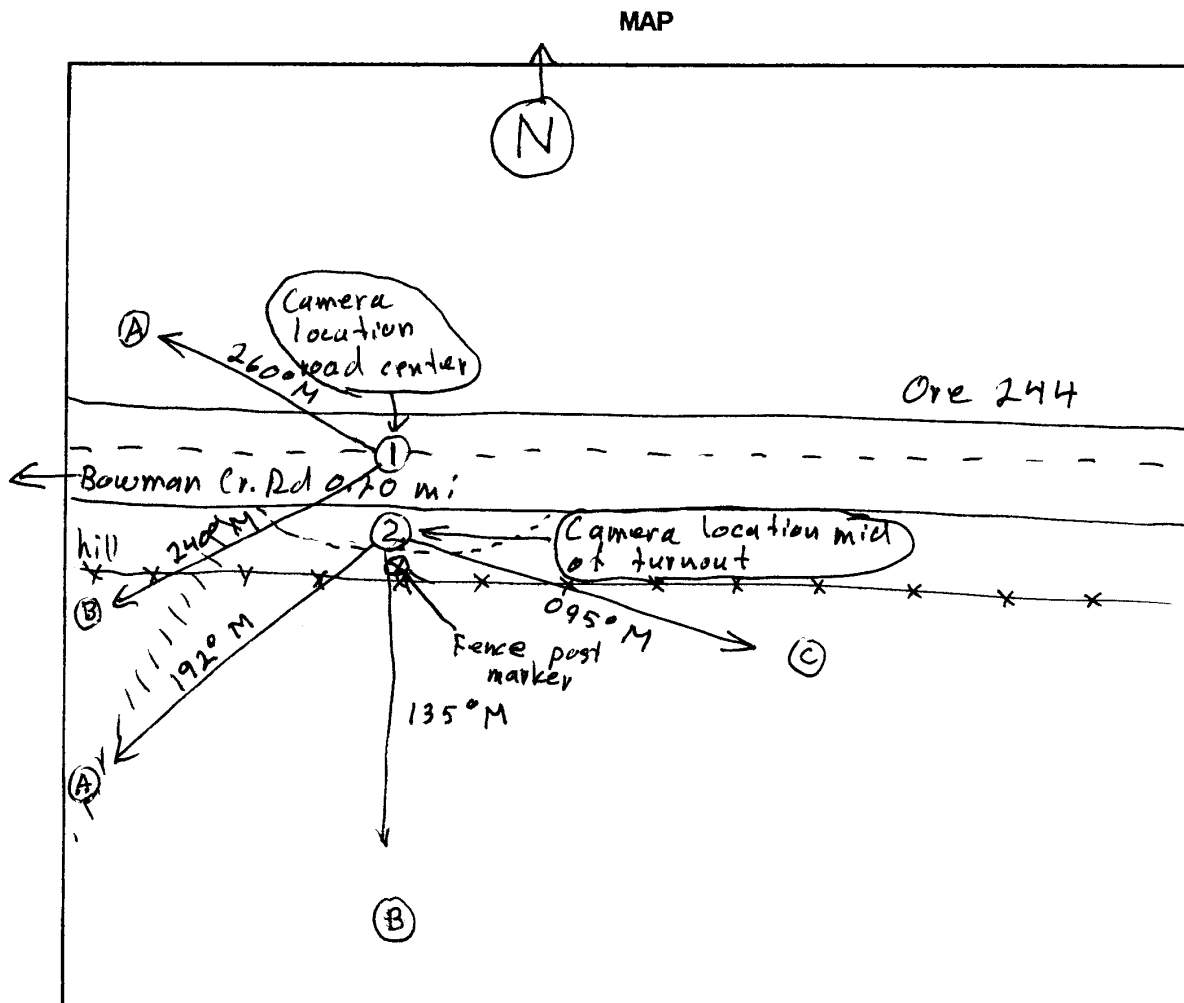
General photographs document a scene rather than a specific topic or conditions along a sampling transect (discussed below). They are similar to landscape pictures in that they do not require a size control board (meter board) on which to focus the camera and to orient subsequent photographs. They usually cover an area of 2 to 20 acres and distance of 50 to 200 yards (figs. 26 and 44).

Concept

In many cases, general photographs document a scene in which a meter board cannot be placed where the camera can be focused on the "1M" of the board for distance and photo orientation (fig. 18). One use of a general photograph is shown in figure 26 depicting the setting of Pole Camp. Figure 44 is filing system form, "Camera Location and Photo Points," containing this and a second view of Pole Camp wherein the fenceposts marking camera locations and photo points may be identified. Another use is illustrated in figures 45 to 48 documenting effects of mountain pine beetle attack on lodgepole pine.

PHOTOGRAPHIC SITE DESCRIPTION AND LOCATION

Date Aug 1976 Area Camas Cr. Meadows
 Unit Ukiah District Observer: F.C. Hall
 Number of photo points 5 Plant community: lodgepole pine
 Location: T. 4S R. 33E Sec. 35 SW of SW
 Location description On Ore. hiway 244 between mile posts 15
& 16; 0.20 mi. east of junction with Bowman Cr. Rd.
 Photo purpose: Document effects of Mt. pine beetle
attack on bottomland climax lodgepole pine
 Discussion Some beetles noticed in 1975; this year major
kill (70%) of dominant lodgepole-needles red. Follow
for each year for 3 yrs, then about 5 yr. intervals.



Use back of sheet for additional details.

Figure 45—Filing system form "Photographic Site Description and Location" with map to locate camera locations and photo points documenting affects of mountain pine beetle on lodgepole pine. Two camera locations are shown. Figures 46 to 48 are from camera location 1 showing photo points 1A and 1B.

Equipment

The following equipment needs to be taken to the photography site:

1. Camera or cameras for different film or digital camera
2. Photograph identification form "Camera-Photo" (see index to app. B; the form itself is not labeled)
3. Clipboard and holder for the photo identification sheets (app. C)
4. Previous photographs for orientation of the camera
5. Filing system form "Camera Location and Photo Points" (app. B)
6. Fenceposts and angle steel stakes, sufficient for the number of camera locations desired, with pounder
7. A tripod to use for camera orientation while viewing the photographs

Technique

Select a scene that will meet your monitoring objectives. Describe it by using the filing system form, "Camera Location and Photo Points," and include plant species, ground cover items, disturbance, or whatever the topic of the photograph is. Photograph the scene.

Make maps of the location and layout of the scene on the filing system form, "Photographic Site Description and Location" (app. B; fig. 45).

Reorientation—Reorientation of subsequent pictures is a major concern if a meter board was not used originally to mark and establish photo orientation. Key items of each view have to be identified. For example, in figure 44, the tall tree in the right background of picture (A) is the same tree in the left background of picture (B). Panoramic views such as figure 44 always should have about 10 percent overlap between photographs.

Systems used for landscape photo reorientation, (see fig. 16) are of major help. On a black-and-white copy of the scene, mark reorientation items as shown in figures 16 and 38. With the camera mounted on a tripod, compare the picture in hand with the scene through the camera. Orient the camera accordingly.

Figure 37 illustrates a method for rephotographing general views. It shows 3- by 5-in photographs mounted on 5- by 5-in cardboard. Instructions are given under each picture for its location and orientation. These fit into a vest pocket for use in the field. Figure 44A is a recent picture of figure 37A.

Example—Figures 45 to 48 illustrate general photography to document effects of mountain pine beetle on lodgepole pine along Oregon highway 244 in the Blue Mountains of eastern Oregon. Figure 45 is filing system form "Photographic Site Description and Location" mapping two camera locations. Camera location 1 has two photo points (figs. 46 to 48) and camera location 2 has three photo points. Monitoring started in 1976 when beetles first attacked the stands.

CAMERA LOCATION AND PHOTO POINTS

Date 7/8/2 Camera Location Orc 244, Series 1
 Area Camas Cr. Meadow Number of Photo points: 5
 Unit Weka Dist Observer JS
 Comments LP 30% with white needles, many shed; 20% red needles, stands 90% dead - all larger trees; mtn. pine beetle
 Slope 10 Aspect E Slope position Top

Photo point A:
 Compass bearing: 260°M
 Distance: --
Camera located on
Orc 244 centerline
massive lodgepole
kill



Photo point B:
 Compass bearing: 240°M
 Distance: --
Camera on Orc 244
centerline



Figure 46—Filing system form “Camera Location and Photo Points” documenting stand conditions in 1977, 1 year after a mountain pine beetle (*Dendroctonus ponderosae*) attack on lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Trees killed the first year have lost their needles. Compare to figures 47 and 48. Photo orientation used the road center line but cut off tops of the trees in both **A** and **B**.

Figures 46 to 48 use filing system form “Camera Location and Photo Points” to document beetle effects over 14 years. Figure 46 depicts effects in the second year of beetle attack when trees killed the first year started to drop their needles. Figure 47 is the third year after attack and shows massive standing fuel in A and salvage in B. Figure 48, taken 14 years after initial attack and 13 growing seasons after figure 46, illustrates tree fall in A and growth of natural regeneration in B.

CAMERA LOCATION AND PHOTO POINTS

Date 7/8/87 Camera Location Ore 244, Series 1
 Area Camas Cr. Meadow Number of Photo points: 5
 Unit ULIAH Dist. Observer FEV
 Comments Lodgepole needles gray & shed; few green trees are mostly less than 3" dbh.
 Slope 10 Aspect E Slope position Top

Photo point A:
 Compass bearing: 260°M
 Distance: —
90% of dominant & codominant trees with gray or shed needles



Photo point B:
 Compass bearing: 240°M
 Distance: —
Salvage logged winter of '77-78, screen of dead trees retained



Figure 47—Stand conditions in 1978, 2 years after beetle attack in 1976. Photo point A shows 90 percent kill and massive standing dead fuel. Photo point B was salvaged in winter 1977-78. These photos were properly oriented to show tree tops and road center line.

Lack of a meter board on which to orient the camera is evident in figures 46 to 48. Treetops are cut off in figure 46, they are visible in figure 47, and again cut off in figure 48. It is important to precisely reorient repeat photos.

Text continues on page 92.

CAMERA LOCATION AND PHOTO POINTS

Date 9/18/5 Camera Location Ore 244 Series 1
 Area Camas Cr. meadow Number of Photo points: 5
 Unit Ukiah Dist Observer ETC
 Comments Lodgepole regeneration growing well.
 Slope 10 Aspect 5 Slope position Top

Photo point A:
 Compass bearing: 260°M
 Distance: —
70% of lodgepole
down by 5th year
after beetle kill



Photo point B:
 Compass bearing: 240°M
 Distance: —
70% of trees in
green down after
5 yrs; salvaged area
well stocked (not
planted) and growing
well



Figure 48—Stand conditions in 1991, 14 years after beetle attack and 13 growing seasons since figure 46. Photo point A shows most dominant trees are down, thereby creating severe burn conditions at ground level. Photo point B illustrates natural regeneration height growth. Compare photo orientation with figure 47, which is optimum; here, B has the tree tops cut off and about a 1/2 inch more pavement at the bottom. Orientation of repeat general photography requires skill and a set of orientation pictures similar to figure 37.

Topic Photography

Topic photography narrows the subject from a general view to a specific item of interest. It adds a meter board, or other size control object, to identify the photographic topic (figs. 40 and 49).

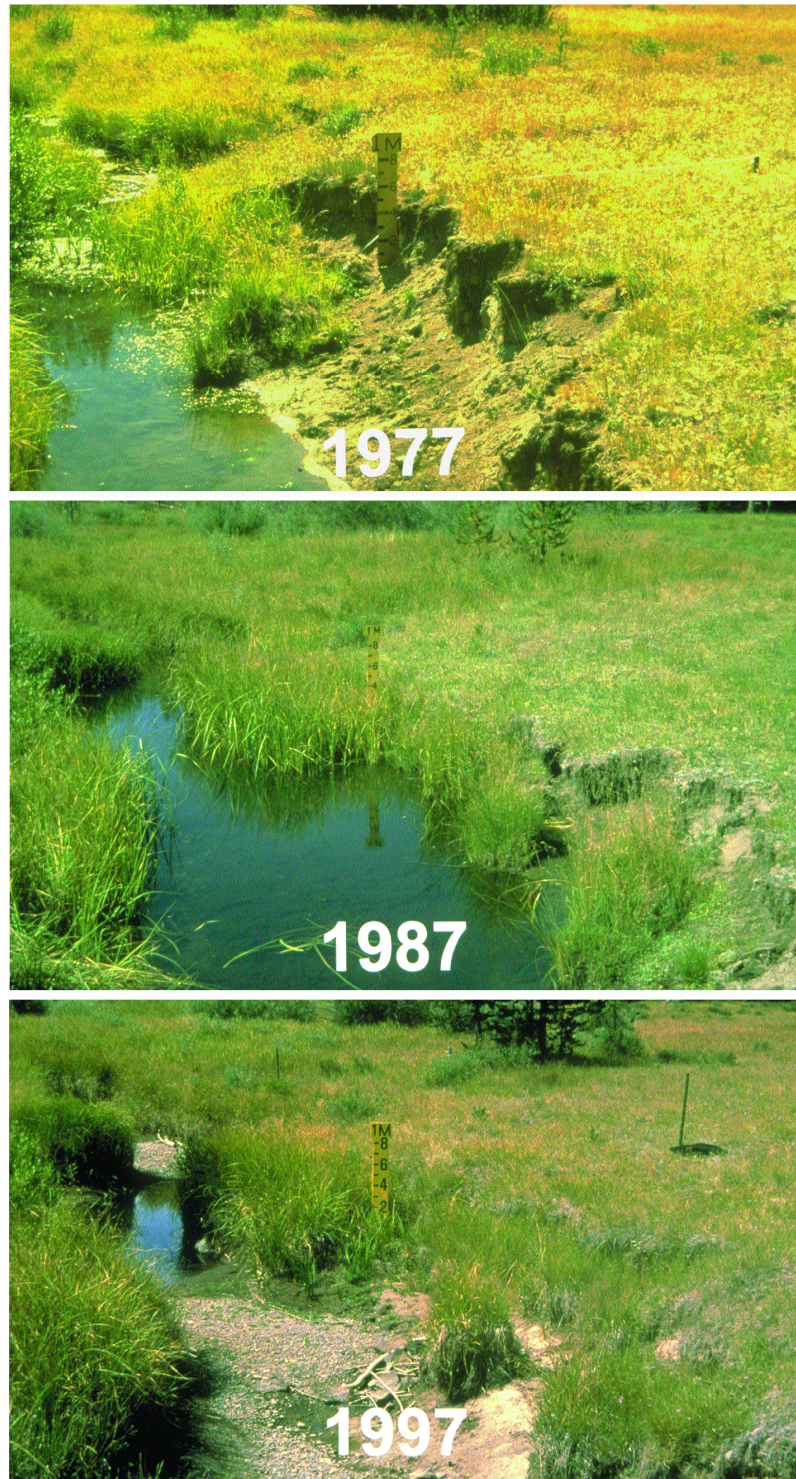


Figure 49—Topic photographs of streambank stability at Pole Camp. The specific topic of interest was fate of the fallen block of sod shown in 1977. Its fate might resolve the question of how fast the streambank will erode under change in livestock management from season-long use to three-pasture rest and rotation. By 1987, beavers had moved into the area raising the stream level, which converted Kentucky bluegrass on the fallen block to aquatic sedge. By 1997 the stream was dry because a flood in February 1996 washed out the beaver dams, cut a new channel, and drained late summer flows from this part of the stream. The block of sod is still present after 20 years of livestock grazing. See figure 23 for effects of a winter ice flood on the original camera location.

PHOTO POINTS AND CLOSE PHOTOS

Date 7/7/66 Camera Plot 226 (669)

Area Snow Mtn. Dist.
 Unit Green Butte
 Photo point: A
 Observer E. C. Hall
 Remarks 15 yr retake
of ecology plot just
prior to partial cut.
Good range condition;
benchmark for range
condition guides. See
plot 226 (669) for data.

Photo point A:
 Left of meter board
 Species/cover:

CAGE 60%
PONE 15%
CARO 5%

Comments: Very good
range condition; tight
soil.

Photo point A:
 Right of meter board
 Species/cover:

CAGE 50%
PONE 25%
CARO 8%
FRVI 2%

Comments: Very good
condition



Figure 50—Filing system form "Photo Points and Close Photos" documenting effects of selection logging in a ponderosa pine/elk sedge community (fig. 29). This area had not been previously logged and had only sporadic sheep use because water was 1.5 mi distant. The general view is followed by pictures to the left and right of the meter board. The concept is to show both a general view and a pair of closeups to document change. Figure 29 illustrates what happened in this view after logging and 18 years later. Figure 51 illustrates the same series to the left of the meter board. Species are CAGE (*Carex geyeri* Boott, elk sedge), PONE (*Poa nervosa* (Hook) Vasey, Wheeler bluegrass), CARO (*Carex rossii* Boott, Ross' sedge), and FRVI (*Fragaria virginiana* Duchesne, strawberry).

Concept

A meter board, or other size control board, is placed at the topic to (1) identify the item to be monitored for change; (2) establish a camera orientation reference point for subsequent photography; (3) set up a constant sized reference by which change may be documented, for example by grid analysis; and (4) provide a point to focus the camera for optimum depth of field.

Figures 40 and 49 illustrate identification of a very specific topic, streambank stability. Figure 50 deals with a general view limited to area around the meter board, the topic being effects of logging and precommercial thinning on stand structure and ground vegetation. The purpose of topic monitoring is the primary factor in selecting a monitoring layout.

Effects of camera focal length and distance from camera to meter board to emphasize the topic are discussed in figures 31 to 33. When the distance from camera location to topic is the same (figs. 6 and 7), the 70-mm and 35-mm pictures can be enlarged or reduced to the same size meter board as in the 50-mm photograph (fig. 7). When cropped, all pictures will be the same. This can be done with prints from negatives or digital images; it cannot be done with slides. Try to use the same focal length for all subsequent photographs.

Equipment

The following equipment is required for topic photography:

1. Camera or cameras with both color and black-and-white film, or digital camera
2. Form "Camera-Photo," from appendix B for photograph identification, printed on medium blue paper
3. Forms from appendix B for site identification: "Photographic Site Description and Location," and photo points: "Camera Location and Photo Points"
4. Meter board (app. C)
5. Clipboard and holder for the photo identification sheets (app. C)
6. Fenceposts and steel stakes, sufficient for the number of camera locations and photo points desired, with pounder
7. Compass and 100-ft tape for measuring distance
8. Metal detector for locating stakes

Technique

Several steps are necessary to establish topic photo monitoring. Pole Camp (fig. 44) will be used as an example.

Define the topics of interest—At Pole Camp, primary topics of interest were effects of livestock grazing on streambank stability, differential utilization of dry and wet meadows, and impacts on willow shrubs. Next, the desired coverage of the monitoring area must be defined. How many streambank sites are desired? How many dry and wet meadows and where? How many shrubs should be monitored and where are they located? Note in figure 44A the distribution of willow shrubs and in figure 44B, the pattern of dry to moist to wet meadow.

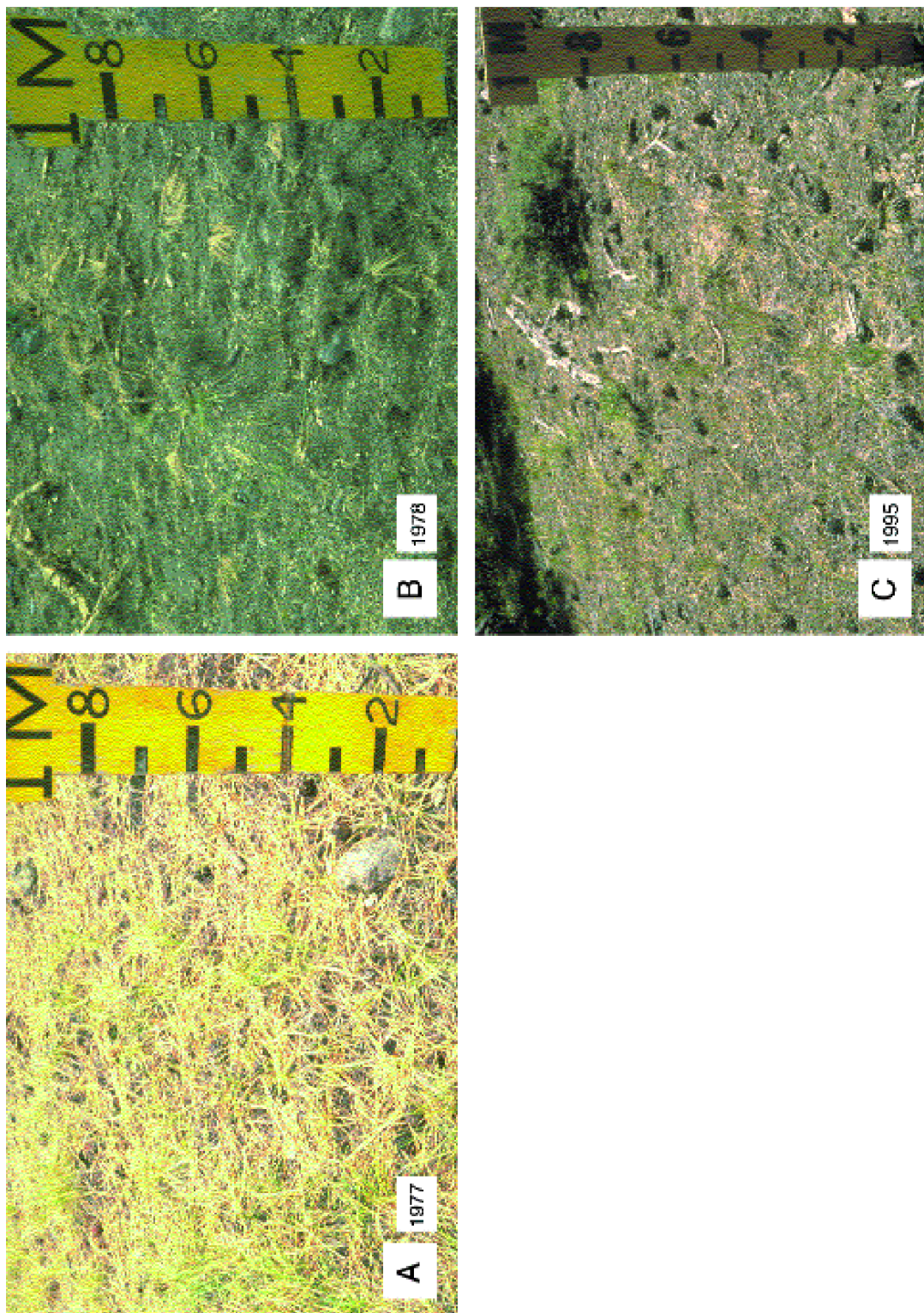


Figure 51—The ponderosa pine logging depicted in figures 29 and 50. (A) Prelogging with elk sedge clearly dominant, (B) tracts and destruction of the elk sedge, and (C) 18 years later, still with very little elk sedge, only some squirreltail grass, and a browsed bitterbrush.

PHOTO POINTS WITH OVERHEAD VIEWS

Date 9/6/85 Camera Wide Thin #3
 Area Prairie City Dist Number of Photo points: 1
 Unit Cold Cr. Observer F.C. Hall
 Comments 25 yrs since pct; clearcut about 1950
 Slope 5 Aspect W Slope position mid Topography undulating

Photo Point A

Compass bearing: 178° M

Distance 32.0 ft

Photo comments:

No cow use, trees
now growing at 22"
per del.



Overhead of Photo Point A

Photo comments:

Ponderosa pine in
fairly good vigor.
100 ft line transect
showed 47% cover



Figure 52—Filing system form "Photo Points with Overhead Views" documenting current tree canopy cover in a stand precommercially thinned 25 years previously. The form is in appendix B. Remember to make notes on what is in each photo.

Closeup photos—In many cases, details might be desired that are not accommodated by a meter board 7 to 10 m distant. Closeup photos, one on each side of the meter board, are recommended (fig. 34). After the general photo is taken, walk up to the meter board and photograph it on each side. With a 50-mm lens, stand 2 m away or with a 35-mm lens, stand 1.5 m away. Figure 34 illustrates the result with a 50-mm lens. The critical element is to always place the top of the meter board all the way up in a corner of the view (fig. 35). Details on the ground are shown in about a 1.5- by 1.5-m area on each side of the meter board (fig. 34). The concept is a general photo and two closeup photos to document change (fig. 50).

Figure 50 illustrates use of filing system form “Photo Points and Close Photos” (app. B) for mounting and filing topic photographs. It is the 1977 view of ponderosa pine shown in figure 29. Figure 51 has close views of general conditions, shown in figure 29 for prelogging, that were taken 1 year later and 18 years later.

Multiple photo points—Coverage could be either multiple photo points from the same camera location or multiple camera locations focusing on the same photo point. Figure 42 maps two photo points (D and W) from camera location 1 and two camera locations (2 and 3) focusing on one photo point (S). Figure 44 shows these camera locations and photo points. Advantages are twofold: First, relocation tends to be easier because only one point must be located that will serve two or more views, and second, one point showing several views tends to tie the sampling area together.

Overhead canopy—Overhead canopy pictures may be useful when documenting changes in tree canopy cover (fig. 52). A word of **caution**: camera focal length **must be the same** for all subsequent pictures because there is no size control board by which to adjust different photos taken at different focal lengths to the same size. Directions for overhead photography are contained in the “Tree Cover Sampling” section, later in this appendix.

Distance from camera to photo point—Distance between camera location and photo point is critical for any repeat photography from the camera location: It **must** remain the same. Exact replication of distance for all rephotography is the reason camera locations and photo points must be permanently marked in the field and their distances measured. I have found the best system is with flimsy fenceposts. The same distance is not required, however, for other photo monitoring. Figure 42 shows different distances of photo points from camera location 1.

An investigator may elect to do all three kinds of photography: topic view, closeups on each side of the meter board, and an overhead view for maximum documentation of treatment effects.

Analysis of Change

The meter board is used as a constant size reference point for analyzing changes. The recommended system is grid analysis, discussed next. A clear plastic form with site identification information is taped to the photo and topics of interest outlined. Then an analysis grid is adjusted to exactly match the size of the meter board in the outline and is printed on white paper. The outline form is taped to the grid, and grid intersects on and within the outlines are counted and recorded. Amount of change between photos can then be determined.

Photo Grid Analysis

Changes in vegetation, soil, fuel loading, streambanks, or other photographed items can be monitored by outlining the items on a clear plastic sheet that is then placed over grid lines. The method involves counting grid intersects falling on and within the outline and recording them. They are then compared to outlines of previous photographs of the same topic to estimate change. Each plastic sheet with its outlines becomes a database and must be identified. Outlines may be laid on top of each other and compared between photographs to visually assess changes.

Concept

The concept of grid analysis is based on a fixed geometric relation between camera and meter board to compare photographs. The basic requirement is a constant distance between camera and meter board (photo point) for the initial and all subsequent photographs. Different distances may be used for other photo points from the same camera location and at other camera locations depending on the topic of interest (figs. 49 and 50). An established camera height is desirable but not essential unless the grid is used to track change in position of items over time. Use of the same camera format, such as 50-mm lens on a 35-mm camera body, is recommended but is not required. Grids are designed to encompass a view limited to 13 to 15 degrees both horizontally and vertically. Views exceeding 15 degrees suffer from parallax caused by light refraction at the edges of a lens. Heavy lines surrounding the grid emphasize this limit.

A photograph of the topic (fig. 53, for example) is enlarged to 8 by 12 in for easy viewing. A clear plastic sheet, with information on date, site location, and topic, is attached to the photograph (figs. 54 and 55). The meter board in the photo is marked and the objects of interest outlined. Then a master analysis grid is adjusted for size by using the meter board on the outlined plastic sheet. For adequate precision in grid size adjustment, the meter board must occupy at least 25 percent of the height of the photograph; 35 to 50 percent is better. Adjustment in grid size requires measurement of the outlined clear plastic meter board (fig. 56), measurement of the meter board on a master grid (fig. 57), and reducing the size of the master to match the outline. Each individual picture must be measured for grid adjustment. Grids are reduced with a copy machine, printed on white paper, taped under the outlined clear plastic sheet, and grid intersects counted that fall on or within each outline (fig. 58).

Requirements

Requirements for photography suitable for grid analysis include the following:

1. Camera location and photo point (meter board) permanently marked so that exact relocation is possible. Consider use of cheap (stamped metal) fenceposts driven 2 to 3 ft into the ground for both camera location and photo point.
2. A size control board, such as a meter board, placed a prescribed distance from the camera for each photo point. The distance selected may be from 5 to 20 m depending on the meter board selected, a single meter board 1 m tall (figs. 49 and 50) or a double board 2 m tall (fig. 31). Distance for other locations may be selected according to the topic identified by the meter board. Make sure the visible part of the meter board occupies at least 25 percent of the picture height.

Text continues on page 103.



Figure 53—A1981 view of the Pole Camp wet photo point to be used as an illustration of grid analysis. This photograph will be compared to one from 1996. The first step is to attach a clear plastic outline form (fig. 54). Fill in the required site information and outline the shrubs (fig. 55).

Date _____ Observer _____ Cluster/Camera _____ GRID INTERSECT ANALYSIS Area _____ Unit _____ Transect/Photo _____		
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Figure 54—Form used to identify photographic outlines. Reproduce the form on clear plastic overhead projection sheets. This form has been reduced to 85 percent of its size in appendix C. The full-sized form is suitable for color photographs of 8 by 12 in. Use of the clear plastic overlay is illustrated in figure 55.

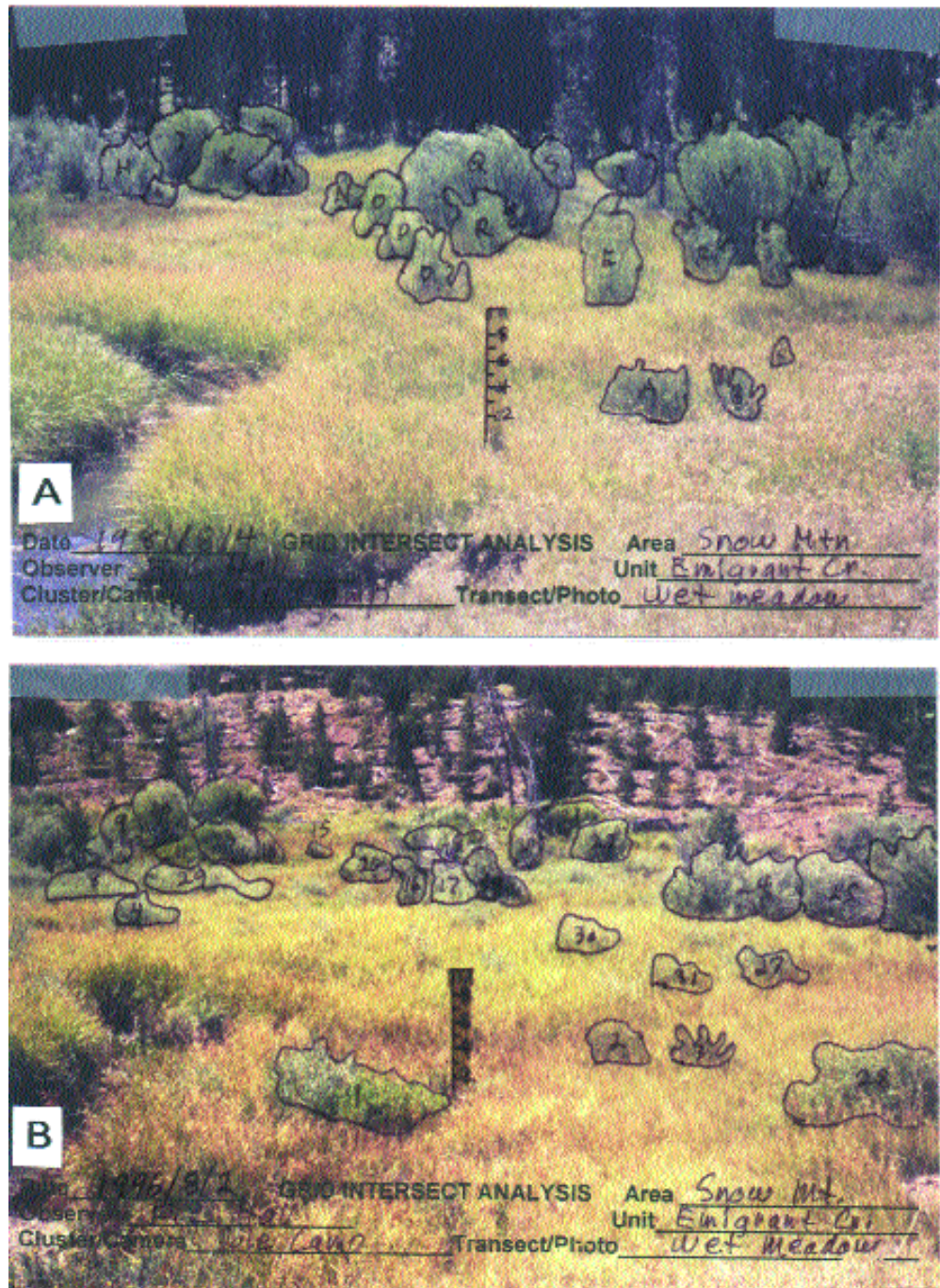


Figure 55—Photographs to be evaluated by grid analysis: (A) 1981 (fig. 53), and (B) 15 years later in 1996. Clear plastic overlays (fig. 54) have been taped to each photo. Each overlay is a data sheet so it must have all information entered to identify the outlines. First the meter board is outlined on its left side and top. Then each visible decimeter line on the meter board has been marked and the decimeter number written on the overlay. Finally, each shrub has been carefully outlined and given either a letter or number identification. The next step is size adjustment of the analysis grid.

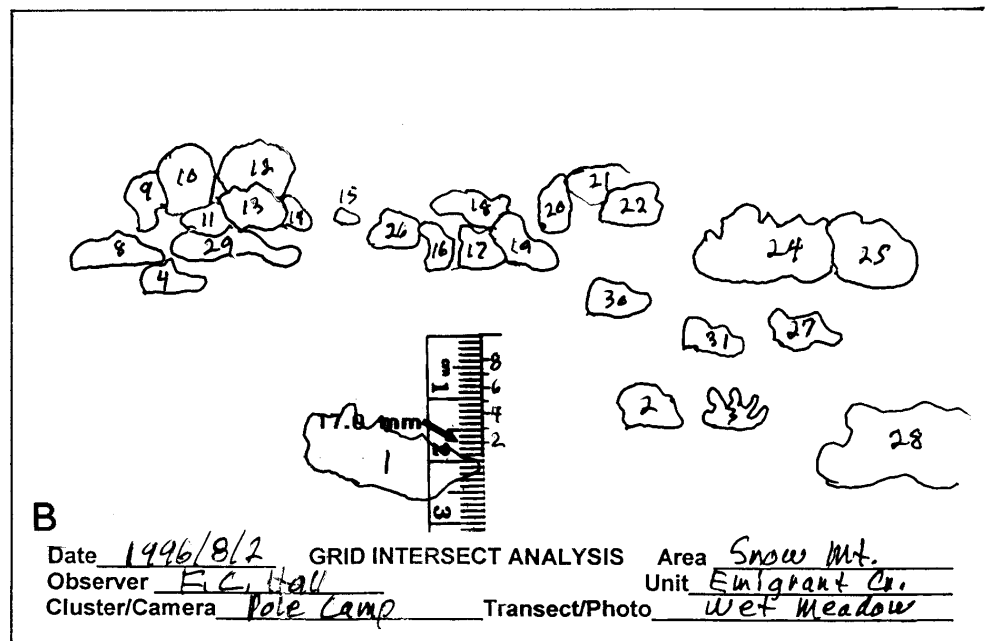
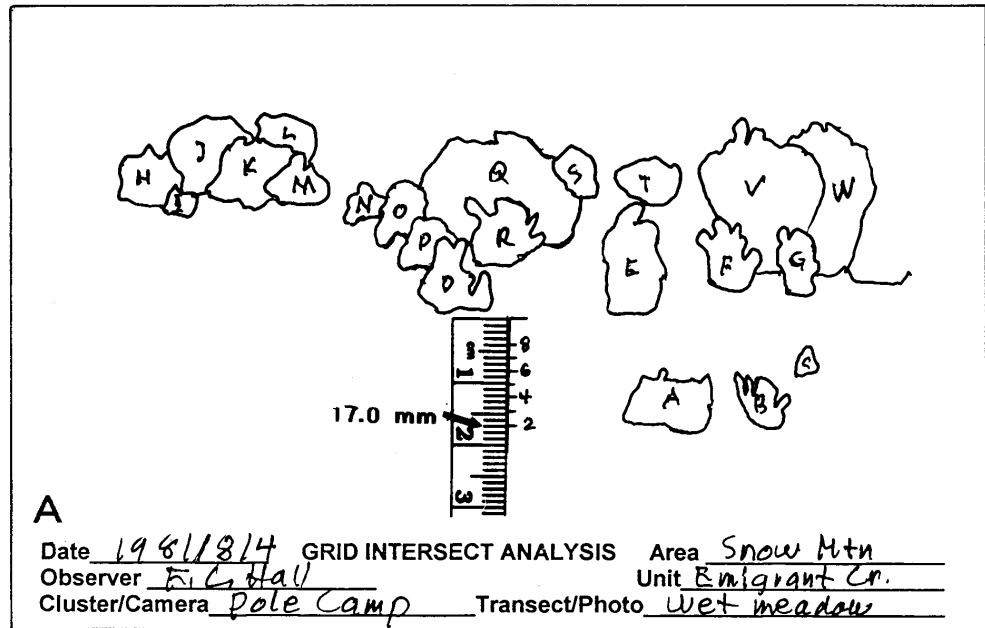


Figure 56—Measurement of meter boards for size adjustment of analysis grids: (A) 1981 and (B) 1996. Measure from the top down to the lowest visible decimeter mark to the nearest 0.5 mm, in these photos the 2-dm mark. Both measurements are 17.0 mm, which indicates the same distance from camera to board in both and consistent enlargement of the photos. The analysis grid (fig. 57) will have to be reduced in size to exactly match size of the meter boards in these outlines. An exact match is required for consistency in measurement between photographs.

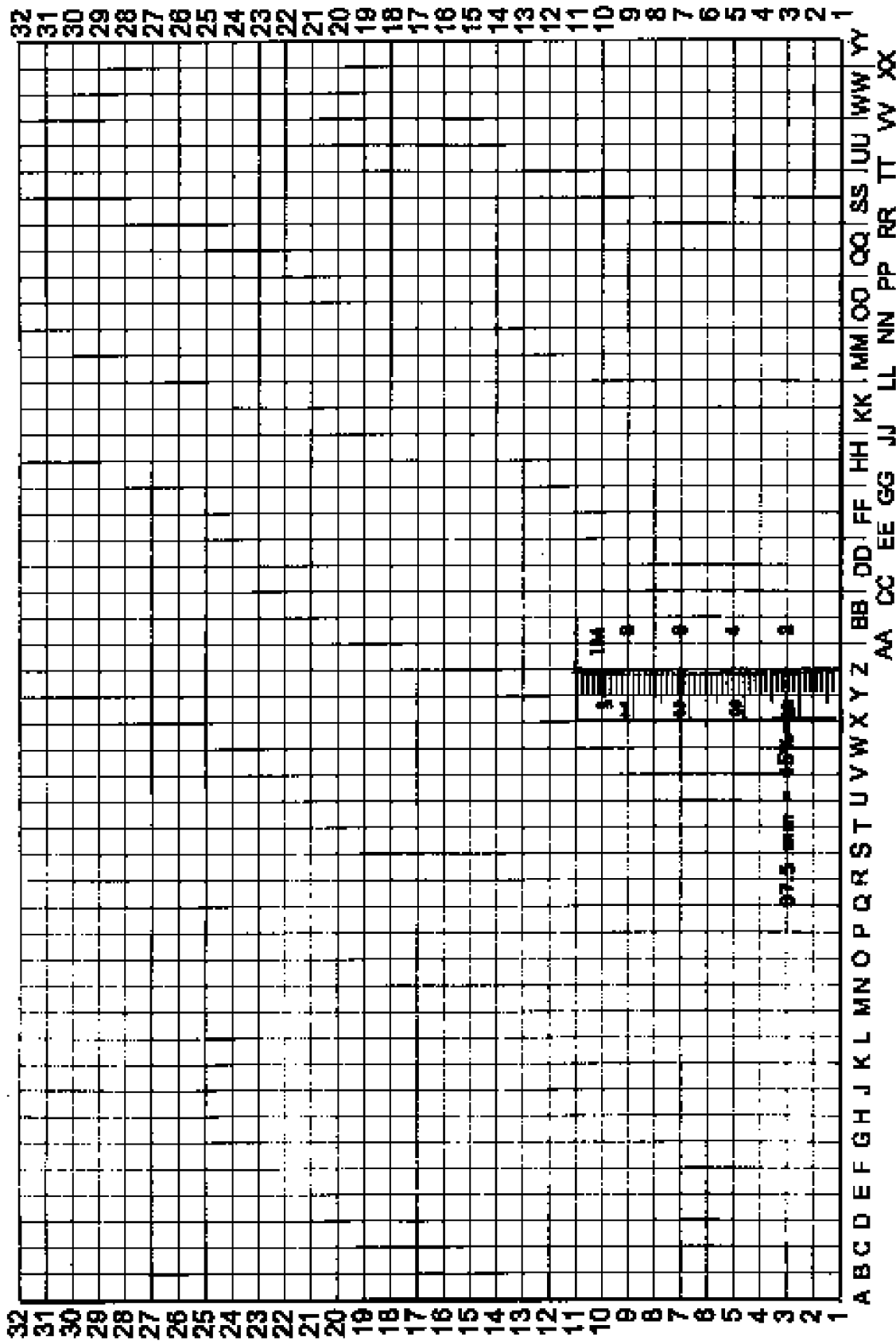


Figure 57—The master analysis grid found in appendix C. Measure from the top of the meter board to the 2-dm mark used in the outlines. This measurement is 37.5 mm. Divide 17.0 mm from the outlines by 37.5 for a reduction to 45 percent of the grid. Print the grid on white paper at 45 percent of its original size. The outline is laid over the reduced grid to check on alignment of meter board marks. Minor adjustments in grid size are made so that marks of the overlay and grid meter boards match exactly (fig. 58).

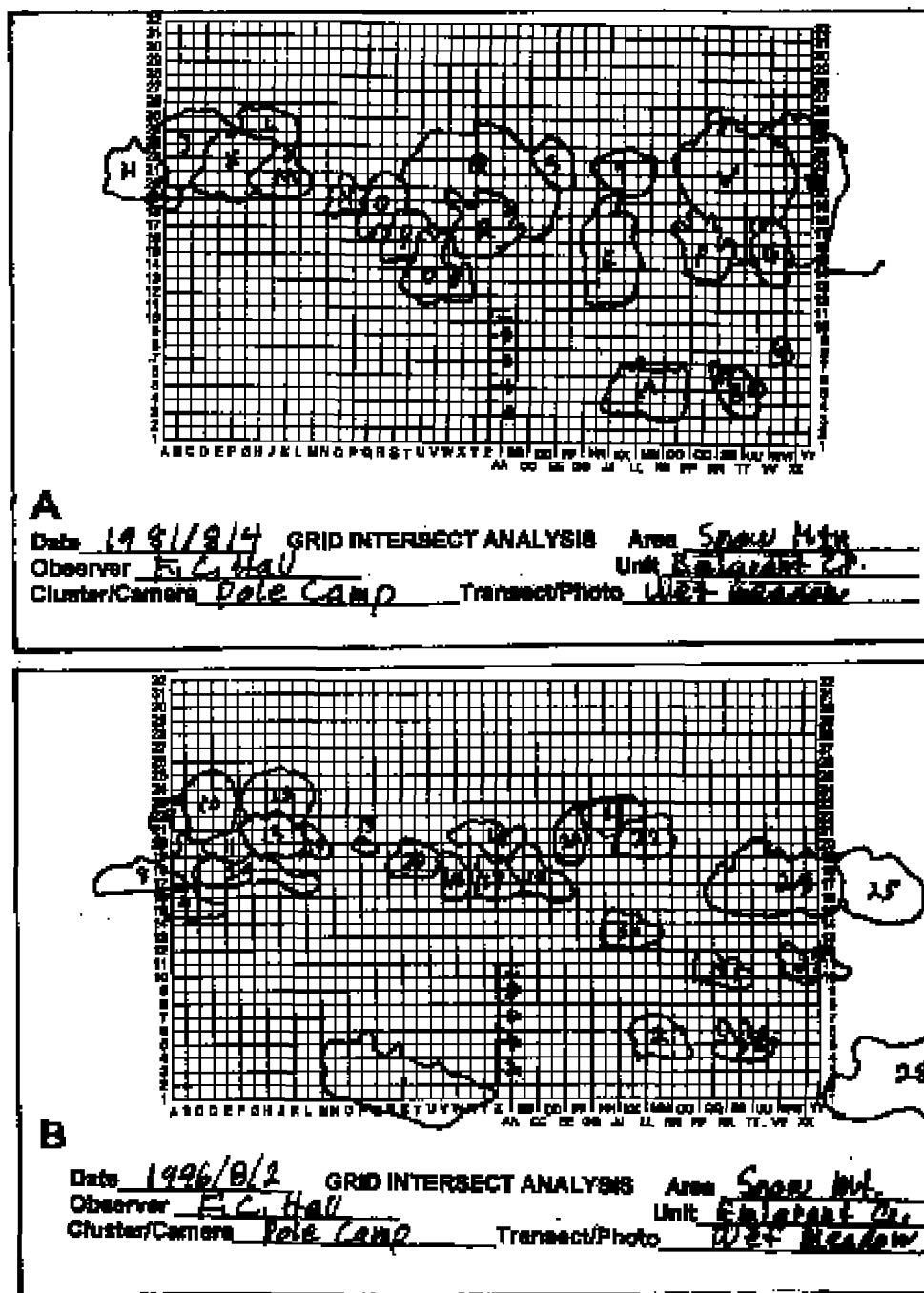


Figure 58—Outline overlays placed on analysis grids: (A) 1981 and (B) 1996. The next step is to count grid intersects within each outline. When an outline crosses a grid intersect, such as the two intersects between shrubs 17 and 19, AA/18 and AA/19 in photo B, count the intersects for the shrub in front (shrub 17). Also count intersects along the grid edge, such as the five intersects in shrub 24 on line YY, photo B.

1999/2/19

PHOTO GRID SUMMARY

Date 1999/10/22 Observer F.C. Hall
 Area Snow Mtn Unit Emigrant Cr.
 Cluster/Camera Pole Camp Transect/Photo Wet Meadow

Item #	Date 1981	Item #	Date 1996	Item #	Date
A	21	1	44		
B	12	2	15		
C	4	3	12		
D	19	4	8		
E	30	5	—		
F	17	6	—		
G	15	7	—		
H	1	8	2		
I	4	9	6		
J	19	10	17		
K	22	11	6		
L	9	12	15		
M	11	13	14		
N	6	14	4		
O	11	15	2		
P	13	16	8		
Q	63	17	10		
R	21	18	12		
S	7	19	13		
T	14	20	8		
U		21	11		
V	59	22	12		
W	26	23	—		
		24	43		
	404	25	—		
		26	9		
		27	10		
		28	—		
		29	16		
		30	10		
		31	11		
			—		
			318		
	404		318		

Figure 59—The filing system form "Photo Grid Summary" where number of grid intersects by outline are recorded. In figure 58A, shrub A had 21 intersects; 21 is entered for shrub A under 1981. The primary purpose for identifying each outline is to aid in recording the number of intersects. Notice that three more shrubs were identified in 1996 than in 1981, even though only 64 percent as many intersects were recorded.

Suggestion: When grid analysis is contemplated, clip vegetation away from the front of the meter board to expose the bottom decimeter line. This will provide for maximum precision in grid adjustment.

Photographed with a 50-mm lens on a 35-mm camera, a single meter board set at 10 m is 25 percent of the photo height (fig. 2A), at 7 m it is 36 percent (fig. 2B). A double meter board, 2 m tall (fig. 31), will be 25 percent of photo height at 20 m. The meter board is used to orient the photograph and adjust size of an analysis grid.

3. Orient the camera view on the meter board. Place the camera focus ring on the "1M" and focus (figs. 29 and 30). This accomplishes two things: (1) it provides for reorientation of all subsequent photographs, and (2) it provides for a sharp image at the topic marked by the meter board and an optimum depth of field.

The following items are required for grid analysis:

1. Photographs of the monitoring situation. Figure 53 is the wet meadow photo point at Pole Camp taken in 1981. It will be compared to a photo taken in 1996 to appraise change in shrub profile area. Print all photographs to be compared at the same size, preferably about 8 by 12 in, and in color for best differentiation of items to analyze.
2. "Grid Analysis Outline" (app. B) printed on clear plastic sheets used for overhead projection (for example, 3M® or Labelon® Overhead Transparency Film). Film is specifically designed for use with various printers (inkjet, plain paper, or laser). These sheets are imprinted with site information from the form in figure 54 and are used for drawing outlines around topics of interest.
3. The "Analysis Grid" form, shown in figure 57 (app. B). The grid must be adjusted in size to precisely fit each picture and outlined meter board (figs. 55 to 58). Instructions are given in the section, "Grid Adjustment," below.
4. "Grid Summary" form (fig. 59 and app. B).
5. Permanent markers for drawing on clear plastic (for example, Sanfords Sharpie® Ultra Fine Point Permanent Marker). Three colors are recommended when encountering overlapping outlines, as in figure 60, to aid in differentiating items. Colors suggested are black, red, and blue.
6. Good quality hand lens to help identify the periphery of items being outlined—in this case, shrub profiles.
7. A copy machine that will produce clear plastic overhead projection copies and can adjust size of the master grid to fit the photographs. Many copy machines can reduce to about 50 percent or enlarge to 200 percent. Be sure to use a copy machine that does not stretch the copy in either direction. Grids, adjusted for size and printed on white paper, are taped under each outline for analysis.

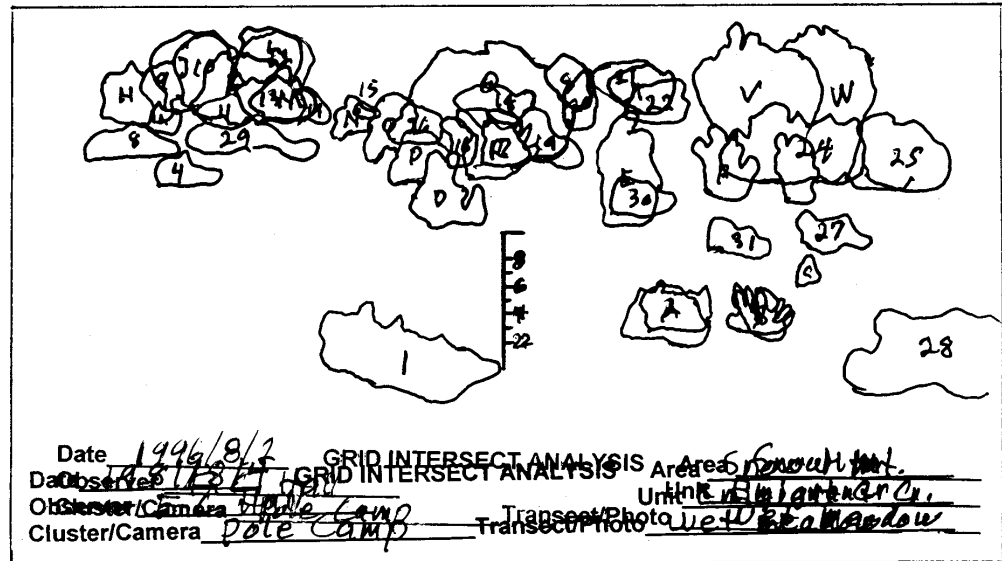


Figure 60—Outlines from 1981 (letters) and 1996 (numbers) overlaid for comparison of change in shrub profile. Note major changes in shrubs Q, V, and W, and a new shrub shown as 1. The dramatic reduction in shrub height of Q, V, and W from 1981 to 1996 was caused by beavers cutting the largest stems for dam construction.

Technique

Technique for grid analysis requires outlining the meter board and selected objects on the plastic overlay, “Grid Analysis Outline” form (app. B). The overlay has site information at the bottom because it becomes a permanent record of conditions on the date of each photograph (fig. 54).

Outlines on the overlay are interpreted by use of a grid that must be adjusted in size to exactly match divisions on the overlay meter board (figs. 56 and 58) in each photograph. The recommended procedure follows.

Outlining—Determine what is to be interpreted. In this example, change in willow profile area is the topic so all other items—grasses, sedges, forests and water—are not outlined. Decide whether individual shrubs will be evaluated or all shrubs lumped together. In this case, combined shrubs will be evaluated. Proceed as follows:

1. Fill out all information on the clear plastic overlay, because it becomes the permanent data record and must be identified (fig. 54). Date is the **photography** date, not when the outline was made.
2. Attach the plastic overlay to the photo at only one edge, such as the top, so that it may be lifted for close inspection of the photograph and then replaced exactly (fig. 55).
3. Using a straight edge, mark the left side of the meter board and its top on the overlay (fig. 55). Next, mark each decimeter division on the meter board and identify even-numbered decimeter marks by their number, such as 2, 4, 6, and 8 (fig. 55).

4. Starting in front, work systematically from left to right, outlining each shrub and labeling it with a letter or number (fig. 55). The primary purpose for identifying each shrub (or any outline) is administrative to assure that grid intersects inside an outline are not repeated or missed if interruptions occur during recording.

At times, identifying change in specific shrubs might be desirable. If so, each shrub identified in the initial photo will have to be identified in all subsequent photos and the letter or number used initially will have to remain exclusive to the shrub or to the location where the shrub used to be. This is best accomplished by shrub profile monitoring, discussed in the next section. Any new shrubs will require their own exclusive new identification.

5. When outlining, pay particular attention to the periphery of the shrub by following as carefully as possible the foliage outline. Do not make a general line around the outside of the shrub. Mark directly on the foliage, not outside of it. Check outlines by lifting the overlay to check on foliage and inspect with the hand lens.
6. Work back into the photograph. The letter inside the front shrub outline identifies the overlapping shrub (figs. 55 and 56). Using different colored marking pens may enhance overlapping outlines. Intersects often will occur under an outline. Count them for the shrub in front only (do not count the intersect twice).

Grid adjustment—Outline interpretation requires use of an analysis grid (fig. 57), whereby each grid intersection on or inside the outline is counted and recorded. The grid must be adjusted in size based on the meter board outlined on each overlay. Proceed as follows:

1. Measure height of the meter board as it appears on the overlay to the nearest 0.5 mm. If the bottom line on the board is not visible, measure to the lowest visible decimeter mark. In figure 56, it is 2 dm and measures 17.0 mm from top to 2 dm. Similar measurements between the 1981 and 1996 photographs indicate that distance from camera to meter board was the same and that both pictures were enlarged identically.
2. Next, measure height of the meter board on the master analysis grid. In figure 57, it is 37.5 mm from the top to the 2-dm grid line (second from the bottom).
3. Determine the percentage of change required for the master analysis grid: $17.0/37.5 = 45$ percent. On a copy machine, reduce the grid to 45 percent and print on plain paper. Overlay the outline on the grid to determine any additional size adjustment (fig. 58). This usually requires two or three trials.
4. Place the clear plastic overlay on the grid and assure that grid divisions exactly match those on the overlay meter board. Orient the overlay on the grid by using the left side of the meter board outline (fig. 58). Adjust the grid as necessary. When both overlay and grid meter board marks match exactly, tape the overlay to the grid.

Note borders on the grid. These mark the maximum 12- to 15-percent angle useful for grid analysis. Do not count intersects on outlines outside the grid.

5. On the filing system form, "Photo Grid Summary" (fig. 59), complete the required information and enter the year of the **photograph** in the "Date" column. This is the same date as on the plastic outline. List shrubs by letter or number in the "Item #" column. The form provides for recording intersects for three photographs. Note that items, shrubs in this case, are not required to have the same identification. Here, shrubs from 1981 are letters and those from 1997 are numbers because exact relocation of shrubs was not possible.
6. Starting in front and working from left to right, count the number of grid intersects on or within each outline. An intersect is where a horizontal and vertical grid line intersect. When the outline covers an intersect, count it for the shrub. Many times, the outline will separate two shrubs. Count the outline intersects for the shrub in front. Do **not** count the intersect twice. See figure 58A: intersect W-20 is on the outline for shrub "R" with shrub "Q" behind it. Record the intersect only for shrub "R." This is why outlining **on** rather than outside of shrub foliage is important. Do not try to count intersects for the shrub behind when they cannot be seen; for example, in figure 58A, intersects of shrub "Q" behind shrub "R" should not be counted. Count intersects on the edge of the grid but not beyond the grid even though the shrub or outline might extend beyond the grid, such as shrub W in 58A along the YY line. The grid defines the area of analysis, not the photo coverage.
7. Record the intersects for each shrub beside its letter or number (fig. 59). Recording by shrub letter or number will simplify record keeping. Disturbances or the need to stop can occur at any time, and a record is needed of shrubs already recorded and where to begin again. When finished, sum all the intersects (fig. 59): 1981 had 404 and 1996 had 318 intersects. Ask yourself if these are significantly different. The next section deals with analysis of change.

Note: Each picture is produced by enlargement of a negative. Seldom are two enlargements made at exactly the same scale even though the negatives might be precisely sized. Therefore, grids must be sized **independently** for each photograph (figs. 56 and 58).

Figure 58 compares outlines from 1981 and 1996. Visually, there is a difference in shrub profile area. These outlines are overlaid in figure 60 as one way to interpret change.

Analysis of Change

This section deals with analysis of change considering grid precision and observer variability. The grid monitoring system provides an opportunity to overcome both problems, which are primarily differences among observers. Let each observer do grid analysis on all photographs and interpret the results. The same personal idiosyncrasies will be applied in object outlining, grid sizing and placement, and interpretation of grid intersects, greatly reducing between-observer differences that affect interpretation of change.

Table 1—Effect of distance from camera to meter board on grid coverage at 10, 20, 30, and 60 m

Distance, camera to meter board	Ratio	Angle	Grid size at distance from camera of:			
			10 m	20 m	30 m	60 m
<i>Meters</i>		<i>Percent</i>	<i>-----Decimeters-----</i>			
5	1:50	2.0	2.0	4.0	6.0	12.0
7	1:70	1.4	1.4	2.8	4.2	8.4
10	1:100	1.0	1.0	2.0	3.0	6.0

Correct grid sizing and differences among observers influence analysis of change. Area within successive grid outlines may be digitized and compared. The data are entirely dependent, however, upon exact duplication of meter board outline size.

Grid precision—Percentage of photo height represented by the meter board is an important factor in precise fit of grids. The minimum is 25 percent and the optimum is 35 to 50 percent. A 35-percent meter board is 1.3 times more precise than a 25-percent board for grid adjustment.

Using a single meter board at 10 m (fig. 53), which is 25 percent of photo height, just a 0.5-mm difference in measurement at the meter board (17.0 vs. 17.5 mm; fig. 56) results in a 2.9-percent change in grid height. Grids 2.9 percent different in height also are 2.9 percent wider which results in a 5.9-percent difference in outline area. This same percentage applies to the number of intersects that may be within an outline.

A meter board occupying 33 percent of photo height would measure 22.5 mm in figure 56. A 0.5-mm difference here is only a 2.2-percent change in grid size. The 2.2 and 2.9 percent represent errors in measurement precision.

Distance from camera to meter board also affects precision of measurement on items beyond the meter board. Table 1 illustrates the effects of three distances between camera and meter board and how they affect grid precision at various distances from the camera. Because grids are adjusted to size at the meter board location, each grid is 1 by 1 dm at that location but this will change as distances increase.

A grid sized to a meter board 5 m from the camera measures 2 dm between grid lines at 10 m from the camera. This is two times greater than a grid sized at 10 m from the camera. At 30 m from the camera, a grid sized to a board 5 m from the camera will cover an area 6 by 6 dm. When sized to a meter board set 10 m from the camera, it will cover an area only 3 by 3 dm, one-half the dimensions and one-quarter of the area—a significant improvement in precision. Monitoring objectives help determine the optimum distance from camera to meter board as grid size adjustment and outline precision are balanced.

Observer variability—“Perfect” outlines are influenced by differences among observers.

1. Size adjustment of grids is influenced by observer skill. With a meter board at 25 percent of photo height, a 0.5-mm measurement difference of the meter board can mean as much as 2.9-percent difference in grid dimensions and 5.9-percent difference in area. Meter boards closer to 33 percent of photo height and larger photographs help to reduce this error. I recommend 8- by 12-in color photographs. A meter board at 33 percent of photo height would measure about 55 mm. A 0.5-mm measurement discrepancy would be only a 0.9-percent precision error.
2. The grid must be oriented exactly along the left side of the meter board as viewed (the observer's left side) and precisely at the top and bottom or lowest clear decimeter mark. Orienting precision is subject to observer skill.
3. Interpretation of what constitutes the periphery of an object profile (shrub in this case) is subject to observer variability. Choices have to be made about where to place an outline and how precise it will be, particularly for overlapping shrubs. An intersect is counted if the outline crosses it. The desirability of the topic being outlined tends to influence a person's willingness to include or exclude marginal parts. Outlining on clear plastic without grid lines tends to reduce observer bias.

A test was made in January 1998 of observer variability in outlining the shrub profile area shown in figure 53. Results of the seven observers are in figure 61. A 6- by 9-in color print with properly sized grid was provided. Observers placed the grid, outlined shrubs, and summarized intersects within each outline. Variation between observers was measured by the 5-percent confidence interval (CI). The CI also was calculated as a percentage of the mean: CI divided by the mean, then multiplied by 100 equals the CI% for each shrub, total of all shrub intersects, and an average CI. Low CI%, such as 5 percent (shrub H), is interpreted as low observer variability, and a change of more than 5 percent in intersects probably is a significant difference. High CI%, such as 25 percent (shrub B), means high observer variability and more than a 25-percent change is required to be significant.

Percentage of confidence intervals ranged from 4.2 percent (shrub L) to 54.4 percent (shrub D) (fig. 61). The average CI% among the observers was 15.4 percent, suggesting that a change of more than 15 percent in intersects is required. However, the CI% for total intersects of all shrubs combined was only 5.7 percent indicating good concurrence among observers.

The number of intersects in an outline seems to influence the CI%. A graph at the bottom of figure 61 show higher CI% with lower intersects per shrub.

Differences in shrub profile area are rather clear in figure 58. Profile area in 1996 was 79 percent of that in 1981 (fig. 59). The reader may wish to test this observer variability; count the shrub profile intersects in figure 58 and compare to the data in figures 59 and 61.

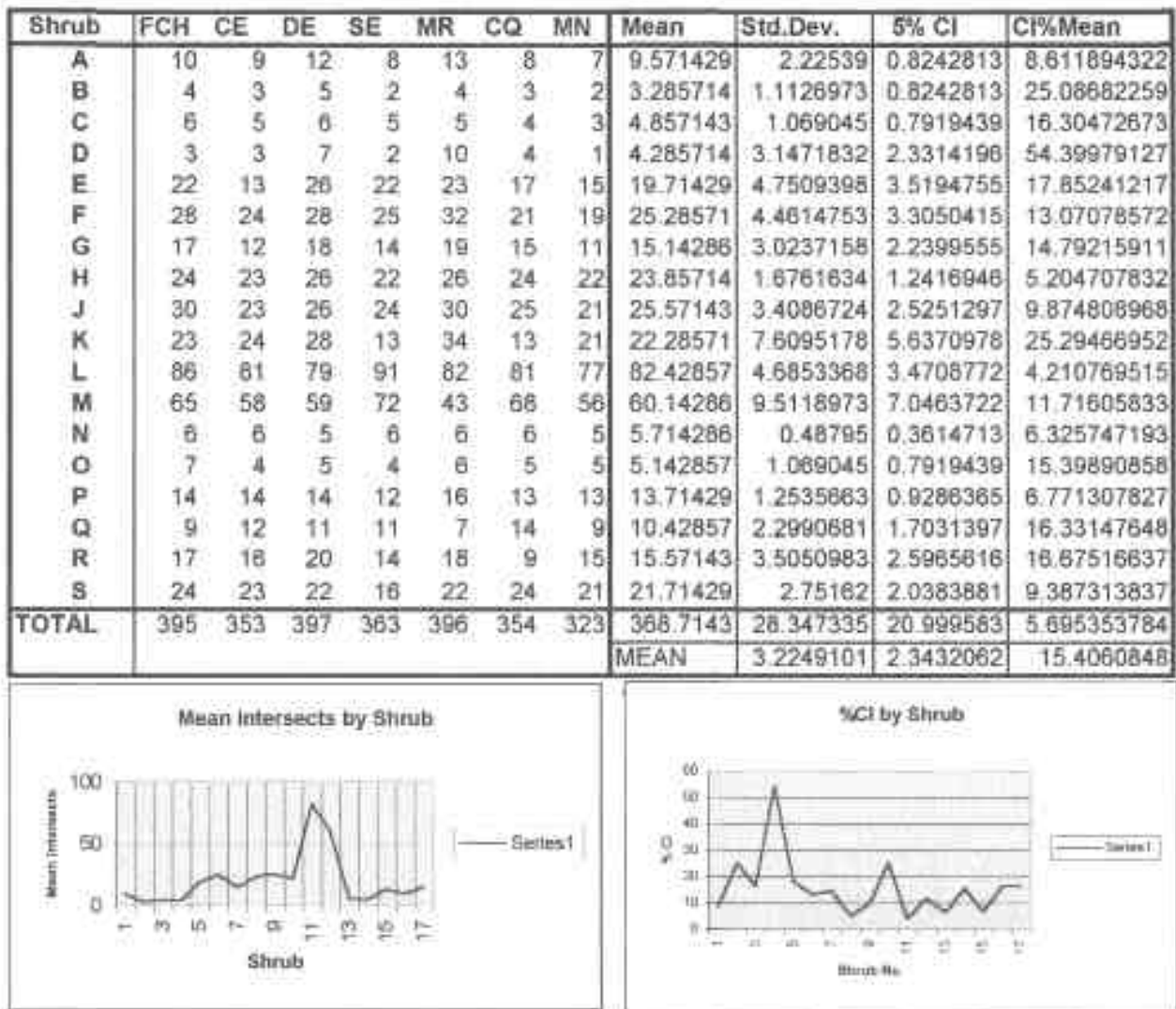


Figure 61—Summary of seven observers determining grid intersects on 18 shrubs from the same photograph. Variability among observers is characterized by the 5-percent confidence interval (5%CI) and is expressed by dividing the 5%CI by the mean intersects by shrub and multiplying by 100 (CI%Mean). The mean and CI%Mean are graphed by shrub.

Because CI% was rather high for individual shrubs, another observer variability test was conducted in winter 1999. Eight observers were provided with two photographs, one from 1975 and another from 1995, and asked to count total intersects of shrub profile. The CI% for 1975 was 7.5 percent and that for 1995 was 11.6 percent (fig. 62). The 1995 photo was more difficult to interpret.

The graph in figure 62 illustrates the mean, 5-percent confidence interval, and observer variability by year. Using the largest CI%, 11.6 percent, the averages are significantly different at the 0.5-percent level. Given a maximum of 12-percent observer variability here and 15 percent for total individual shrubs, a value greater than 12 percent of the average intersects is proposed as being significant at the 5-percent level of confidence for observer variability; for example, a mean of 384 intersects must change by more than 46 to say that the change was real and not due to observer variability at the 5-percent level of confidence ($384 \times 0.12 = 46.1$). This may be expressed as 384 ± 46 so that intersects greater than 430 or less than 338 may be considered a real change.

Outline Analysis - 2 photos, 99/3

Photo	FH1	FH2	EC	DR	DF	MN	SE	CQ	Mean	Std.Dev.	Cof.Var.	Max.	Min.	Range	% Range	5%CI	C1%mean
1975	376	364	394	473	386	330	359	393	384.38	41.59305	10.82096	394	330	64	0.1665041	28.8219	7.49839184
1995	201	241	255	232	208	152	263	196	218.5	36.53961	16.72293	263	152	111	0.5080092	25.3202	11.5881706

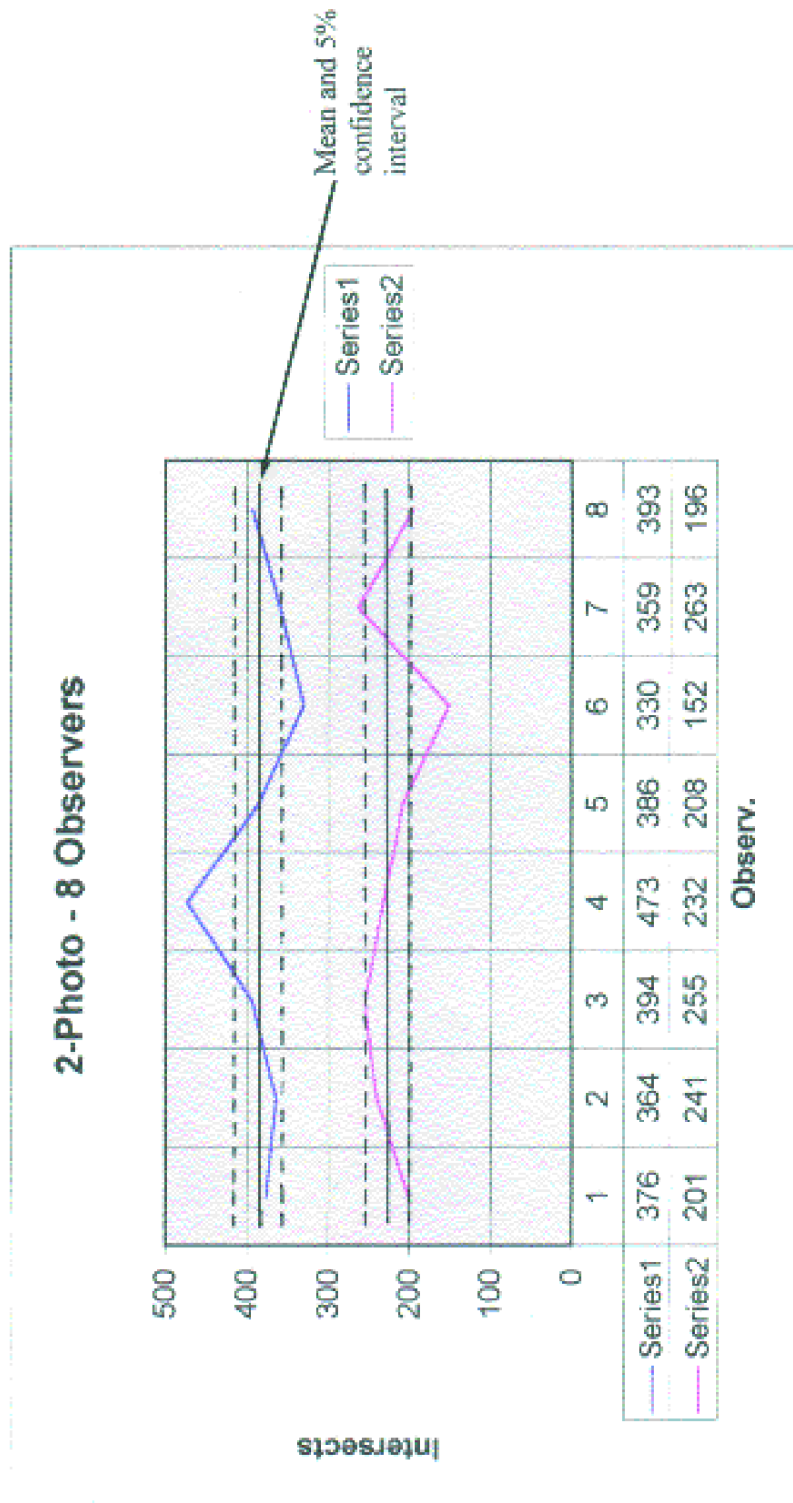


Figure 62—Outline analysis test for variability among eight observers in estimating shrub profile intersect. Photographs from 1975 and 1995 taken at the Pole Camp wet meadow photo point were compared. Series 1 is 1975 and series 2 is 1995. The 5-percent confidence interval for 1995, 12 percent of the mean, was used to determine a significant change in shrub profile.

25-year regression Pole Wet

Year	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	Mean
Area	378	401	422	379	394	392	353	436	407	393	365	363	229	247	247	227	249	228	262	214	254	267	330	380	412	329.2

Beavers

Pole Wet - Shrubs

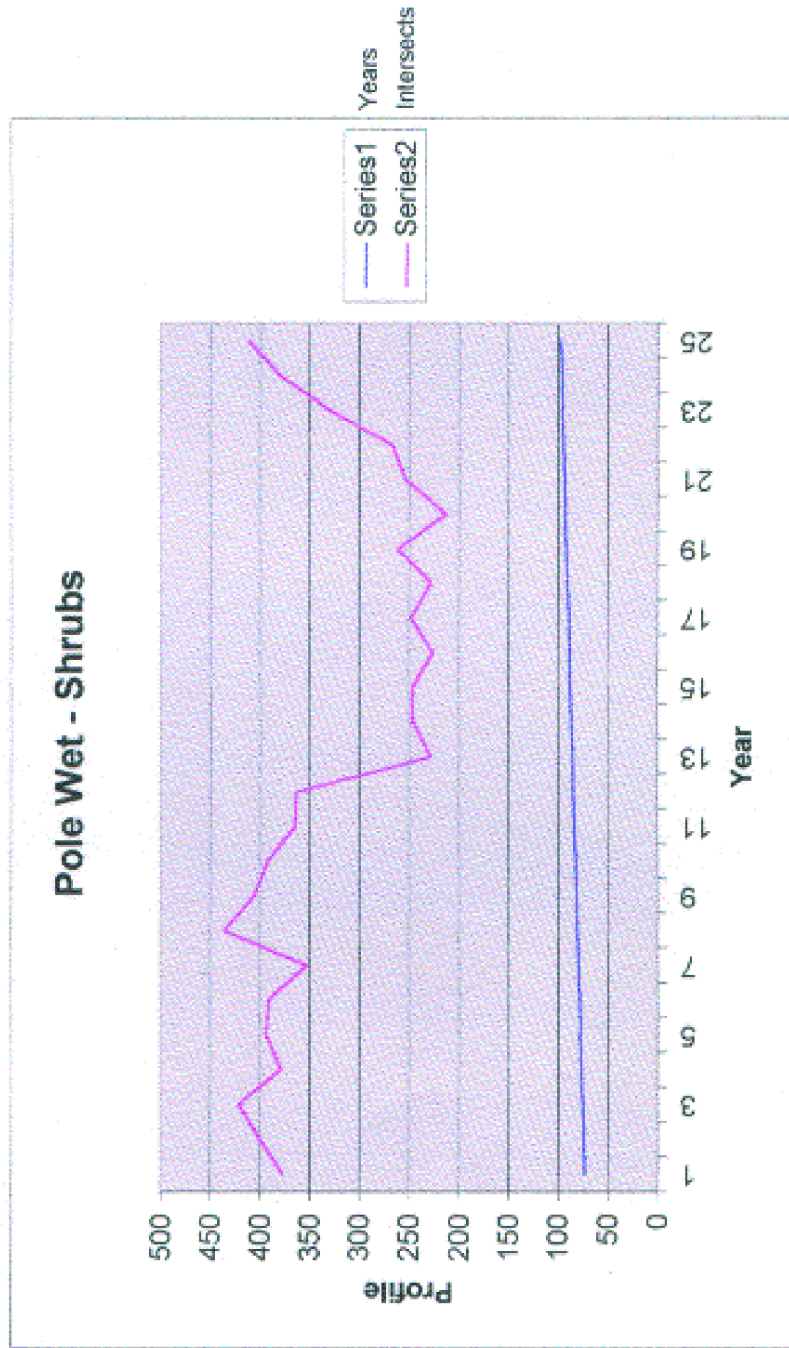


Figure 63— Regression of outline intersects from 1975 through 1997 for shrub profile changes at the Pole Camp wet meadow photo point. Intersects are total inside the grid area. Series 1 are the dates by year and series 2 are the intersects.

Studies, such as at Pole Camp where photographs are taken every year, are amenable to regression analysis of grid intersects. If the same person does the outlines, observer variability is greatly reduced. Figure 63 illustrates regression on shrub profile intersects at Pole Camp from 1975 to 1997 as determined from yearly photographs. Regression for the entire data set showed a decline of -0.63; however, when data were selected for the time of beaver activity in the area, 1983 to 1994, the regression was at -0.90, highly significant. Trendlines such as these seem very useful.

Grid Location of Items

Documenting change in position of items on a photograph requires precise photography. Three kinds of precision are required: (1) Distance between camera location and meter board must be the same for all repeat photos, (2) height of camera above the ground must be the same for all repeat photos, and (3) sizing and orientation of the grid must be precise.

Height of camera above the ground or orientation over the camera-location fencepost will change position but not size of objects. Figures 8 to 10 illustrate this relation by using the photo test view. Figure 10 overlays two sets of object outlines illustrating effect of camera position on location of objects and thus on the overlay grids. Reasons for this are shown in table 1.

Grid sizing and placement on the outline overlay, discussed previously, also are critical in detecting change in position.

None of these precision variables consider observer interpretation. They suggest that attempts to use photographs for monitoring change in position of objects seems questionable. If documentation of position change is desired, place the meter board in close proximity to the topic of interest, such as a streambank (figs. 23, 40, and 49), and measure from the meter board to the object of interest.

Shrub Profile Photo Monitoring

Change in shrub profile area can refer to either shrub utilization or shrub growth. It may be documented by repeat photography that uses grid analysis and horizontal camera orientation. Permanent camera locations and photo points, marked by either steel fenceposts or stakes, are required. Season of photography is a key factor in documenting change and causes of change in shrub profiles owing to shifts in leaf density.

Concept

Documenting change in shrub profile area involves photographing a shrub on two sides with the camera location moved 90 degrees for the different views. This photographs all profiles of a shrub. Camera locations and photo points must be marked with steel fenceposts or stakes to assure the same distance from camera to meter board for all future photographs. The same distance need not be used, however, for other camera locations. Adjust distance to suit the topic being photographed. Tall shrubs, where double meter boards are used (fig. 31), require a much greater distance than short shrubs.

The primary objective in monitoring change in shrub profile area or shape is to document utilization (reduction in area) or growth (increase in area). Thus, season of photography is of critical concern. If effects of animal browsing are the topics of interest, then photography both before and after utilization may be necessary. This

requires selecting two seasons to photograph, such as just before livestock grazing and immediately after. If livestock graze at different seasons in the same pasture over several years (as with rest-rotation systems), as many as four dates may be required to document grazing effects over the period. Other dates, established by local knowledge, probably would be required with wildlife.

If growth in shrub profile area were the topic of interest, then photography after termination of growth would be desirable. Dryland shrubs usually have a definite termination of growth, called determinate shrubs. Some riparian shrubs, such as many willows, continue to grow until environmental conditions (for example, frost) cause a termination in growth. These are known as indeterminate shrubs. For these, the season to photograph must be based on the phenological development of the shrub species under consideration.

Once photographs have been taken, use the "Photo Grid Analysis" procedure (previous section) to document and estimate change in shrub profile area and shape.

Requirements

All basic photo monitoring requirements must be met for relocating the monitoring area and maintaining the same distance from camera to meter board:

1. Establish a monitoring objective when selecting an area and shrub species to evaluate. Determine a photography date or dates.
2. Make a map to find the monitoring area (fig. 64) and a map of the transect layout (fig. 65). The transect layout must include direction and distance from the witness site to the first shrub photo point and then its two camera locations, and from there, the direction and distance to the next shrub photo point and its camera locations. All shrub photo points must be tied together for ease in future location. The transect layout need not, probably will not, be a straight line (fig. 65).
3. Placement of the meter board is of critical interest because it will be used to document changes in shrub profile. There are three concerns: (1) Placing the meter board far enough to the side of the shrub to allow the shrub to grow in crown diameter (figs. 66 through 69)—consider a distance that is half the current shrub crown diameter (fig. 66); (2) placing the bottom of the meter board far enough toward the camera to assure the lowest line of the grid will be **below** the bottom of the shrub if it grows—consider placing the 2-dm line opposite the current bottom of the shrub (figs. 67 through 69); and (3) placing the board in one location and moving the camera for a 90-degree change in view (figs. 66 and 67).
4. Select a camera-to-photo-point distance that will permit the shrub to grow in both height and diameter. Consider a distance where the current shrub is about 50 percent of the camera view height and 70 percent of the camera view width (fig. 67, B and C).

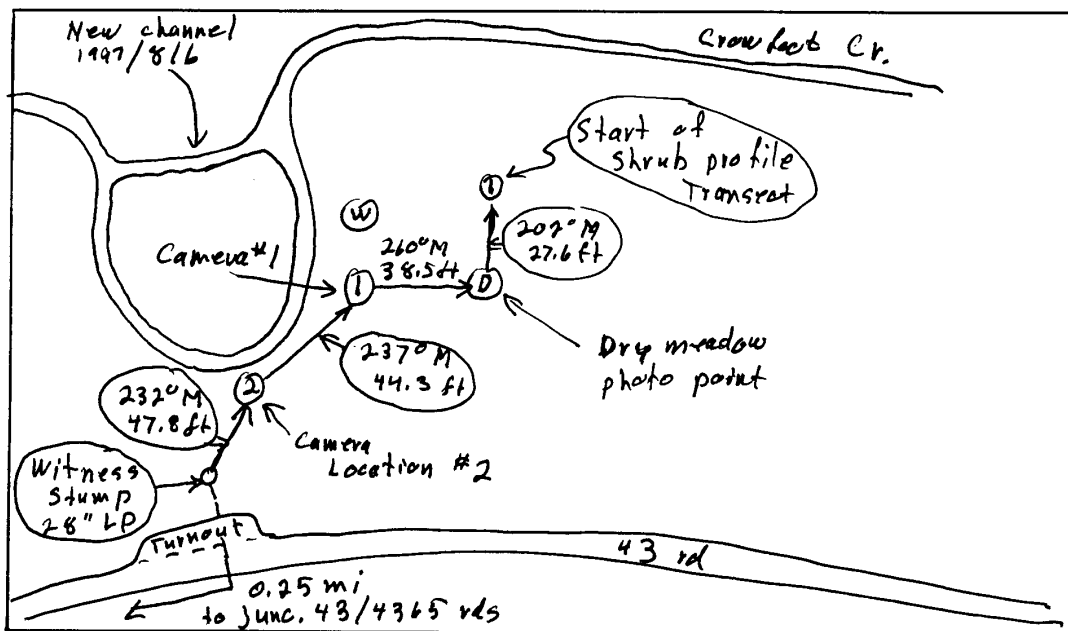
Text continues on page 118.

SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft. Nested Freq. 1 sq.m. Robel Pole Shrub Form

Date 1997/6/17 Site Data: Elev. 5200 % slope 1
Area Snow mtn. Slope aspect: N NE E SE S SW W NW
Allot. Pole camp Slope position: top up 1/3 mid low 1/3 (bottom)
Cluster No. 1 Micro topography: convex flat concave
Transects: (1) 2 3 4 5 Macro topography: flat undulating rolling
Plant community SAGE/ steep rough broken
CLAR
Geology:
Grazing system: Deposition: wind stream lake colluvial
Type rest/rot. Date 1977 residual
Type _____ Date _____
Type _____ Date _____
Material: limestone mudstone sandstone
granite serpentine diorite
basalt andesite rhyolite
tuffaceous cinders pumice ash
Kind of animal: cattle sheep
horses goats deer
elk _____
Soil:
Restrictive layer: absent clay pan bedrock
cemented
Location: T. 19S R. 27E
Sec. 29 SW of NE
Description: open meadow
between 43 rd and
Crowfoot Cr. 0.25 mi
W. junc. 43/4365 rds
Surface compaction: none moderate severe
Soil profile stone: absent gravel stony
Soil texture: sandy loamy silty clayey ashy
Other notes: 1998/8! fence across old
access trail to meadow

MAP



See attached page for details

Figure 64—The filing system form "Sampling Site Description and Location" identifies the Pole Camp shrub profile monitoring system. The first line of the form provides for circling one of several monitoring systems; here, "Shrub Form" has been circled. Information on the area is entered, and a map is drawn to locate the monitoring system. This shrub profile transect is one of several photo monitoring installations at Pole Camp. Figure 42 diagrams four other camera locations and four photo points. A note at the bottom of this map says an attached page has details. The page is shown in figure 65.

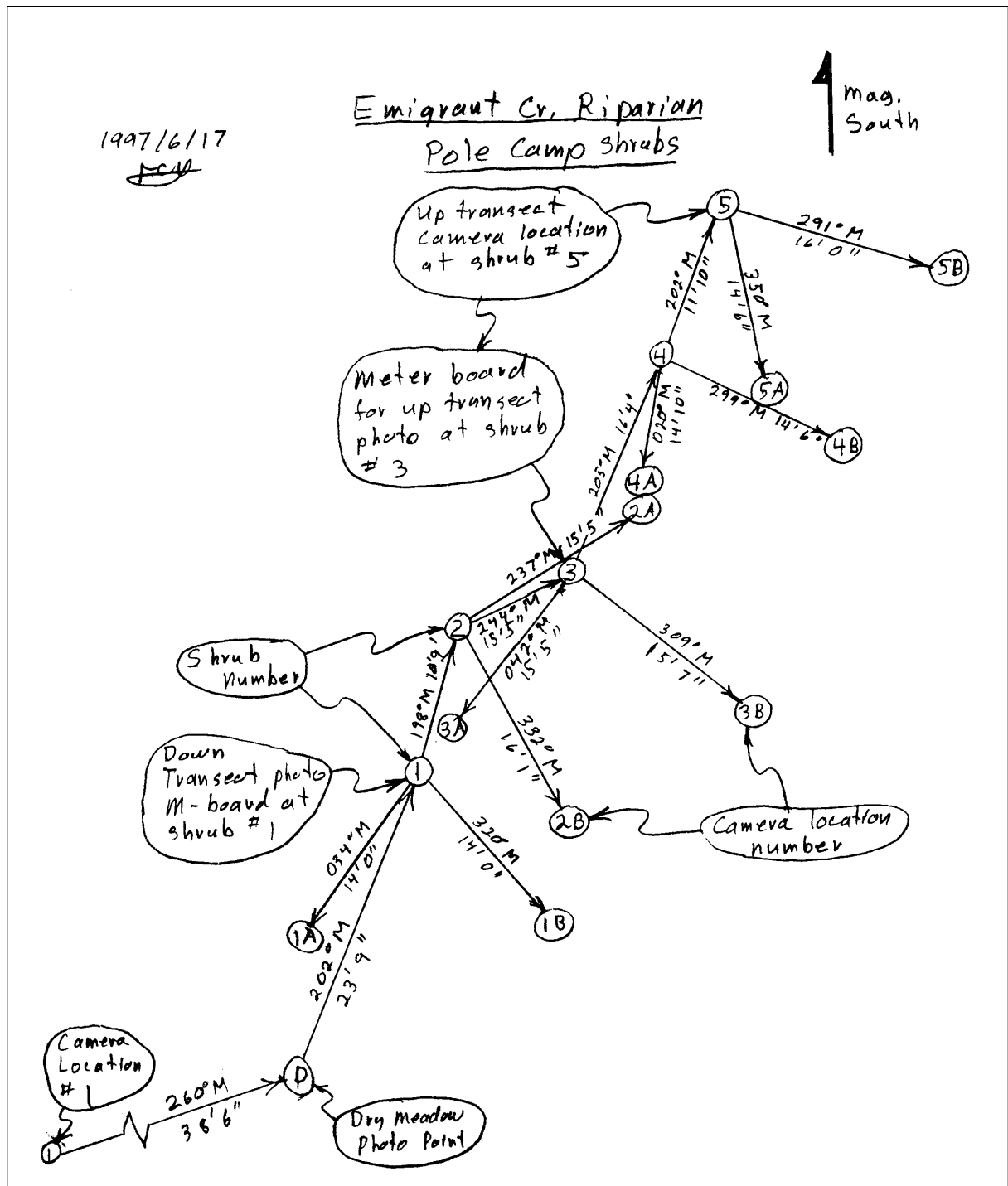


Figure 65—Details on the Pole Camp shrub profile transect. Instructions begin at camera location 1 for Pole Camp monitoring. The dry meadow photo point has been used as a camera location for a view down the transect (fig. 64). Direction in magnetic degrees and distance are shown for the five shrubs and the 10 camera locations.

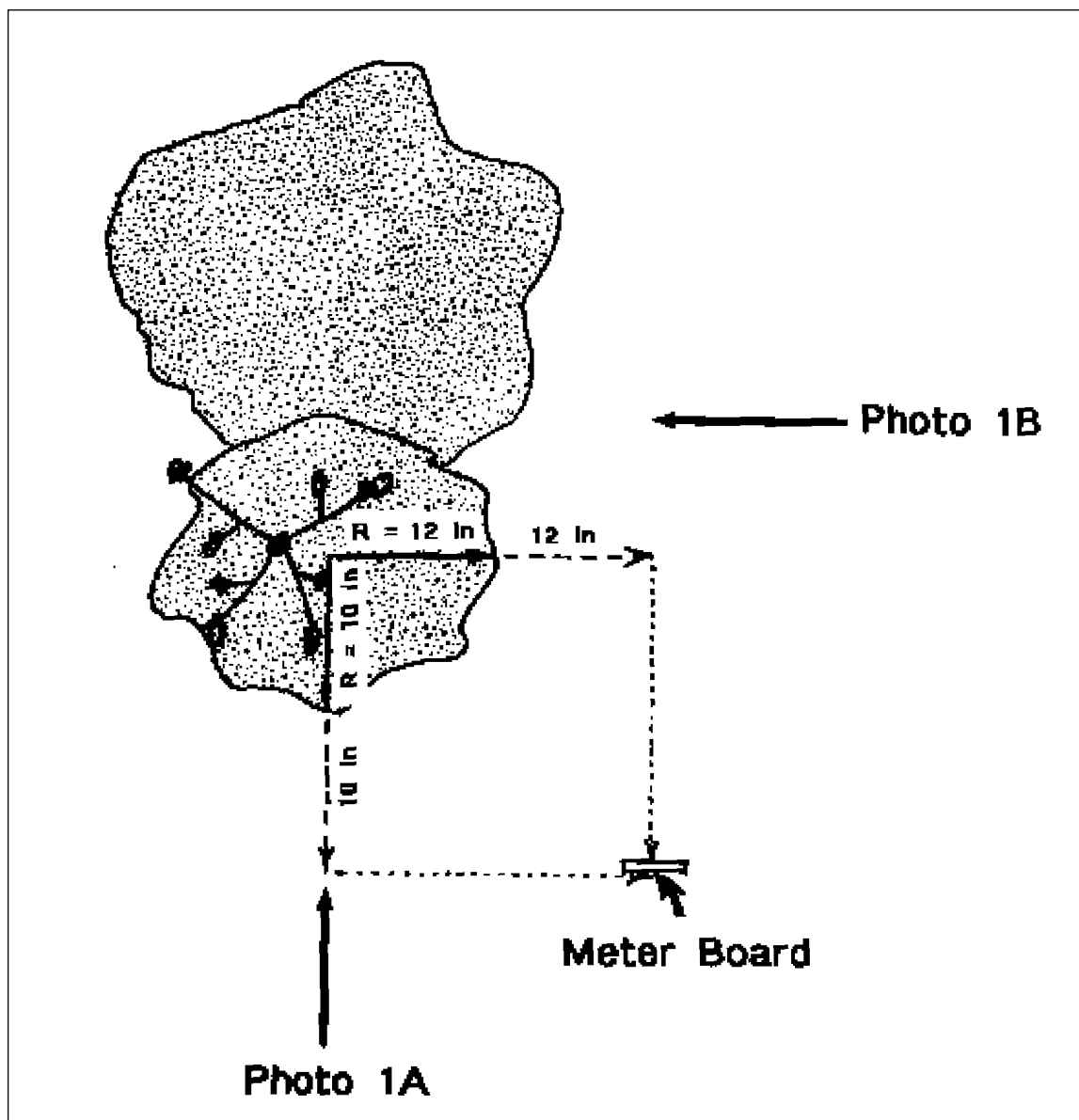


Figure 66—System for location of a meter board when photographing shrub profiles. Figure 67 shows the views from photo 1A and photo 1B. Locate the board as follows: Measure the shrub radius in two directions at 90 degrees to correspond to the direction of photographs (12 in and 10 in). Move out from the shrub the same distances (12 in and 10 in) and locate the meter board at the intersection of the distances. This will place the meter board far enough to the side and front of the shrub so that the shrub can grow and still be analyzed with a grid.

SHRUB PHOTO TRANSECT	
Date <u>97/6/17</u> Cluster <u>1</u> Transect <u>①</u> 2 3 4 5	
Area <u>Snow Mt. Dist</u>	
Allot. <u>Pole Camp</u>	
Investigator: <u>FCH</u>	
Season of use <u>late</u>	
Grazing system: <u>Rest -</u>	
<u>rotation - 3 pasture</u>	
Animals <u>Cow / calf</u>	
Direction <u>202° N</u>	
Distance <u>23' 9"</u>	
Shrub 1A Direction <u>214° M</u> Distance <u>14' 0"</u> Comments <u>SALIX</u> <u>GEYERIANA</u> <u>Browsed 2 yrs ago.</u> <u>CAREX SIMULATA,</u> <u>POA PRATENSIS &</u> <u>POTENTILLA</u> <u>PLABEILIPOLIA</u> <u>suggest a dryish moist</u> <u>meadow</u>	
Shrub 1B Direction <u>140° M</u> Distance <u>14' 4"</u> Comments <u>SALIX</u> <u>GEYERIANA</u> <u>Browsed 2 yrs ago;</u> <u>2 shrubs</u>	

Figure 67—The filing system form "Shrub Photo Transect" (app. C) showing Pole Camp willow transect 1 and both views of shrub number 1. The top photograph (A) was taken down the transect and B and C are of shrub number 1. Notes on the vegetation and item photographed are made opposite each photograph. The form provides for two views each of 10 shrubs with views down the transect from each end.

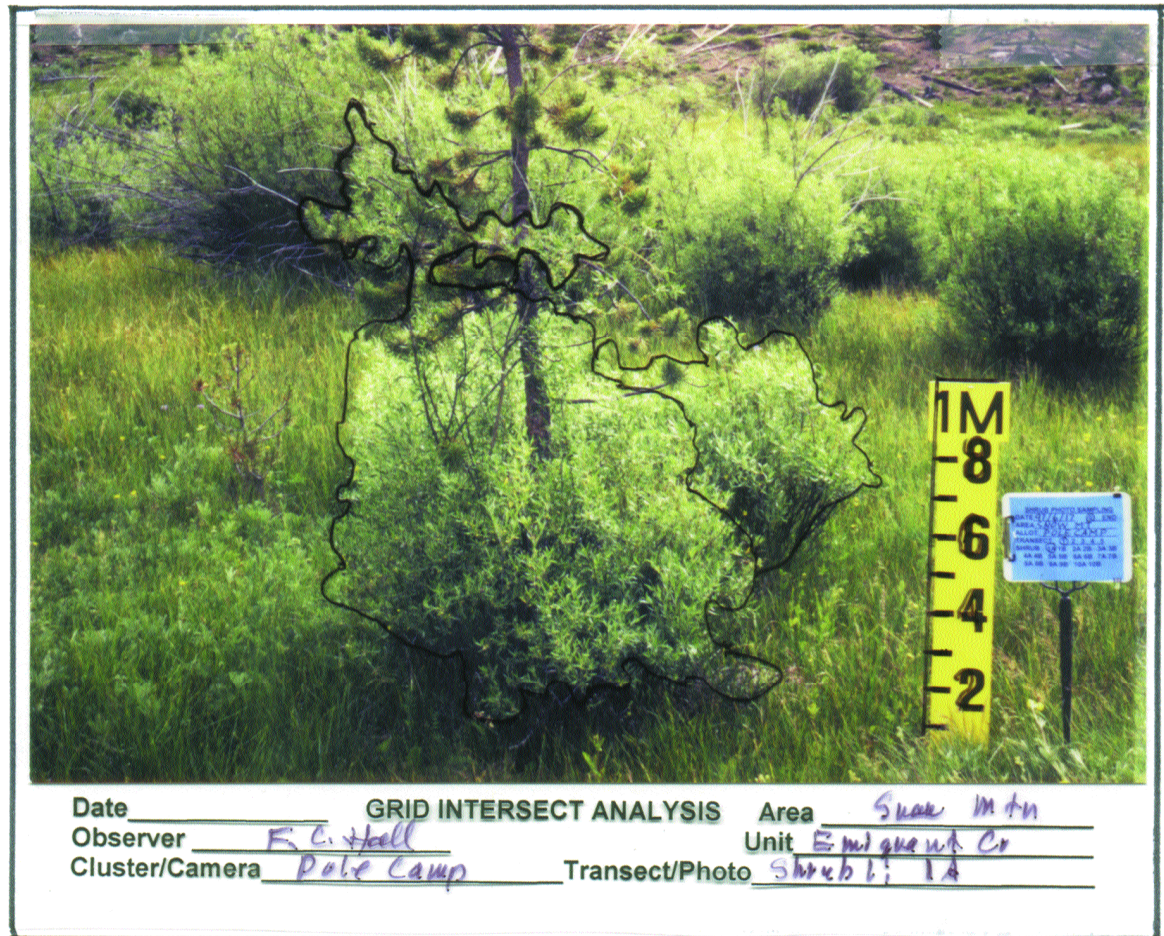


Figure 68—Grid analysis of shrub 1, view A, on the Pole Camp shrub profile transect. The outline form has been placed on the photo, information filled in, and the meter board marked. Outline as carefully as possible the shrub profiles. Do the same for photo B of shrub number 1 (fig. 69).

5. Try to select a single shrub or several shrubs separated from other shrubs in the camera view. If shrubs grow in profile area, their outer crown periphery may become difficult to separate from adjacent shrubs. Color photographs greatly aid in shrub-profile delineation.
6. Aim the camera so that the meter board is in the extreme left or right of the view (figs. 67 through 69). The shrub grid analysis overlay shows the meter board at the sides. Next, orient the camera so that the bottom of the meter board is just **above** the bottom of the camera view (figs. 67 through 69). Thus, a maximum amount of photo is allocated to current and future profile area of the shrub.

Notice in figures 67 through 69 the relation between placement of the meter board bottom about 2 dm below the bottom of the shrub and orientation of the camera at the bottom of the meter board. The objective is to document change in shrub profile both upward and outward.

When tall shrubs require double meter boards, such as in figure 31, the boards may be placed centered in front and the 2-m board grid (board in the center) used for analysis.

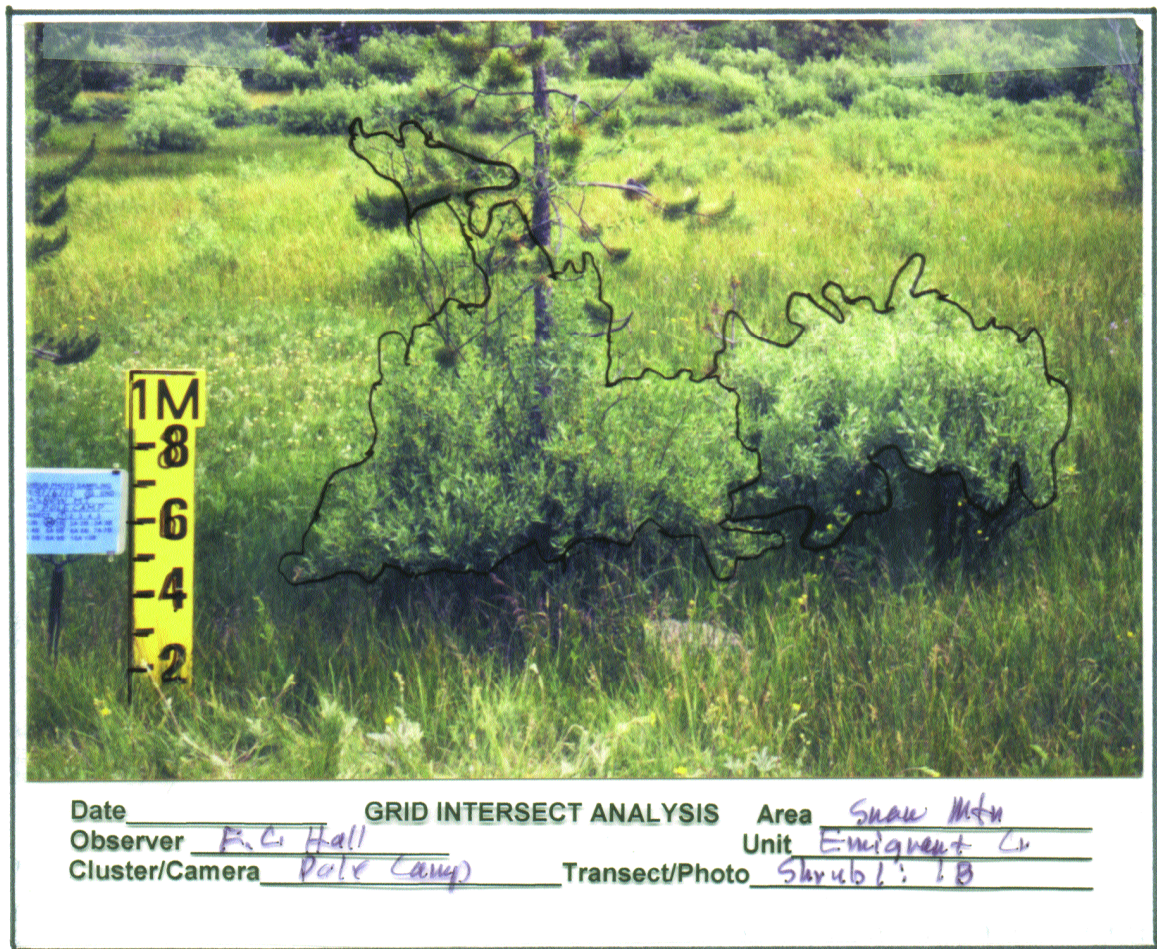


Figure 69—Outlines of view B, shrub 1, on the Pole Camp shrub profile transect. When two shrubs are present, separate their outlines as shown. Information on the bottom of the clear plastic overlay must be filled in for each photo. Remember to outline and mark the meter board.

7. Fill out and place the photo identification card, "Shrub Photo Sampling," next to the meter board (figs. 67 through 69). This is essential for labeling each slide, negative, or digital image.
8. Focus the camera on the meter board to assure greatest depth of field for the shrub. Then swing the camera either left or right to place the meter board at the side.

Equipment

The following equipment is required for shrub profile sampling:

1. Camera or cameras with both color and black-and-white film or digital camera
2. Forms from appendix B for photo and transect identification: "Shrub Photo Sampling" printed on medium blue paper, data and photo-mounting form "Shrub Photo Transect" printed on medium yellow paper, the "Grid Analysis Outline" printed on clear plastic, and "Analysis Grid-Shrub Analysis" adjusted in size and printed on white paper
3. Meter board (app. C)
4. Clipboard and holder for the photo identification sheets (app. C)

5. Fenceposts and steel stakes sufficient for the number of transects desired: 1 fencepost and 2 steel stakes per shrub; for a 10-shrub transect, 10 fenceposts and 20 stakes required; include a pounder
6. Compass and 100-ft tape
7. Metal detector for finding camera locations

Technique

The technique for shrub profile monitoring combines a transect system with principles discussed under “Photo Grid Analysis,” above. A primary objective is to monitor **change** in shrub profile area and not to measure canopy cover of shrubs or shrub profile area per acre. Shrubs therefore are objectively selected for photography. The following technique emphasizes this selectivity.

1. Locate the area of consideration. Walk the area to select shrubs to be monitored. In many cases, shrub distribution does not lend itself to straight line transects, particularly in riparian areas with winding streams. Ask, “Why am I concerned with change in shrub profile area?” Is it to appraise utilization, assess vigor, or document increase in profile area? Is the location of shrubs important, such as shade along streams?
2. Mark each shrub to be photographed with steel fenceposts or a combination of posts and stakes: a fencepost to mark the meter board and two more posts or stakes to mark camera locations that view the shrub at 90 degrees (two different sides). Whenever possible, select a single meter board position that will accommodate the two camera locations (figs. 66 through 69). Measure distances from the photo point to camera locations.
3. After marking all the desired shrubs, diagram the transect layout (fig. 65). Take a direction and measured distance from the witness mark to the first shrub meter-board position. Diagram the two camera locations with direction and measured distance from the meter board. Then take direction and measured distance from the first shrub meter board to the second, documenting direction and distance of the camera locations. Continue to the end of the transect. Remember to indicate magnetic or true north.
4. When ready to photograph, fill out the filing system form, “Shrub Photo Sampling,” for photograph identification (app. B) as shown in figure 67.
5. Take a general picture of the transect by setting the meter board at shrub 1 (fig. 67A). Stand 7 to 10 m from the board and place the “Shrub Photo Sampling” form in view (fig. 67A). Stake the camera location and add to the sampling layout diagram. Reference it to the witness location.
6. For each shrub, place the photo identification form, “Shrub Photo Sampling,” next to the meter board (fig. 67, B and C). The form has a shrub number and letter for 10 shrubs. Match the shrub number and letter on the form with the transect diagram and circle it (in fig. 67B, 1A is circled).

7. Photograph the shrub. Then move to the second camera location, turn the meter board and the photo identification form to face the camera, cross out the last shrub view on the form, and circle the current one. In figure 67C, 1A is crossed out and 1B is circled.
8. Make notes of what is in the view (fig. 67). Identify the shrub, list herbaceous vegetation, and note anything of interest, such as browsing and by what.
9. Then move to the next shrub and repeat the process until completed.
10. Mount the photographs as shown in figure 67. The filing system form, "Shrub Photo Transect," is designed for 3- by 4½-in photos.
11. Conduct grid analysis of the pictures as discussed next.

Shrub Profile Grid Analysis

A complete review of the "Photo Grid Analysis" section, above, is necessary to do this evaluation. Only highlights specific to shrub-grid interpretation are presented here.

Print the photographs to be analyzed, in color, at 8 by 12 in. From appendix B, select the "Grid Analysis Outline" form (fig. 54) and duplicate on clear plastic. Fill out all information at the bottom of the outline form. The completed outline becomes a data file and must be identified. Tape the outline form to the photograph along one edge or top so that the outline can be lifted for close inspection of the photo and then replaced exactly (figs. 68 and 69).

Outline the shrub or group of shrubs in the photo. Do not try to guess the outline of a shrub hidden behind another. Outline, only what can be seen. Be as precise as possible.

Next, adjust the grid (with meter boards at each side) for shrub analysis (app. B) to exactly match the outline meter boards as discussed in "Photo Grid Analysis" (figs. 56 and 57). Tape the outline form to the grid (fig. 70).

Count intersects within each outline including intersects falling under an outline line (figs. 58 and 67), and enter on the filing system form, "Photo Grid Summary" (fig. 71). Please refer to the section "Photo Grid Analysis," and within it "Analysis of Change, Observer Variability," for a discussion of what constitutes a significant change in shrub profile area.

Test your own observation skills. Count grid intersects in figure 70 and compare to the results shown in figure 71. Expect a difference of three to six grid intersects.

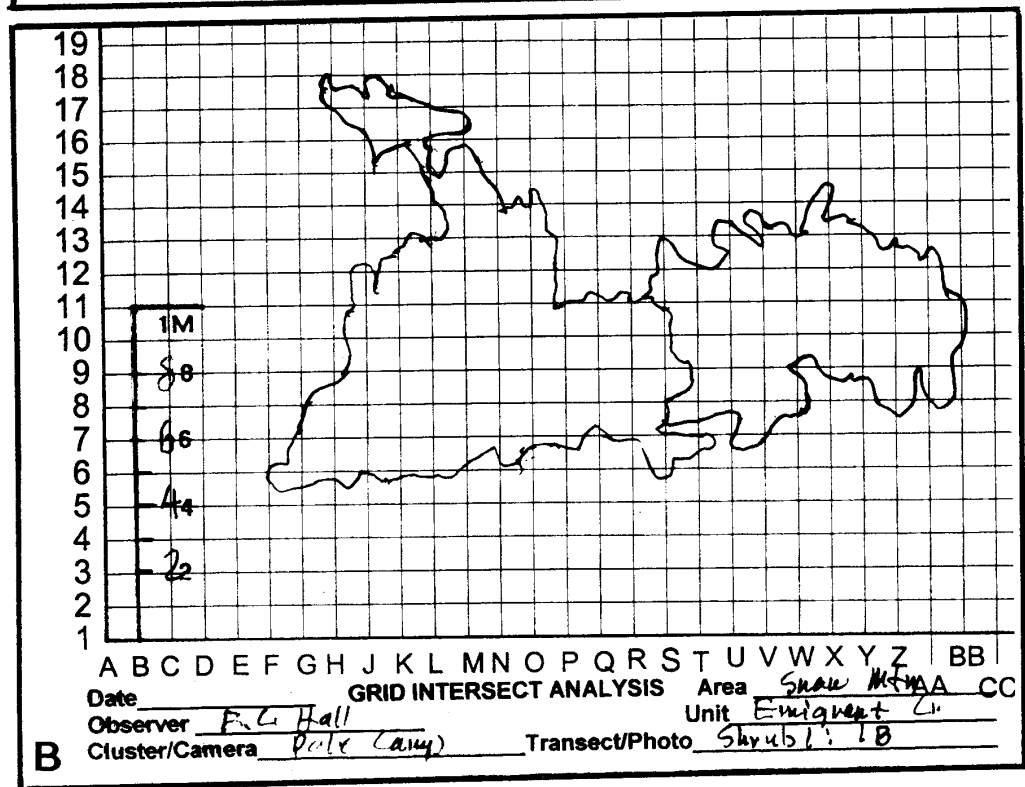
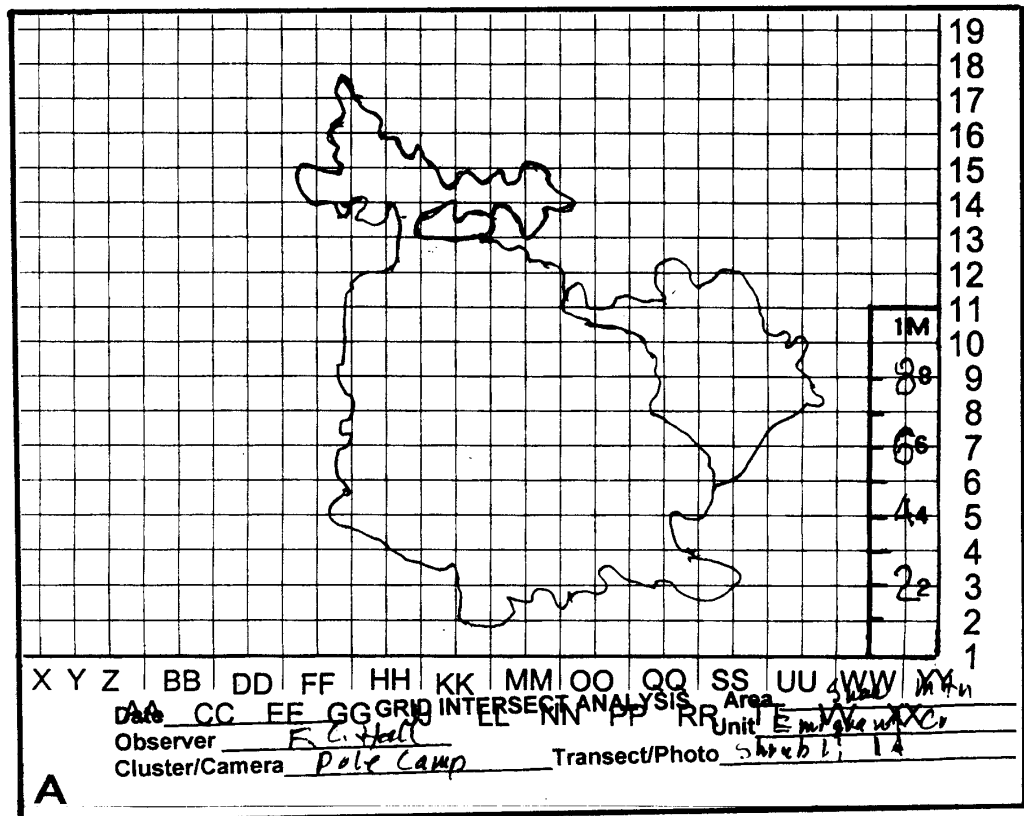


Figure 70—Grid outlines for shrub 1, views A and B on the Pole Camp shrub profile transect. Grids have been adjusted for size by the outlined meter board. Outlines are then taped to the grid. Count the grid intersects and record on the filing system form "Photo Grid Summary" (fig. 71).

PHOTO GRID SUMMARY

[illegible]

CONTINUE

Transect Photo Sampling

The historical purpose for transect sampling was to document change in vegetation and soil caused by livestock grazing, commonly called range trend analysis (Parker 1954, Parker and Harris 1959). The Parker three-step method (Parker 1954) was designed for this purpose. It used a 0.75-in diameter loop dropped at each foot along a 100-ft line. The system was supplemented by photographs taken of the transect from the 0- and 100-ft ends with additional closeup pictures of a 3- by 3-ft square at each end.

By 1970, the system had been installed at 16,500 locations and reviewed by the Rocky Mountain Forest and Range Experiment Station (Reppert and Francis 1973). The findings suggested that photographs are the most valuable part of the system. Photos (1) documented transects across two or more sites, (2) helped to evaluate species identification, and (3) were used to validate interpretation of measured data through a four-step process.

Based on these findings, Hall (1976) developed a photo monitoring method, which has been updated for presentation here.

Five kinds of photo transects will be discussed and illustrated: (1) 1-ft² frequency photographed with a stereo attachment on the camera (or photographed without the stereo), (2) nested frequency using four plot sizes in a 0.5- by 0.5-m frame, (3) 1-m² plot frame photographed at an angle, (4) vertical photographs of tree canopy cover, and (5) measurement of herbaceous stubble height using the Robel pole system. All five may be applied on top of any three-step transect or they may be installed in new areas for any documentation of ground vegetation and soil surface monitoring. The following factors apply to any transect system.

Locating a Sample Area

The introduction to this appendix discussed selection of an area and when to photograph. Probably the most important of these suggestions was to **define a purpose** for monitoring. In addition, several other elements might be considered: livestock grazing, wildlife distribution, and planned and unplanned disturbance because the investigator must be guided by factors not under their control. Transect photo monitoring is not limited to livestock effects analysis.

Livestock considerations—The three-step sampling system (Parker 1954) was designed to evaluate livestock grazing impacts on vegetation and soil. Instructions called for one to three transects. The objective was to attain 60 or more hits on vegetation with a 0.75-in loop. If more than 60 hits were not recorded on the first transect, then a second or third transect was installed until either 60 hits were obtained or three transects were established. Each set of transects was called a cluster. Nested frequency, also an appraisal tool for livestock impacts, requires five transects.

Location of transects has three primary requirements:

1. The site under each transect must be homogeneous. If an entire cluster of two to five transects is to represent a single site, vegetation and soil surface conditions under each of the transects must be homogeneous and similar to each other.

2. The kind of site selected should be one sensitive to livestock use. For example, in a complex meadow where dry meadow around the edge grades into moist meadow, which finally grades into wet meadow, the most desirable sampling location would be in the dry meadow because it is most sensitive to livestock use.
3. Locate the sample in an area best representing current livestock utilization.

These three criteria generally will satisfy the objectives of monitoring management effectiveness by photographic documentation of conditions; evaluation of sensitive areas which, when indicating an upward trend, imply that less sensitive areas are in a faster upward trend (or are in better condition); and distributing sampling locations on a least-cost or cost-effective basis.

The most difficult aspect of sample location deals with suitable representation of current livestock activity. Samples on a range area (allotment) grazed season long may not be adequately located or sufficient in number for the same area under rest-rotation grazing. Furthermore, locating a transect may be difficult in an allotment that has had a major change in management—for instance, from season long to rest-rotation—until livestock distribution over an entire grazing sequence has been evaluated. Selection of a site sensitive to livestock use in a unit under spring grazing might be quite different from that selected in the same unit under fall grazing.

Locating a sampling site requires a great deal of professional expertise liberally mixed with artistic finesse. Investigators must understand seasonal and topographic effects on livestock distribution, seasonal effects on plant community, and soil sensitivity to grazing, and they must have a critical eye for site homogeneity.

Wildlife considerations—Locating transects or clusters suitable for monitoring impacts of wildlife, including big game, on vegetation and soil requires knowledge of animal distribution and most critical season of use. Wild animals may be year-round residents or may be moved by snow or other weather conditions. The investigator must determine which season is most critical and where the animals are at that season for both transect or cluster location and season of sampling.

Planned disturbance—Planned disturbance sampling is where a treatment is prescribed and the area is sampled before and after implementation. Figure 21, a logged and precommercially thinned ponderosa pine stand, is an example of planned disturbance sampling. Two important factors to consider are (1) where to locate the sampling transects so they best represent effects of the treatment, and (2) use of camera location and photo point stakes pounded flush with the ground to resist mechanical displacement. These require use of a metal detector to relocate (White's Electronics, Inc. 1996). Use maps with directions and measured distances to aid in relocating stakes.

Fenceposts, flimsy or strong, used in any kind of disturbance other than prescribed fire, tend to do two things: (1) they bias operators of equipment to stay away from the posts, and (2) they may be removed completely from their location making exact replacement of camera locations and photo points nearly impossible. Prescribed fire

sampling, however, might well use fenceposts, particularly for photo point locations. Pound the fenceposts down to the exact height of the meter board. Then photograph the fire as it passes the fencepost to document fire intensity, flame length, and burn aftermath. Coordination with the fire boss on transect layout and direction given topography and fire behavior might be advisable.

Unplanned disturbance—Unplanned disturbance, such as fire, blowdown, or flood, generally preclude predisturbance transect or cluster installation. Care should be taken to select areas where change is most critical or where postdisturbance activity, such as salvage logging, most likely would occur. If activity is probable, consider use of steel stakes driven flush with the ground and a metal detector to find them

Maps—Each cluster should have two maps: one to find the monitoring area (fig. 72), and another of the cluster layout (fig. 73). A blank form for “Sampling Site Description and Location” is in appendix B.

To use the “Sampling Site Description and Location” form shown in figure 73, circle the type of sample in the (top line), in this case “1 sq. ft.” Most items are self-explanatory such as entering the date installed, the name of the area, and the allotment. Grazing system should be entered, such as season long, enclosure, deferred-rotation, elk fall range, deer fawning area, etc., and the date when initiated or season of use. Circle the kind (or kinds) of animals using the sample area.

Describe location with both standard survey nomenclature and a description of where the sample is located in relation to land, vegetation, or road features. Describe it as if you were telling someone how to find it. Then diagram the sample layout in the map space (fig. 73). Note, location of identifiable features, compass headings as either true (T) or magnetic (M), measured distances, transect location and orientation, and the 0- and 100-ft ends. With transects laid end to end, continue the sample layout map on the back of the form (fig. 74).

The front side of the form is for a site description (fig. 73). Enter elevation and percentage of slope. Then circle the item best describing aspect, slope position, micro (within one acre) and macro (within one section) topography, kind of soil deposition, soil parent material, and kind of restriction to rooting depth (if there is a restriction within 5 ft of the soil surface). Enter depth to restriction and rooting depth. Circle items describing soil compaction, soil stone, and texture. A space is provided for comments not otherwise addressed.

Note: A single site description presumes all transects are on the same site. If they are not on the same site, fill out a new form for each different site.

Choice of film—Choice of film is a concern. Photo trend sampling is designed to measure change in vegetation and soil over time. Photographs taken 5, 10, or 15 years earlier are compared to current photographs. Film therefore must be selected that will retain its sharpness and clarity for a long time. Black and white film should be the first choice, but it can be supplemented by color film.

Text continues on page130.

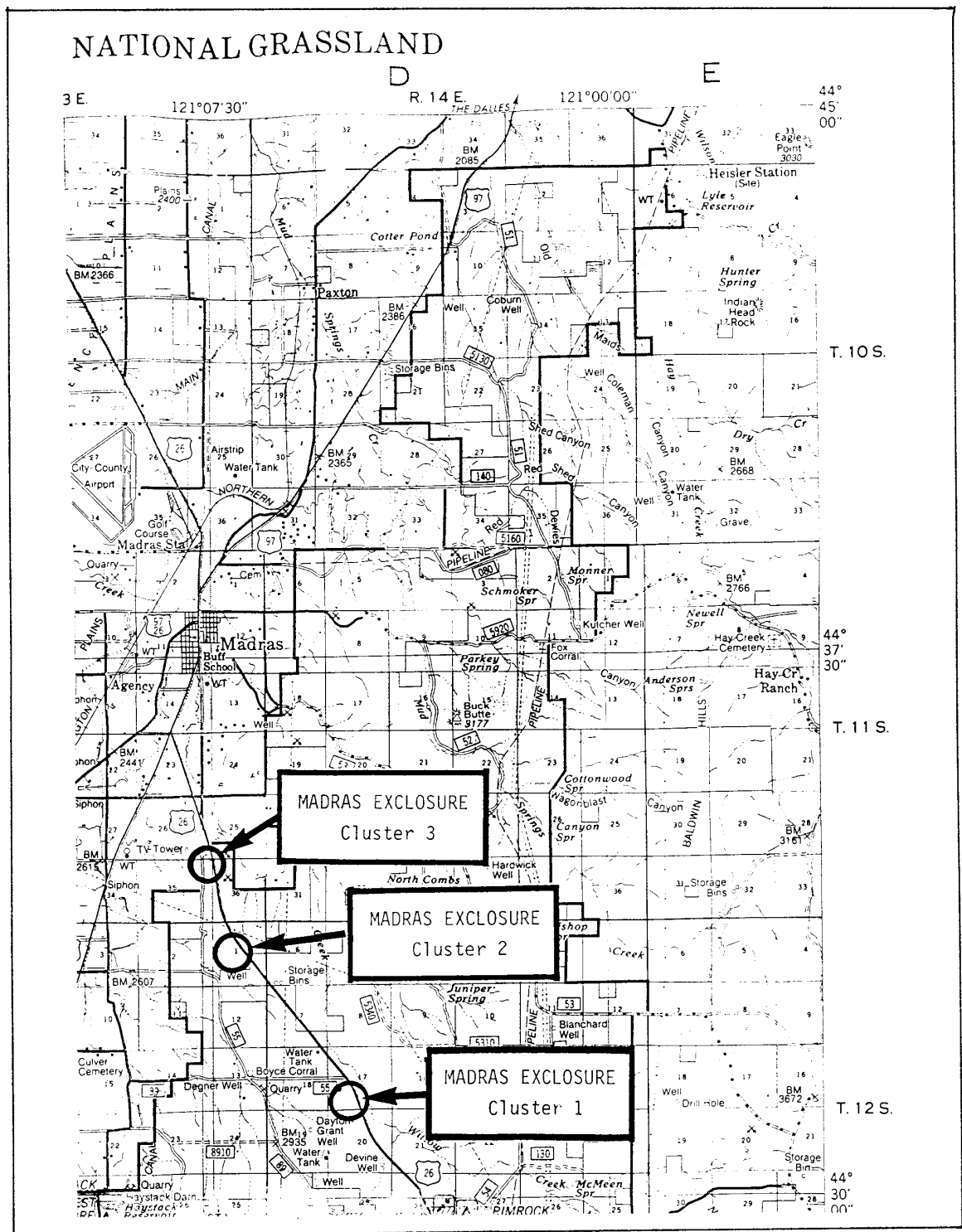


Figure 72—Ranger District map locating the Madras Exclosure and three range trend sampling clusters having three transects each in the Crooked River National Grassland. Cluster number 3, transect 1, will be used to illustrate photo sampling of square-foot frequency, nested frequency, and square-meter systems.

SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft Nested Freq. 1 sq.m. Robel Pole Shrub Form _____

Date 1997/3/22 Site Data: Elev. 2775 % slope 8
 Area Crooked River N.G. Slope aspect: N NE E SE S SW W NW
 Allot. Madras Slope position: top up 1/3 mid low 1/3 bottom
 Cluster No. 3 Micro topography: convex flat concave
 Transects: 1 2 3 4 5 Macro topography: flat undulating rolling
 Plant community ARTL steep rough broken
AGSP/POSA3 Geology:
 Grazing system: Deposition: wind stream lake colluvial
 Type Exclusion Date 1954 residual
 Type _____ Date _____ Material: limestone mudstone sandstone
 Type _____ Date _____ granite serpentine diorite
 Kind of animal: cattle sheep basalt andesite rhyolite
 horses goats deer tuffaceous cinders pumice ash
 elk jack rabbits Soil:
 Restrictive layer: absent clay pan bedrock
 cemented
 Location: T. 11S R. 13E Surface compaction: none moderate severe
 Sec. 36 NW of NW Soil profile stone: absent grave stony
 Description: US hiway 20 Soil texture: sandy loamy silty clayey ashy
at Crooked River N.G. Other notes: Livestock excluded when
sign; 2.1 mi. from junct. hiway was fenced in 1954
US 97 & US 26 S. of Madras.

MAP

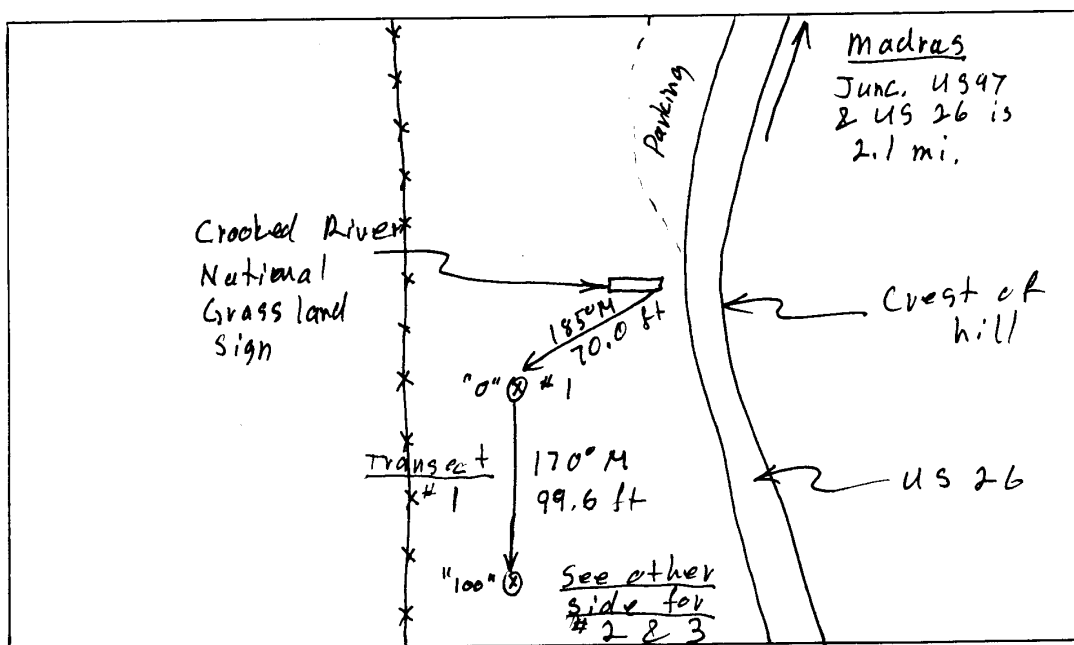


Figure 73—Filing system form "Sampling Site Description and Location" for finding the Madras Exclusion cluster 3. The first line lists a choice of sampling systems. Circle "1 sq. ft." Fill in the required information as shown. After laying out the photo sampling system, plot it in the map space provided. If several transects require more space, use the form back (see fig. 74). Take direction and measured distance between the witness point (Crooked River National Grassland sign) and the first transect (185 degrees magnetic, 70.0 ft). Next take direction and measured distance to the 100-ft end of the tape (170 degrees magnetic, 99.6 ft). The 100-ft end-stake is at foot mark 99.6. See figure 74 for continuation of the map.

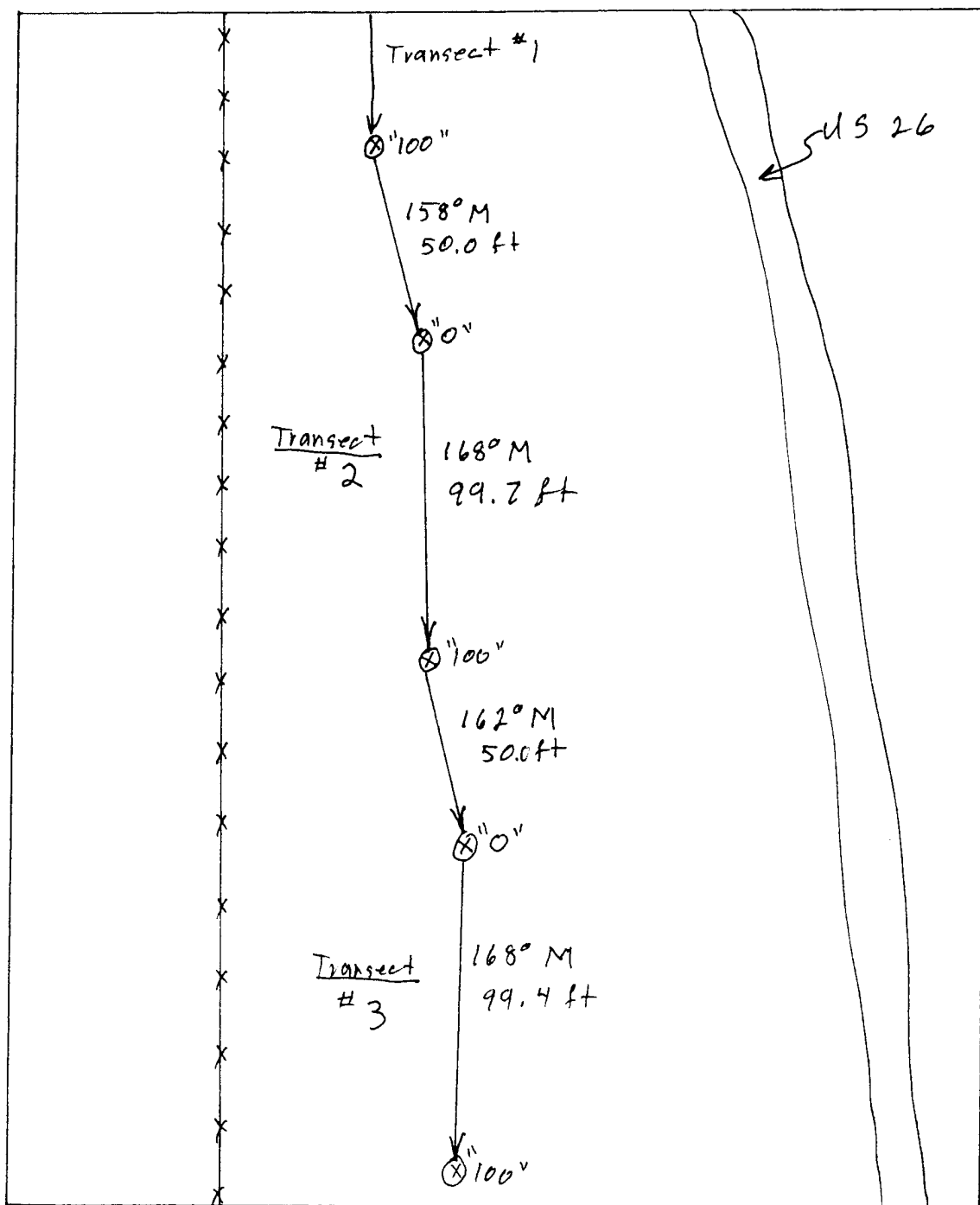


Figure 74—Map on back of figure 73 showing location of transects 2 and 3. When distances are measured, as shown here, use feet and tens of feet, for example, 50.0 ft between transect 1 at its 100-ft end and transect 2 at its 0-ft start. Then 99.7 ft between the 0-ft stake and the end stake located at foot mark 99.7 for transect 2. Continue for transect 3.

Film with an ISO rating of 100 or better should be used, particularly in forested conditions. A film of ISO 160 will have good contrast and fine grain. ISO ratings up through 400 may be considered. Higher ISO ratings mean smaller f-stops (higher f-number) and produce greater depth of field. Photos taken with films rated higher than ISO 400 will be grainy and nullify lens sharpness.

Digital cameras should have 2.1 megapixels or more. Graininess of images from cameras of 1.6 megapixels or less usually precludes accurate analysis of prints.

Season of year—Season of year for photography depends on objectives and past history. Reppert and Francis (1973) recommend repeat sampling within plus or minus 2 weeks of the original date. When placing the 1-ft², nested frequency, or 1-m² transects on top of existing three-step transects, date of sampling should be governed by the original readings. For newly established transects, date of installation should be governed by plant growth development (phenology) and season of critical concern. In general, a good time to sample is when plants are well into flowering or just completing their maximum seasonal growth.

Transect Installation

Document the direction and measured distance from a witness site to the 0-ft end of the first transect. Set a fencepost to mark the transect. Drive stakes to leave about 6 in aboveground onto which the 100-ft steel tape is clamped. Vice grips are very convenient. The 0-ft mark on the tape is aligned with the first angle iron stake and clamped in place. A mid-stake is located between foot marks 50 and 51, and the end-stake is located between the 99- and 100-ft marks and clamped in place. Make sure the zero end is labeled and that 0- and 100-ft ends are properly documented on the map (figs. 73 and 74). Mark both ends with fenceposts for easy relocation.

In disturbance sampling, presample the area with 6 in of stake aboveground for fastening the steel tape. After sampling, drive the stakes flush with the ground. For postsampling, plan on adding a stake nested inside the flush stake extending 6 in aboveground on which is clamped the 100-ft steel measuring tape. Relocation of the flush-pounded stakes will probably require a metal detector (White's Electronics, Inc. 1996).

From the 0-ft stake, record direction (note true or magnetic) and measured distance to the 100-ft steel stake (figs. 73 and 74) for each transect. Tie the transects together for easy relocation by direction and measured distance from one to another (fig. 74). Always record location of both the 0- and 100-ft ends.

Every transect should have a photograph taken from both the 0- and 100-ft ends (figs. 75, top, and 77). Each photograph down the transect should be identified with the cluster-transect form (app. B). Place the identification form at 15 ft, a size control board at 33 ft, hold camera at eye level, and photograph the transect with the camera focus system on the size control board's "1M" and the photo identification sheet at the bottom of the picture (fig. 75). Repeat this procedure at the 100-ft end of the tape by placing the identification sheet at foot mark 85 and the size control board at foot mark 67 (fig. 77).

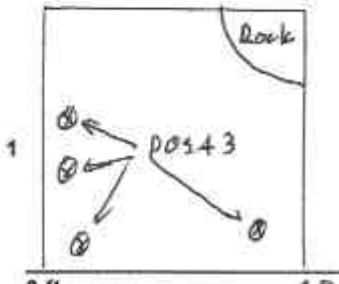
Text continues on page 134.

PHOTO TREND SAMPLE - 1 SQ. FOOT
 Date 1997/3/22 Cluster 3 Transect (1) 2 3 4 5

Area Crooked River N.G.
 Allot. Madras
 Investigator FEH

Season of use none
 % use —
 Grazing system exclusion

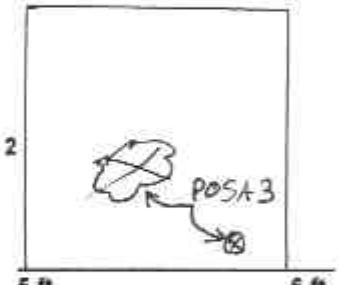
Remarks Highway exclusion



Soil surface: B G R L C
 Line Intercept:
 Species From To Feet







Soil surface: B G R L C
 Line Intercept:
 Species From To Feet




Figure 75—Filing system form "Photo Trend Sample - 1 sq. ft." illustrating its use (continued in figs. 76 and 77). Two additional forms are shown: transect identification (top picture) and plot identification (lower two pictures). Fill out required information on each form: CRNG (Crooked River National Grassland), Madras Exclusion, cluster 3, transect 1, date, and notes. Photograph the transect from the 0-ft (top picture) and the 100-ft ends (fig. 77). Then place the square-foot plot at the specified foot mark (plot 1 from 0 to 1 ft). Fill out the plot identification form, circle plot 1, and place in view. Soil surface items are B = bare ground, G = gravel, R = rock, L = litter, and C = cryptogamic crust. Circle each item occurring in the plot.

PHOTO TREND SAMPLE - 1 SQ. FOOT

3

Nothing

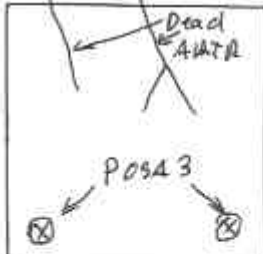
10 ft 11 ft

Soil surface: **B G R L C**

Line intercept

Species	From	to	feet
ARTR	12	15	3

4



15 ft 16 ft

Soil surface: **B G R L C**

Line intercept

Species	From	to	Feet

5



20 ft 21 ft

Soil surface: **B G R L C**

Line intercept:

Species	From	To	Feet
ARTR	22	23	1



Figure 76—Second page of the "Photo Trend Sample - 1 sq. ft." form with provision for three more sample plots. Notice under plot 3 that ARTR (*Artemisia tridentata* Nutt., big sagebrush) intersected the tape between foot marks 12 and 15 for 3 ft of line intercept. Intercept is counted between the first foot mark from one plot to the next; in this case, from foot 10 to 15. ARTR also intercepted the line as shown under plot 5. Additional pages provide for all 20 ft² plots. Other species are AGSP (*Agropyron spicatum* vis. *Pseudoroegneria spicata* (Pursh) A. Love., bluebunch wheatgrass), and POSA3, (*Poa secunda* J. Presl., Sandberg's bluegrass).

A black and white photograph of a desert landscape. In the foreground, there is a small, rectangular sign with some text, partially obscured by low-lying desert vegetation. In the background, a tall, slender antenna tower stands prominently against a clear sky. To the right of the tower, there is a large, dark, rectangular structure, possibly a building or a large sign. The overall scene is arid and open.

Species	Frequ. Interc.
POSA3	17
AG3P	5
LOMAT.	2
PHLOX	
BASA	
SIHY	1
STOC	
ARTA	6
PUTA	1
CHNA	

Logging _____
Fire _____
Revegetation _____
Insects _____
Wildlife deer, few pronghorn antelope
Other _____

	<u>This Yr.</u>	<u>Last Yr.</u>	<u>Two Yrs.</u>	<u>Three Yrs.</u>	<u>Four Yrs.</u>
Temp	+0-	+0-	+0-	+0-	+0-
Ppt.	+0-	+0-	+0-	+0-	+0-

Apparent range condition Good
Apparent range trend Static

Hydrolytic exposure

Species	% Use
_____	_____
_____	_____
_____	_____

133

The cluster-transect identification form (app. B) is used for both the 0- and 100-ft ends of a transect. Print information in large letters similar in size to those on the form. This size can be read on the photographs (figs. 75 and 77). Circle "0" in upper right corner for the 0-ft end (fig. 75). After taking the picture, cross out the "0" and circle the "100" for the picture at the 100-ft end (fig. 77).

A size control board is required (specifications in app. C). The illustrations in figures 75 and 77 have a size control board marked with "1M" (indicating 1 m) and decimeters labeled as 2, 4, 6, and 8. Use of a size control board has several purposes: (1) depth of grass, height of shrubs, or other items can be estimated; (2) when the camera focus system is placed on the "1M," pictures will be consistently oriented both horizontally and vertically for easy comparison; (3) focusing the camera on the "1M" assures sharp picture clarity and greatest depth of field at the meter board; and (4) grid analysis may be performed if desired.

General transect photographs from the 0- and 100-ft ends should be taken with the three-dimensional attachment (fig. 78) on 1-ft² transects (fig. 75 through 77) if available, otherwise with a 50-mm lens. For other sampling, use a 50- or 35-mm lens for nested frequency, 1-m², and canopy cover. A 50-mm lens should be used with Robel pole to adequately document pole divisions. In addition, a standard photograph (without 3-D) is highly recommended on 1-ft² transects to encompass a broader horizon of the plant community and, when color slides are produced, to use in slide talks dealing with range trend (fig. 77).

Transect data forms—Forms are provided in appendix B. The series of "Photo Trend Sample-..." forms double as both data forms and a filing system for the photographs. Another form identifies the cluster and transect photograph in letters large enough to be read on the negative. The plot identification form identifies each plot and labels it on the photo negative. Because these forms are used in the field, they should be printed on a paper color that is easy on the eyes and will not burn out in photography under direct sun. "Photo Trend Transect" forms should be printed on medium yellow paper, such as Champion Goldenrod® or Hammermill Copy Plus Goldenrod®, which have been found quite acceptable. Light yellow paper, common in the office environment, is less satisfactory. Transect and plot photograph identification forms will resist fading out under direct sun if printed on medium blue color paper. Tests have shown that Hammermill Brite Hue Blue® or Georgia Pacific Papers Hots Blue® are most useful.

One-Square-Foot Plot Transect

One-square-ft sampling employs a square-foot plot placed every 5 ft along a 100-ft transect for a total of 20 plots. It is designed to document changes in species, their density, and frequency as a means to estimate change in vegetation and soil surface conditions.

Concept

Each 1-ft² plot is photographed in stereo to provide a permanent, visual record of vegetation and soil surface conditions. At the same time, each plant species rooted in the plot is recorded and presence of bare soil, gravel (1/8- to 3/4-in diameter), rock, litter, and cryptogams are noted. At a later time, the same transect will be

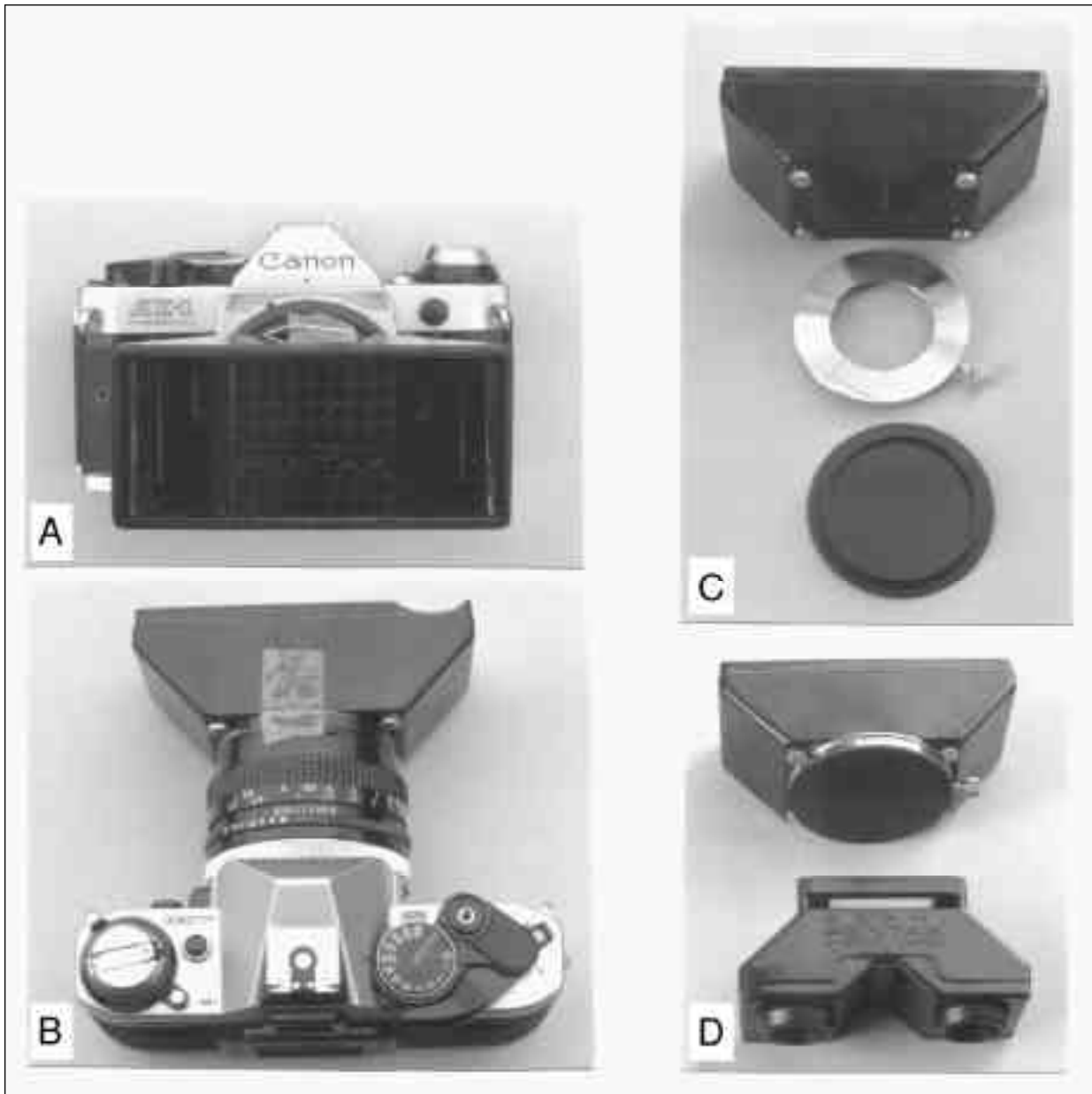


Figure 78—Camera using a 50-mm lens with stereo adapter mounted (**A** and **B**). This a Honeywell Pentax Stereo Adapter® with the connection plate removed because it will not fit on a Canon® camera. (**C**) The connection plate and its cover are shown removed. In **B**, the stereo system has been taped to the camera over a filter. It must be aligned horizontally with the camera (**A**). (**D**) The complete system includes the stereo adapter and slide viewer.

reread and rephotographed to provide a comparison set of pictures and data. Range trend is interpreted by comparing original and followup photos and data of each 1-ft² plot to appraise changes in species presence, density, basal area, frequency, shrub and tree line intercept, and soil surface characteristics.

Photographs are used to measure or estimate vegetation and soil parameters, aid in evaluating plant identification, facilitate illustration of range trend or lack of trend, and reduce observer variability in comparing transect readings taken at different times. Anybody can compare and measure the difference between photographs.

Stereo photographs greatly aid species identification and interpretation of vegetation and soil parameters. Try evaluation on one-half of a stereo pair—then view it with a stereoscope (fig. 75)!

Equipment

The following equipment is required for 1-ft² sampling:

1. Camera or cameras with color and black-and-white film and stereo adapter (fig. 78)
2. A 1-ft² plot frame (app. C)
3. Forms from appendix B: for photo identification “Cluster-Transect” and “Square Ft Frequency” printed on medium blue paper; and the data and photo-mounting form “Photo Trend Sample - 1 sq. ft.” printed on medium yellow paper
4. Meter board (app. C)
5. Clipboard and holder for the photo identification forms (app. C)
6. Compass and a 100-ft steel tape with clamps or vice grips to clamp onto angle iron stakes
7. Fenceposts and angle iron stakes sufficient for the number of transects desired: two fenceposts and three angle iron stakes per transect and a pounder
8. Metal detector for locating transect stakes

Technique

Map the location of the transect cluster (fig. 72). Establish the transects and map them on the filing system form “Sampling Site Description and Location” (fig. 73). If slope exceeds 10 percent, orient transects on the contour so that uphill is left of the transects when viewed toward the 100-ft end. Placing plot frames and photographing uphill is easier than working downhill. Fill out information on the form and circle “1 sq. ft.” on the top line. If transects fall in a line, continue the map on the back of the form (fig. 74).

A three-dimensional adapter for 35-mm cameras with 50-mm lenses is desirable for both general and 1-ft²-plot photographs (fig. 78). Such adapters may not be available, however. If not, use a 50-mm lens in preference to a 35-mm for best detail resolution. Take general pictures from the 0-ft (fig. 75, top) and 100-ft ends (fig. 77) to show vegetation prior to trampling from placing and photographing the 1-ft² plot (figs. 75 and 76).

The filing system form, “Photo Trend Sample – 1 sq. ft.” (app. B), is illustrated in figures 75 to 77. It should be printed on medium yellow paper such as Champion’s or Hammermill’s Goldenrod® to ease eyestrain. It is used to diagram plants and mount photographs of the 20 plots. Fill in date, area (Crooked River N.G.), allotment (Madras grazing unit), cluster number (3), transect number (1), and the investigator’s name. “Season of use” means when during the previous 12 months the area was used, such as season long, spring, summer, fall, or winter. The “% use” is the average utilization at the time of sampling. “Grazing system” means the kind currently being used, such as season long, rest-rotation, or alternate year. Any comments may be made under “Remarks” (fig. 75) or “Comments” (fig. 77).

Transect photos are identified by the filing system form “Cluster-Transect” (figs. 75 and 77). It should be printed on medium blue paper. Fill in the date (97/3/22), circle either “0” or “100” (fig. 75 is 0, and fig. 77 is 100) to indicate which end of the transect is being photographed, area (CRNG), allotment (Madras), cluster number (3),

and the transect number (1). For the downtransect photo, place the camera at the 0-ft stake, photo identification form at 15 ft, and the meter board at 33 ft; for uptransect photos, camera at 100 ft, photo identification form at 85 ft, and meter board at 67 ft.

Each square-foot plot and its photograph is labeled individually ("Square Foot Frequency") and positioned on the transect as noted on the form "Photo Trend Sample - 1 sq. ft." Place the 1-ft² plot at the first location, between 0 and 1 ft, with its identification card. Diagram the location of each plant species and label as shown in figures 75 and 76. Diagram basal area in bunchgrasses and area of rhizomatous or single-stemmed species when they occur within the square foot. The diagram is used for species identification and counting frequency, not for measurement of change. The stereo photograph is used to measure plant and soil change.

Under the plot diagram, circle soil surface items in the plot: "B" is bare ground (> 50 percent ground cover), "G" is gravel (> 50 percent ground cover of stones 1/8- to 3/4-in diameter), "R" is rock (> 3/4 in), "L" is litter (> 50 percent ground cover), and "C" is cryptogamic crust (> 50 percent ground cover).

Identify each square foot plot with the "Square Ft Frequency" form (app. B). It labels each 1-ft² plot and its photograph (figs. 75 and 76). One sheet is designed for use with all 20 plots on a transect. Try to print the necessary information in letters similar in size to those on the form. This will ensure readability in photographs. For plot 1, circle number 1, place form on ground next to the tape and adjacent to the square-foot plot. Place the plot frame at footmarks 1 and 2 as noted on the form. With a stereo adapter attached to the camera, hold the camera at eye level directly above the plot and expose for both the square-foot plot and the photo identification paper (fig. 75). For plot 2, cross out number 1 and circle number 2 (fig. 75). Place the plot frame at foot marks 5 and 6 as noted on the form. For plot 3, cross out number 2 and circle 3 (fig. 76) and place at foot marks 10 and 11. Repeat for all 20 plots. Use a new sheet for each transect.

Caution: Expose for both the photo identification paper and the plot. Generally, paper will reflect more light than vegetation and soil; the paper therefore should be slightly overexposed while soil and vegetation are slightly underexposed. Acceptable paper exposure is essential to read the printing in each plot photo. Medium blue paper, not office blue color, may be attained at most office supply stores.

In addition, from plot number 1, record shrub and tree (under 6 ft tall) canopy cover intercept by species above the transect tape between the start of one plot and the start of the next. Record beginning and ending foot marks and number of feet between intercepts. For example, in figure 76, plot 3 starting at 10 ft had a shrub intercept from 12 to 15 ft between it and plot 4, for a total of 3-ft crown intercept. Plot 5 starting at 20 ft had a shrub intercept from 22 to 23 ft between it and plot 6, for a total of 1 ft.

Another important source of supplemental information, particularly in the Pacific Northwest where many range types are forested, is the effect of tree cover. Cover must be sampled on all forested ranges. It is discussed as an additional transect sample in the "Tree Cover Sampling" section, below.

Summarize Data

After all 20 plots have been photographed and diagrammed, the transect is summarized on the last page of the "Photo Trend Sample - 1 sq. ft." form (fig. 77). The left side documents frequency and line intercept by species as well as by soil surface items. List all species found on the transect. Sometimes a shrub or tree species will be rooted in a plot for frequency and also will be recorded for crown intercept. Record the shrub or tree species in both cases. For frequency, count the number of plots in which the species occurred and record. For intercept, total the number of feet for each species and record (fig. 77).

The same procedure is followed at the bottom of the species listing for bare ground, gravel pavement, rock, litter, and cryptogams. Determine the number of plots in which each of these items occurred (fig. 77). Bare soil occurred in 18 sample plots, gravel pavement in 15, rock in 2, litter in 15, and cryptogams in only 8 plots.

The rest of the "Photo Trend Sample - 1 sq. ft." form is devoted to supplemental information (fig. 77). At the bottom left, record the two or three species sustaining the greatest utilization regardless of whether they are decreasers or not. The objective is to document how much utilization occurred for which species, not to estimate "proper use."

On the lower right side of figure 77, briefly describe any activities that occurred since the last transect reading. Provision is made for logging disturbance, fire, revegetation, insects, wildlife effects, and other.

Evaluate recent climatic conditions (fig. 77). Circle whether temperature was hotter, about average, or colder for this growing season (when the sampling was done), last year, two years ago, three years ago, and four years ago. Do the same for precipitation falling between January 1 and July 1: Was it above average, about average, or below average? This information should be available from local weather stations. Precipitation in the mountains can differ considerably from local stations, and no attempt is made to quantify differences.

Estimate whether apparent range condition is good, fair, poor, or very poor. These are range management terms equivalent to ecological definitions of potential natural vegetation (PNV), late seral, mid seral and early seral. PNV is the stable, native plant community that will become established after succession following disturbance. In much of the Pacific Northwest, livestock forage rating guides can be used to determine range condition. For areas without livestock forage rating guides, estimate range condition to the best of your ability.

Next, estimate apparent range trend. If you have a strong feeling that range trend is down, say so; if you have a strong feeling the trend is up, say so; if you are not sure about trend, say that also.

Space is provided for other comments. Whenever possible, make these additional comments in the field while you are looking at the transect.

If the site is forested, add the "Tree Cover Sampling" transect to this file.

Circle the sampling system: 20 plots 1 sq.ft. 100 plots Nest. Frequ. 5 Plots 9 sq.ft.(1 sq. m)
Area Crackled R. N. G. Allotment Madras Cluster 3 Transect 1 2 3 4 5

[illegible]

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RANGE TREND REREADINGS (Continued)

Elements	Averages by Year									
	1957	1982	1997							
Range Condition Guide/date										
Bunchgrass 1951	P									
4RTR 1983	F	F	G							
Decreasers:	2	3	5							
Palatable Increasesers	14	16	18							
Unpalatable Increasesers	7	3	2							
Invaders	—	—	—							
Vegetation - (root crown)	16	17	17							
Bare Soil	20	20	18							
Gravel (1/8 to 1/4 inch)	16	14	15							
Rock (> 1/4 inch)	2	2	2							
Litter	8	12	15							
Cryptogams	4	6	8							
% Utilization by species										
None	—	—	—							
Season of Use	—	—	—							
Climate										
Temp: Current	+	0	0							
Last year	0	0	0							
2 yrs. Ago	0	+	0							
3 yrs. Ago	0	0	—							
4 yrs. Ago	—	0	—							
Ppt.: Current	0	+	+							
Last year	0	+	+							
2 yrs. Ago	0	0	0							
3 yrs. Ago	—	0	0							
4 yrs. Ago	+	0	—							
Apparent range condition	F	F	G							
Apparent range trend	S	U	S							

Figure 80—Back of the "Range Trend Rereadings" form providing for data analysis by use of rating guides for livestock forage (range condition guides). The remaining transect summary data from figure 77 may also be added by date.

Range Trend Analysis

Data obtained by square-foot frequency are summarized for trend analysis in the filing system form "Range Trend Rereadings" (fig. 79). The form is designed for a series of up to 10 transect readings that may be compared side by side. The columns under "Averages by Year" require the year of reading to be entered at the top. The form in appendix B is printed front and back corresponding to figures 79 and 80.

Figure 79 is the front of the form. Circle which sampling system was used, "20 plots 1 sq. ft." in this case. Enter the information on area, allotment, and cluster number and circle the transect number. Enter the date of reading at the top of the "Averages by Year" column. Figure 79 shows three hypothetical transect readings: 1957, 1982, and 1997. The data in figure 79 refer to the 1997 reading.

If tree cover was sampled (trees over 6 ft tall), enter the total number of feet of intersect by species and total. Then enter the total number of feet of intercept by shrub species and total. Shrub species intercept is summarized on the last page of the form "Photo Trend Sample - 1 sq. ft." (fig. 77), a total of 7 ft.

The next data set (fig. 79) is for herbaceous species sampled by either 1-ft² or 1-m² or nested frequency. The data are summarized on the last page of the form "Photo Trend Sample - 1 sq. ft." (fig. 77). Circle the sample plot used ("1 sq. ft."). Enter the number of plots in which each species was rooted. Maximum number of plots for 1 ft² is 20 and 9 ft² or 1 m² has five plots. Nested frequency uses a different value. It is the total value of all five transects (100 plots) by species. See the "Nested Frequency Transect" section, below, for details.

Figure 80 shows the back of the form, which summarizes additional information and data. Enter data by date in the column "Averages by Year." If a range condition guide (or livestock forage rating guide) is available, list it and its date. In this case, an old bunchgrass guide of 1951 was used for the 1957 reading, which rated P (poor condition). A 1983 guide for big sagebrush (ARTR, *Artemisia tridentata* Nutt.) was used to estimate range condition for all three years. The 1983 guide showed data for 1951 rated F (fair) condition instead of poor.

These range condition guides list species by their reaction to livestock grazing: *decreasers* decrease under heavy use; *palatable increasers* are less palatable and tend to increase with heavy use. However, if heavy use continues, these species also decrease. *Unpalatable increasers* are species that livestock do not like to eat, and they tend to increase. *Invaders* are species generally not found on rangeland in good condition.

Data are summarized by the above categories of plant species (fig. 80). Total the number of plots by species in each category and enter. For example, AGSP (*Agropyron spicatum* vis. *Pseudoroegneria spicata* (Pursh) A. Love, bluebunch wheatgrass) is the only decreaser, so its data are entered (5 plots). Palatable increasers are POSA3 (*Poa secunda* J. Presl, Sandberg's bluegrass), SIHY (*Sitanion hystrix* (Nutt.) J.G. Sm., squirreltail), STOC (*Stipa occidentalis* Thurb. Ex S. Wats., needlegrass), and BASA (*Balsamorhiza sagittata* (Pursh) Nutt.,

arrowleaf balsamroot), so their data are summarized and entered in "palatable increasers" (18 plots). LOMAT (*Lomatium* species) and PHLOX (*Phlox* species) are considered unpalatable increasers and are entered as such (2 plots).

The next section of figure 80 deals with soil surface conditions. "Vegetation - (root crown)" is the number of plots in which a root crown of a bunchgrass is present. In 1997, 17 plots had a root crown and 3 had no vegetation rooted in them. Single stem plants, like many forbs, do not contribute directly to soil surface protection. This information is taken from the stereophotographs as is the frequency of bare ground, gravel, rock, litter, and cryptogams. The latter five items are summarized at the bottom left of the "Photo Trend Sample - 1 sq. ft." form (fig. 77). The section on "% Utilization by species" provides space to enter stubble height or other means to estimate utilization by species as taken from the "Photo Trend Sample" form, lower left. In this enclosure, there was no utilization. If there was use, estimate the season of use, as spring (spr), summer (sum), fall (fall), or winter (wint).

Climate information is listed in the next section for the current and preceding three years, which has been summarized in the lower right of the form, "Photo Trend Sample - 1 sq. ft." (fig. 77). Finally, copy the estimates of apparent range condition and trend from the "Photo Trend Sample." Abbreviations are G = good, F = fair, P = poor, and VP = is very poor, a condition where decreasers are absent and livestock management is no longer a feasible means for attaining an upward trend to good condition. Trend abbreviations are U = upward trend, S = static or no trend, and D = downward trend.

Trend Interpretation

Interpretation of trend is accomplished by comparison of data in the columns. Data for 1997 were measured; those for 1982 and 1957 were constructed. A current, soundly developed livestock forage rating guide (range condition guide) is a major aid in trend interpretation. Statistical analysis is not possible on this kind of data. No trend, or stable status, is indicated by little change in either vegetation or soil surface data.

Upward trend, or successional change to good condition (potential natural vegetation: PNV), is generally indicated by increased decreasers, and often palatable increasers, accompanied by a decrease in unpalatable increasers. If earlier condition was below fair, there should be improvement of soil surface conditions, such as litter and cryptogamic crust, with less bare soil. Seldom will rock or gravel change in an upward trend. Consult the livestock forage rating guide (range condition guide) for data characterizing the PNC soil surface status

A downward trend, or successional change to poorer condition (earlier seral status), is characterized by reduction in decreasers, increase in palatable increasers initially in fair and good condition (late and PNV seral status), and then their decrease as seral status approaches very poor condition (early seral). Soil surface data also should change with decreases in vegetation, litter, and cryptogams and increases in bare soil and possibly gravel.

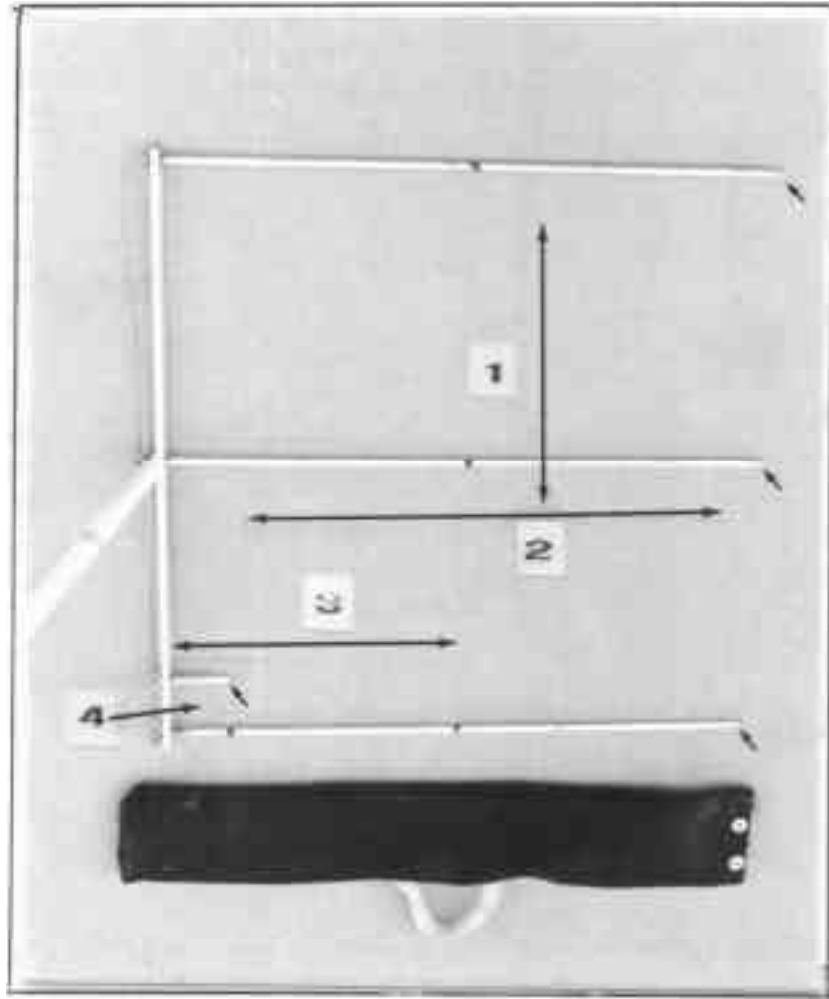


Figure 81—Nested frequency sampling frame with four plot sizes and its carrying case. Plot size 4 is 5 by 5 cm, size 3 is 25 by 25 cm, size 2 is 25 by 50 cm, and size 1 is 50 by 50 cm. Plant species rooted within each of the plot sizes are assigned the plot size value. The ends of each prong are sharpened for use as point samples of soil surface conditions (short arrows). The frame case has a strap for easy handling.

Poor and very poor condition classes (early and mid seral ecological status) pose two important questions: (1) Has vegetation passed a threshold whereby it may not be able to regain its PNV composition and density of species? An example is a cheatgrass-dominated stand where decreasers are absent and only a few palatable increasers are present. Adjustment in livestock management is no longer feasible to attain an upward trend. (2) Has the soil been damaged sufficiently that it has passed a threshold and no longer can support the historic PNV community? Such threshold changes are indicated by erosion of the A-horizon, increase in gravel as a result of erosion, and severe compaction. A well-developed livestock forage rating guide contains parameters on PNV status of bare ground, gravel pavement, rock, and A-horizon characteristics that may be compared with current soil conditions. It should specify criteria when a soil threshold has been crossed.

Nested Frequency Transect

Nested frequency employs a sample frame with four nested plot sizes. It documents change in species frequency along five 100-ft transects of 20 plots each. Statistical analysis suggests significant change in frequency at the 80-percent level of probability.

Concept

Frequency is defined as the number of times a species occurs (is rooted) in a given number of plots and considers only whether species are present or absent. It is an objective and repeatable means of collecting data to evaluate change.

The nested frequency concept involves sampling vegetation with four various sized plots nested within a frame (fig. 81). The overall frame is 50 by 50 cm with smaller subplots of 25 by 50 cm (50 percent of the large plot area), 25 by 25 cm (25 percent of the large plot area), and 5 by 5 cm (1 percent of the large plot area). The assumption is made that a species rooted within the 5- by 5-cm subplot also occurs in the 25- by 25-cm subplot, the 25- by 50-cm subplot and in the 50- by 50-cm subplot. Similarly, a species rooted in the 25- by 25-cm subplot occurs in the larger subplots. Therefore, once a species is recorded in a subplot, it is **not** recorded if found in a larger subplot.

Samples are taken along five randomly selected transect lines confined to a single ecological type (range site). The data collected are a function of plot size, which is related to density and distribution of the vegetation. These data serve as a basis for determining trend and can be evaluated by applying statistical procedures. Statistical analysis requires use of 100 plot frames or 400 total plots. Twenty plot frames on each of five transects yield 100 plot frames.

Ground cover measurements are obtained by sampling soil surface items under pointed ends of four prongs of the nested frequency frame (fig. 81). Twenty sample frames on five transects will yield 400 sample points. Items recorded are vegetation (root crown), bare soil, gravel (1/8- to 3/4-in diameter), rock (>3/4-in), litter, and cryptogams.

When trees or shrubs occur on the transect, their canopy intercept above the transect is recorded.

It is recognized that the nested plot has apparent replication. A plant occurring in the 5- by 5-cm plot also occurs in the 25- by 25-cm plot, the 25- by 50-cm plot, and the 50- by 50-cm plot. As this is a question of statistical bias, two things overcome the possible sampling error. One is that each frame is not an independent sample; therefore, only one degree of freedom is used. Secondly, empirical analysis indicates that if a site is adequately sampled, in this case 400 nested plot samples (100 plot frames), the final result is highly similar whether all plots are randomly tested or if a nested plot (with apparent replication) is used.

Plants rooted within each of the four plots in the frame are recorded by plot size. The 5- by 5-cm plot is assigned the value of 4 (fig. 81), the 25- by 25-cm plot the value of 3, 25- by 50-cm plot a 2, and the 50- by 50-cm plot a 1. These values are then assigned by species and recorded on the filing system form, "Nested Frequency Transect Data" (fig. 86, discussed below).

Table 2—Table of random numbers

Row	Random Number									
1	23	25	75	48	59	01	83	72	59	93
2	10	53	74	35	08	90	61	18	37	44
3	50	05	10	03	22	11	54	38	08	34
4	32	42	87	16	95	97	31	26	17	18
5	11	74	26	93	81	44	33	93	08	72
6	11	01	64	56	23	93	00	90	04	99
7	55	75	11	89	32	38	47	55	25	71
8	77	73	80	95	27	36	76	87	26	33
9	07	09	25	23	92	24	62	71	26	07
10	44	86	38	03	07	52	55	51	61	48
11	63	14	89	51	23	35	01	74	59	93
12	62	58	48	69	19	57	04	88	65	26
13	09	24	34	42	00	68	72	10	71	37
14	40	89	48	83	29	52	23	08	25	21
15	56	67	16	68	26	95	99	64	45	69
16	71	68	75	18	67	61	02	07	44	18
17	97	83	98	54	74	33	05	59	17	18
18	22	23	29	06	37	35	05	54	54	89
19	02	82	35	28	62	84	91	95	48	83
20	65	01	71	65	45	11	32	25	49	31
	42	36	23	42	86	08	62	49	76	67
	95	91	73	78	66	99	53	61	93	78
	22	03	42	30	00	89	16	09	71	92
	25	96	68	82	20	62	87	17	92	65
	05	04	95	48	06	74	69	00	75	67
	42	24	52	32	45					

Equipment

The following equipment is required for nested frequency sampling:

1. Camera or cameras with both color and black-and-white film, or digital camera
2. A nested frequency plot frame (app. C)
3. Forms from appendix B: "Cluster-Transect" for transect identification, and "Nested Frequency" for plot identification both printed on medium blue paper, and data and photo mounting form "Photo Trend Sample - Nested Frequency" and "Photo Trend Sample -Nested Frequency Summary" printed on medium yellow paper
4. Meter board (app. C)
5. Clipboard and support for holding the photo identification forms (app. C)
6. A compass and 100-ft steel tape with clamps or vice grips to clamp onto angle iron stakes
7. Fenceposts and angle iron stakes sufficient for the number of transects desired: 2 fenceposts and 3 angle iron stakes per transect and a pounder
8. Metal detector for locating transect stakes

Technique

Each of the five transects is defined as a randomly selected line along which data are collected. A minimum of five transects are established at five randomly selected compass directions radiating from a central point whenever site conditions are suitable.

Select compass headings in 10-degree increments between 0 and 35 from table 2. If site conditions require placement in a line, distances between transects should be randomly chosen. The example below illustrates transect placement around a central witness location by using the first five values in table 2 that are between 0 and 35 (from 0 degrees; that is, 360 degrees to 350 degrees). Chose numbers less than 36 (360 degrees) and add a "0" to the value for compass bearing. For example, in the first row, "23" would be a compass bearing of 230 degrees for transect 1. Transect 2 would be 250 degrees, transect 3 is 10 degrees, transect 4 is 240 degrees, and transect 5 is 80 degrees. Select a different row for each new cluster of five transects.

Placement of the transects requires a witness site with direction (indicate whether magnetic or true) and measured distance to the central marker for five radiating transects or to transect number 1 (fig. 82). For radiating transects, measure out 5 ft from the central marker (fencepost) and start the transect as discussed under "Transect Layout" in the "Transect Photo Sampling" section above. Record direction determined above (magnetic or true) and distance to the three angle iron stakes. If transects are in a line, record direction and measured distance between the 100- and 0-ft ends of each transect (fig. 74).

Diagram the transect layout on the filing system form (fig. 82), and fill out information on the form. Remember to circle "Nested Freq." on the top line of the form. Note the transect numbers at their 0-ft ends.

Each transect photo is identified by the filing system form shown in figures 83 and 85. The photo identification form should be printed on medium blue paper for use in the photographs. Fill in the date (97/3/22), circle either "0" or "100" (fig. 83 is 0, fig. 85 is 100) to indicate which end of the transect is being photographed, note area (CRNG), allotment (Madras), and cluster number (3), and circle the transect number (1).

Place the nested frequency plot frame uphill on the left of the transect tape as viewed toward the 100-ft end. Locate the 5- by 5-cm plot against the tape, open end of the frame toward the 100-ft end. Figures 83 and 84 show, under the plot diagram, foot marks on the tape where each plot frame is placed. Print this form on medium yellow paper to reduce glare because it is used to record data.

Place the nested plot frame at the first location, between 0 and 1.6 ft. The form "Nested Frequency" (app. B) shown in figures 83 and 84 identifies each plot frame. It should be printed on medium blue paper to reduce overexposure in the Sun. For photo plot 1, circle number 1 and place on the ground at the open end of the plot. For plot 2, cross out number 1 and circle number 2 (fig. 83). Repeat for all 20 plots (fig. 84).

List all species in each frame and diagram their locations (figs. 83 and 84). A plant is considered rooted within the plot if any portion of the stem or root crown is contained therein. For mat-forming species, any portion of the crown extending into the plot will constitute presence of that plant.

Text continues on page 151.

SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft. Nested Freq. 1 sq.m. Robel Pole Shrub Form _____

Date 1997/3/22 Site Data: Elev. 2775 % slope 8
Area Crooked River N.G. Slope aspect: N NE E SE S SW W NW
Allot. Madras Slope position: top up 1/3 mid low 1/3 bottom
Cluster No. 3 Micro topography: convex flat concave
Transects: 1 2 3 4 5 Macro topography: flat undulating rolling
Plant community ARTL steep rough broken
AGSP/POSA
Geology:
Grazing system: Deposition: wind stream lake colluvial
Type Exclosure Date 1954 residual
Type _____ Date _____ Material: limestone mudstone sandstone
Type _____ Date _____ granite serpentine diorite
Kind of animal: cattle sheep basalt andesite rhyolite
horses goats deer tuffaceous cinders pumice ash
elk jack rabbits
Soil:
Restrictive layer: absent clay pan bedrock
cemented
Location: T. 11S R. 13E Surface compaction: none moderate severe
Sec. 36 NW of NW Soil profile stone: absent grave stony
Description: US hiway 20 Soil texture: sandy loamy silty clayey ashy
at Crooked River N.G. Other notes: Livestock excluded when
sign; 2.1 mi. from junct. hiway was fenced in 1954
US 97 & US 26 S. of Madras.

MAP

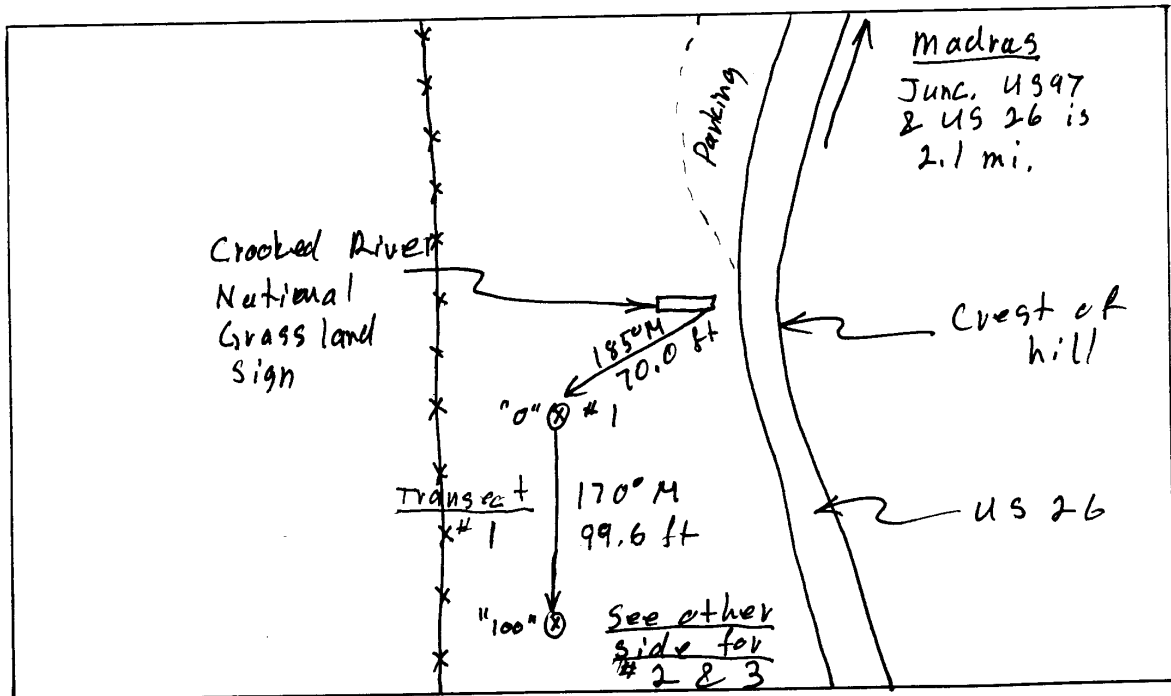


Figure 82—Filing system form "Sampling Site Description and Location" for this nested frequency discussion (same as fig. 73). First, circle "Nested Freq." on the top line, then fill in the information requested, and diagram the transect layout. Figures 73 and 74 are the complete documentation.

PHOTO TREND SAMPLE - NESTED FREQUENCY
 Date 1997/3/22 Cluster 3 Transect (1) 2 3 4 5

Area Crooked River N.G.
 Allot. Madras
 Investigator JCH
 Season of use none
 % use —
 Grazing system exclosure
 Remarks Highway exclosure

Line intercept:
 Species From To Feet

Line intercept:
 Species From To Feet

Figure 83—Filing system form “Photo Trend Sample - Nested Frequency” illustrating its use. Two additional forms are required: transect identification (top picture) and plot identification (lower two pictures). Fill out required information on each form: CRNG (Crooked River National Grassland), Madras Exclosure, cluster 3, transect 1, date, and notes. Photograph the transect from the 0-ft (top picture) and the 100-ft ends (fig. 85). This is the same transect shown in figure 75. Notice the soil surface items at the end of each prong: B = bare ground, G = gravel, R = rock, L = litter, and C = cryptogamic crust.

PHOTO TREND SAMPLE – NESTED FREQUENCY

Plot 3

10.0 ft 11.6 ft

Line intercept

Species	From	to	feet
ARTR	12	15	3

Plot 4

15.0 ft 16.6 ft

Line intercept

Species	From	to	Feet

Plot 5

20.0 ft 21.6 ft

Line intercept:

Species	From	To	Feet
ARTR	22	23	1

Figure 84—Nested frequency data sheet and photo-mounting form for plot frames 3 to 5. A space on the left is available for recording crown canopy intercept along the transect. Under plot frame 3, ARTR (*Artemisia tridentata* Nutt., big sagebrush) canopy intersected the transect at foot marks 12 to 15 for 3 ft of intercept. Record intercept between plot frames starting and ending with the beginning footmark for each plot. For plot frame 3, the intersect is from footmark 12 to 15. Plot 5 had ARTR intercept between footmarks 22 and 23 for 1 ft of intercept. Other species are AGSP (*Agropyron spicatum* vis. *Pseudoroegneria spicata* (Pursh.) A. Love., bluebunch wheatgrass), and POSA3, (*Poa secunda* J. Presl., Sandberg's bluegrass).

PHOTO TREND SAMPLE - NESTED FREQUENCY

SUMMARY

NOTE: use the nested frequency data forms on the next two pages.



ACTIVITIES

Logging _____
Fire _____
Revegetation _____
Insects _____
Wildlife deer, rabbits
Other exclosure

CLIMATE compared to Average

	<u>This Yr.</u>	<u>Last Yr.</u>	<u>Two Yrs.</u>	<u>Three Yrs.</u>	<u>Four Yrs.</u>
Temp	+0-	+0-	+0-	+0-	+0-
Ppt.	+0-	+0-	+0-	+0-	+0-

Apparent range condition Good
Apparent range trend Static

COMMENTS

Estimated Utilization

<u>Species</u>	<u>% Use</u>
_____	_____
_____	_____
_____	_____

Hiway exclosure

Figure 85—Last page of the filing system form "Photo Trend Sample - Nested Frequency." Notice that data are not summarized on this form. Instead, they are summarized for each transect on the filing system form, "Nested Frequency Transect Data" (figs. 86 and 87), and all five transects are summarized on another form, "Nested Frequency Cluster Summary" (figs. 88 and 89). Fill in activities, climate, and comments as appropriate.

Next, record point sampling by noting what is under the pointed end of the four prongs (figs. 83 and 84). Use the following abbreviations: V = vegetation (plant root crown), B = bare soil, G = gravel (stones 1/8- to 3/4-in diameter), R = rock (> 3/4 in), L = litter, and C = cryptogams. These are point samples.

After photographing and diagramming a plot, determine shrub or tree (under 6 ft) intercept along the line from the start of one plot to start of the next. For example, figure 84 between plot numbers 3 and 4 (between foot marks 10.0 ft and 15.0 ft), ARTR (big sagebrush) intersected the line from foot marks 12 to 15 for 3 ft of intercept.

Proceed down the transect with photographs and diagrams of each plot frame. Complete the last page of the form "Photo Trend Sample - Nested Frequency" (fig. 85).

Another important source of supplemental information is the effect of tree cover. Cover should be sampled on all forested ranges. It is discussed below in the "Tree Cover Sampling" section.

Summarize Data

Transect summary—Using diagrams for each sample on the form, "Photo Trend Sample - Nested Frequency" (figs. 83 and 84), summarize them on the filing system form, "Nested Frequency Transect Data" (figs. 86 and 87). Fill in information at the top for unit, area, cluster, and transect. This form is printed front and back. The table lists "Sample Number" across the top. These correspond to the sample numbers shown on figures 83 and 84. Species are listed down the left side.

Using "Nested Frequency Transect Data" (fig. 86), start with sample 1 of the transect (fig. 83) and evaluate the smallest subplot (rated 4 in fig. 81), record species rooted within it, and assign the frequency value of 4 (no species in sample 1). Next record species rooted within the next largest subplot (rated 3 in fig. 81) and assign a frequency value of 3. POSA3 is recorded at 3. Continue with the next largest plot (25 by 50 cm) rating species a 2 (none in sample 1). Do **not** record a species rooted within a smaller plot. Finally, record species only in the whole plot frame (50 by 50 cm) with a 1 (none in sample 1).

Continue to record the frequency value in each sample by species (fig. 86). Total the value for each species on the right. These totals will be entered in the form, "Nested Frequency Cluster Summary" (figs. 88 and 89). The maximum total would be 80 if the same species occurred in every 5- by 5-cm plot rating 4. Species that do not fall in a plot of the frame are not given a value; that is, ARTR and BASA in figure 86.

Next summarize point sampling at the bottom of figure 86. Dot tally the occurrence of each of the six items from abbreviations at the ends of the four frame prongs (figs. 83 and 84). Sum the dot tallies in the "Totals" space. Next add the totals row for a grand total, which must equal 80 because there are 80 points in the 20 samples.

Text continues on page 158.

NESTED FREQUENCY TRANSECT DATA

Area: Crooked R. N. G. Allotment: Madras Date: 97/3/22
Investigator: FC & GPH Cluster: 3 Transect: (1) 2 3 4 5
Plant community: ARTR / AGSP / POSA 3

[illegible]

POINT SAMPLING

POINT SAMPLING							
Ground cover	Veg.	Soil	Gravel	Rock	Litter	Crypt.	Total
Dot tally	-	☒ ☒	☒	''	☒ ☒	☒ ☒	
Totals	-	20	15	2	20	23	80

NEXT SHEET FOR LINE INTERCEPT OF SHRUBS AND TREES

Figure 86—Filing system form “Nested Frequency Transect Data,” where frequency values by species and point sampling on the plot frame prongs are recorded. Starting with plot frame 1 (sample number 1), list the frequency value for each species in the “Sample Number” column. POSA3 rated a “3” (fig. 83). Next, add up the 20 frequency values and enter in the “Total Value” column. POSA3 added to 56. Transfer these values to the “Nested Frequency Cluster Summary” form (fig. 88). Then, dot tally in “Point Sampling” the items at each of the four prong points. Plot 1 had one litter (L), two bare soil (B), and one cryptogam (C). Add the dot tallies in each column by item. The sum of these “Totals” tallies should be 80. The sum of each item is then transferred to the “Nested Frequency Cluster Summary (continued)” form (fig. 89).

NESTED FREQUENCY TRANSECT DATA (Continued)

Line intercept of trees and shrubs

Shrub species	Line Intercept								Total	Percent
ARTR	3	1	1	1					6	6
PUTR	1								1	0.5
Totals									7	6.5

Tree species	Line Intercept								Total	Percent
Totals										

Figure 87—Second page of the “Nested Frequency Transect Data (Continued)” form where line intercept data for shrubs and trees are summarized. ARTR added to 6 ft of line intercept for 6 percent canopy cover. Line intercept data are summarized in the “Nested Frequency Cluster Summary (Continued)” form (fig. 89).

NESTED FREQUENCY CLUSTER SUMMARY

Area: Crooked River N.G. Allotment: Madras Date: 9/3/22
Investigator: FCH & GPH Cluster: 3
Plant community: ARTR / GSP / POSA3

[illegible]

OVER FOR LINE INTERCEPT AND POINT SAMPLING

Figure 88—The filing system form “Nested Frequency Cluster Summary” where five transects of the nested frequency cluster are summarized. The frequency values for transect 1 (fig. 86) are entered in the “Transect Number” column 1. Add the frequency values by species and enter in the “Total Value” column. The maximum value is 400 if the same species occurred in all 5- by 5-cm plots rating a 4. These values are then transferred to the filing system form “Range Trend Rereadings” (fig. 90) according to date of the rereading. The data summarized above are shown for 1997.

LINE INTERCEPT

POINT SAMPLING

Ground Item	Transect Number					(To trend summary)	
	1	2	3	4	5	Total Hits	Percent
Vegetation (root crown)	—	2	—	1	3	6	2
Bare soil	20	34	4	36	16	110	28
Gravel (1/8 to 3/4 in.)	15	12	21	7	16	71	18
Rock (> 3/4 in.)	2	2	4	—	—	8	2
Litter	20	18	20	17	19	94	24
Cryptogams	23	12	31	19	26	111	28
Totals:	80	80	80	80	80	400	100

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RANGE TREND REREADINGS

Circle the sampling system: 20 plots 1 sq.ft., 100 plots Nest. Freq., 5 Plots 9 sq.ft.(1 sq. m)
Area Crooked R. N. G. Allotment Madras Cluster 3 Transect 1 2 3 4 5

	<u>Averages by Year</u>					
<u>Species</u>	<u>1957</u>	<u>1982</u>	<u>1997</u>			
Tree Crown Cover (in percent)						
TOTAL						
Shrub intercept (in feet)						
AATR	38	36	35			
PUTR	6	3	2			
CHNA						
TOTAL						
Frequency: No. plots for 1 sq.ft. & 9 sq.ft. (1 sq. m); <u>nested frequ. value</u>						
P03A3	261	288	274			
AGSP	58	92	114			
AATR	4	5	5			
LOMAT	43	36	29			
PHLOX	7	10	8			
BASA	12	8	2			
SHTY	11	16	9			
STOC	15	8	2			

OVER FOR ADDITIONAL DATA

Figure 90—The filing system form “Range Trend Rereadings” where transect data are entered each time the cluster is read. Circle the sampling system on the first line (“100 plots Nest. Frequ.”). Enter the cluster identification information. Notice that “Transect 1 2 3 4 5” are all circled. Enter the line intercept for shrubs and trees from each “Nested Frequency Cluster Summary (Continued)” (fig. 89) by year. Circle “nested frequ. value” and enter the sum of frequency values by year from figure 88. These values, by species, will be tested for significant change by using table 3. See text for details.

RANGE TREND REREADINGS (Continued)

Elements	Averages by Year								
	1957	1982	1997						
Range Condition Guide/date									
None	—	—							
ARTA 1983	F	F	G						
Decreasers:	58	92	114						
Palatable Increases	299	320	287						
Unpalatable Increases	54	51	42						
Invaders	—	—	—						
Vegetation - (root crown)	3	4	6						
Bare Soil	139	121	110						
Gravel (1/8 to 1/4 inch)	79	82	71						
Rock (> 1/4 inch)	8	7	8						
Litter	81	88	94						
Cryptogams	90	98	111						
% Utilization by species									
None	—	—	—						
Season of Use	—	—	—						
Climate									
Temp: Current	+	0	0						
Last year	0	0	0						
2 yrs. Ago	0	+	0						
3 yrs. Ago	0	0	—						
4 yrs. Ago	—	—	0						
Ppt.: Current	0	+	+						
Last year	0	+	+						
2 yrs. Ago	0	0	0						
3 yrs. Ago	0	0	—						
4 yrs. Ago	—	—	0						
Apparent range condition	F	F	G						
Apparent range trend	Sat	Up	Sat						

Figure 91—Second page of the "Range Trend Rereadings (Continued)" form where data are interpreted for change in vegetation and soil surface characteristics. If a range condition guide (livestock forage rating guide) applies to the monitoring area, list it and its date. Then rate the condition of each rereading. Next list the frequency values for decreaseers, palatable increaseers, unpalatable increaseers, and invaders. There is no maximum value because species are lumped together and may total more than 400. See text for details.

Table 3—Table of significant change for nested frequency^a

Less than	Initial value	More than	Less than	Initial value	More than	Less than	Initial value	More than
17	25	31	137	155	171	257	280	301
21	30	37	142	160	176	261	285	307
25	35	43	147	165	181	266	290	312
30	40	48	151	170	176	271	295	317
35	45	55	156	175	192	276	300	322
39	50	59	161	180	197	281	305	327
43	55	65	166	185	202	285	310	333
48	60	70	170	190	208	290	315	338
53	65	75	175	195	213	295	320	343
57	70	81	180	200	218	300	325	348
62	75	86	185	205	223	307	330	353
67	80	91	189	210	229	309	335	359
71	85	97	194	215	234	314	340	364
76	90	102	199	220	239	319	345	369
81	95	107	204	225	244	324	350	374
85	100	113	209	230	249	329	355	379
90	105	118	213	235	255	334	360	384
95	110	123	218	240	260	339	365	389
99	115	129	223	245	265	343	370	395
104	120	134	228	250	270	348	375	*
109	125	139	233	255	275	353	380	*
113	130	145	237	260	281	358	385	*
118	135	150	242	265	286	363	390	*
123	140	155	247	270	291	368	395	*
128	145	160	252	275	296	372	400	*
132	150	166						

^a Using 100 nested frequency plot frames, the table shows a significant change in frequency value at the 80-percent probability level. Enter the table at "Initial value" with the *previous* frequency value for the 5 transects(100 plot frames). Compare the *previous* value with the *current* value to determine whether a significant change has occurred. A change is significant if the *current* value is smaller than the "Less than" value or greater than the "More than" value.

Finally, if shrubs and trees were intercepted, record the number of feet of intercept on the form, "Nested Frequency Transect Data (Continued)" (fig. 87). Total the number of feet and determine the percentage cover. For ARTR, 6 ft of intercept in 100 ft of line is 6 percent. If a tree or shrub was not intersected, there will be no data for it.

Cluster summary—Once the transect has been summarized, transfer data to the filing system form, "Nested Frequency Cluster Summary" (fig. 88). Fill in the required information at the top. List species down the left side and enter their frequency values by transect. Add the species values for a "Total Value." These total values are transferred to the "Range Trend Rereadings" summary to test for significant change in species (fig. 90). The maximum value possible would be 400 if the same species occurred in all 5- by 5-cm plots on all transects.

Next, transfer the line intercept data for each transect to the "Nested Frequency Cluster Summary (Continued)" form and total (fig. 89). A total of 35 ft of ARTR was intersected in 500 ft of transect for 7 percent cover. Transfer the intercept in feet to the "Range Trend Rereadings" form (fig. 91).

Finally, transfer the point sampling data by transect to the "Nested Frequency Cluster Summary (Continued)" form (fig. 89). These data must be added in two directions. Each transect column must add up to 80. Then add each item by row for their total hits. Add the "Total Hits" column, which must add to 400. Finally, determine the percentage of each item (hits/400). Transfer total hits to the form, "Range Trend Rereadings (Continued)" (fig. 91).

If the site is forested, tree canopy cover must be determined, a topic discussed in the "Tree Cover Sampling" section, below

Trend Interpretation

Interpretation of trend in species frequency values is facilitated by table 3, used in conjunction with the "Range Trend Rereadings" summary form (fig. 90). Interpretation is illustrated with measured data for 1997 and constructed data for 1957 and 1982. For example, AGSP, a decreaser, is a key species used to indicate trend. In 1982, its total frequency value was 92 and in 1997 it was 114. The previous value of 92 is located in table 3 in the "Initial value" column, falling between 90 and 95. Then the current value of 114 is compared to the values in the "More than" column opposite 90 and 95. These table values are 102 and 107. Because 114 exceeds the values, there is an 80 percent probability that a significant upward trend in AGSP frequency has occurred.

Downward trend is a reverse of this procedure. The 1982 total frequency value for POSA3 of 288 was the initial value and the value for 1997 of 274 is the current value (fig. 90). In table 3 in the "Initial value" column, find 288 and read 266 as the "Less than" value. The current value of 274 is not less than 266 and the downward change in POSA frequency therefore is not significant.

LOMAT, an unpalatable increaser, on the other hand, did show a significant decrease between 1957 and 1997. The initial value of 43 (fig. 90) is found in the "Initial value" column with a "Less than" value of about 33. The 1997 frequency value of 29 is less than 33, thereby suggesting an 80-percent significant probability of a reduction in frequency.

One could conclude that an increase in AGSP, a decreaser, and a decrease in LOMAT, an unpalatable increaser, indicate an upward trend in range condition. There is no statistical test for line intercept or point sampling data. Interpretation would suggest little change in ARTR cover. A decrease in bare soil and an increase in cryptogams, from 1957 to 1997 (fig. 91), suggested by table 3, would tend to support an upward trend interpretation.

In the upper left of the "Range Trend Rereadings (Continued)" (fig. 91) form under the "Elements" column, provision is made for use of range condition guides (live-stock forage rating guides). List the guide name and date if one is applicable to the ecological type. The guides group plant species into four categories. Decreasers are

species that are most palatable and decrease in frequency with heavy livestock use. Palatable increasers are species that are eaten but are less palatable than decreasers. They tend to increase in frequency or percentage of composition as decreasers decline. If heavy grazing continues, these species also decline. Unpalatable increasers are species that livestock do not care to eat but are present in good range condition (potential natural community ecological status). Invaders are those species that generally do not occur in good condition; they invade the site after serious heavy grazing.

Add the frequency values of those species falling into each category. For example, AGSP is the only decreaser so its frequency value for 1997 is 114. Palatable increasers are POSA3, BASA, SIHY, and STOC, whose frequency values (fig. 90) add up to 287 ($274 + 2 + 9 + 2 = 287$). Unpalatable increasers are ARTR, LOMAT, and PHLOX whose frequency values add up to 42. There is no statistical test for significant change in these items. They are presented to aid interpretation.

Nine-Square-Foot (1-Square-Meter) Plot Transect

Nine-square-foot transects are designed to enhance the three-step sampling system by increasing the number of ground view photographs from two to five. Reppert and Francis (1973), in their analysis of the three-step method, found photographs to be the most useful part of the method and could be used to test and validate the transect data.

Concept

The 9-ft² (1-m²) plot system is derived directly from the three-step concept of a general transect photograph plus a photo of a 3-ft square at each end of the transect. This system adds three more 9-ft² (1-m²) plots at the 25-, 50-, and 75-ft locations on the transect. Photographs are taken of the plot frame at an oblique angle from eye level. There are no plot measurements involved, but line intercept of woody species is provided. A grid may be imposed on the plot frame by physically connecting marks on the frame, but interpretation is difficult owing to the oblique angle.

The 9-ft² (1-m²) plot is not a sample of frequency because five plots are too few and 9 ft² is too large. In many cases, two or more species will occur at 100-percent frequency. A person cannot determine whether plants were spaced at 2 ft 10 in in distance (which would mean 100-percent frequency) or at 10 in in distance (which also would result in 100-percent frequency). The difference between 10 in and 2 ft 10 in can be important in evaluating range trend. Five plots of 9-ft² do provide, however, a repeatable view of vegetation and soil surface conditions for comparison between photos taken over time, a subjective means for interpreting trend.

Equipment

The following equipment is required for 9-ft² (1-m²) sampling:

1. Camera or cameras with both color and black-and-white film, or digital camera
2. A 9-ft² (1-m²) plot frame (app. C)
3. Forms from appendix B are for transect identification, "Cluster – Transect," and for plot identification "9 sq. feet - 1 sq. meter" printed on medium blue paper; and data and photo-mounting form, "Photo Trend Sample – 9 sq. ft. (1 sq. m)," printed on medium yellow paper
4. Meter board (app. C)

5. Clipboard and support for holding the photo identification forms (app. C)
6. Compass and a 100-ft steel tape with clamps or vice grips to clamp onto angle iron stakes
7. Fenceposts and angle iron stakes sufficient for the number of transects desired: 2 fence posts and 3 angle iron stakes per transect, and a pounder
8. Metal detector for locating transect stakes

Technique

Establish the transects and map them on the filing system form, "Sampling Site Description and Location" (fig. 92). Fill out information on the form and circle "1 sq. m" on the top line. If transects fall in a line, continue the map on the back of the form (fig. 74).

General photographs from the 0- and 100-ft ends of the tape are required (figs. 93 and 95). Remember to circle "0" for the front photo and cross it out and circle "100" for the end photo.

The 9-ft² (1-m²) plot transect is different in several respects from the 1-ft² and nested frequency transects:

1. Plot photographs are taken from an oblique angle rather than overhead
2. The picture is taken down the transect line
3. The transect line bisects the center of the plot (figs. 93 and 94)
4. The photograph of the last plot is taken from a different direction. Photo plot 1 is taken with camera over the 0-ft stake and the plot at 3.5 to 6.5 ft, whereas the last plot at 96.5 to 93.5 ft is taken with the camera over the 100-ft end and aiming back down the transect to the plot

Place the plots, on center, down the transect. Figures 93 and 94 illustrate the foot marks on the transect where each plot is located. Place a 9-ft² (1-m²) plot between the 3.5- and 6.5-ft marks (fig. 93). Roughly diagram the location of each species and label. Circle soil surface items listed under the plot diagram: B = bare soil (> 50 percent of ground cover), G = gravel (> 50 percent cover of stones 1/8 to 3/4 in), R = rock (> 3/4 in), L = litter (> 50 percent of ground cover), and C=cryptogams (> 50 percent of ground cover).

Fill in photo identification form "9 square feet-1 square meter," circle photo 1 and place at a far edge of the plot (fig. 93). Handhold the camera over the 0-ft stake (see note in fig. 93 under the photograph), make sure the photo identification sheet is visible, and take the photo.

Move to the next plot location at 25 ft (fig. 94). Determine canopy intercept along the line for trees less than 6 ft tall and shrubs from the start of plot 1 (0.0 ft) to the start of plot 2 (25.0 ft). A single species may have more than one intercept if more than one individual crosses the transect between 0 and 25 ft (fig. 93).

At plot 2, repeat diagrams. Camera location is at foot mark 21.5 (3.5 ft away from the plot) as shown in figure 94 under the photograph. On photo identification form, "9 square feet - 1 square meter," cross out "1," circle "2," and photograph.

Text continues on page 166.

SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft. Nested Freq. 1 sq.m. Robel Pole Shrub Form _____

Date 1997/3/22 Site Data: Elev. 2775 % slope 8
Area Crooked River N.G. Slope aspect: N NE E SE S SW W NW
Allot. Madras Slope position: top up 1/3 mid low 1/3 bottom
Cluster No. 3 Micro topography: convex flat concave
Transects: 1 2 3 4 5 Macro topography: flat undulating rolling
Plant community ARTL steep rough broken
AGSP/POSA
Geology:
Grazing system: Deposition: wind stream lake colluvial
Type Exlosure Date 1954 residual
Type _____ Date _____ Material: limestone mudstone sandstone
Type _____ Date _____ granite serpentine diorite
Kind of animal: cattle sheep basalt andesite rhyolite
horses goats deer tuffaceous cinders pumice ash
elk jack rabbits Soil:
Restrictive layer: absent clay pan bedrock
cimented
Location: T. 11S R. 13E Surface compaction: none moderate severe
Sec. 36 NW of NW Soil profile stone: absent grave stony
Description: US hiway 20 Soil texture: sandy loamy silty clayey ashy
at Crooked River N.G. Other notes: Livestock excluded when
sign; 2.1 mi. from junct. hiway was fenced in 1954
US 97 & US 26 S. of Madras.

MAP

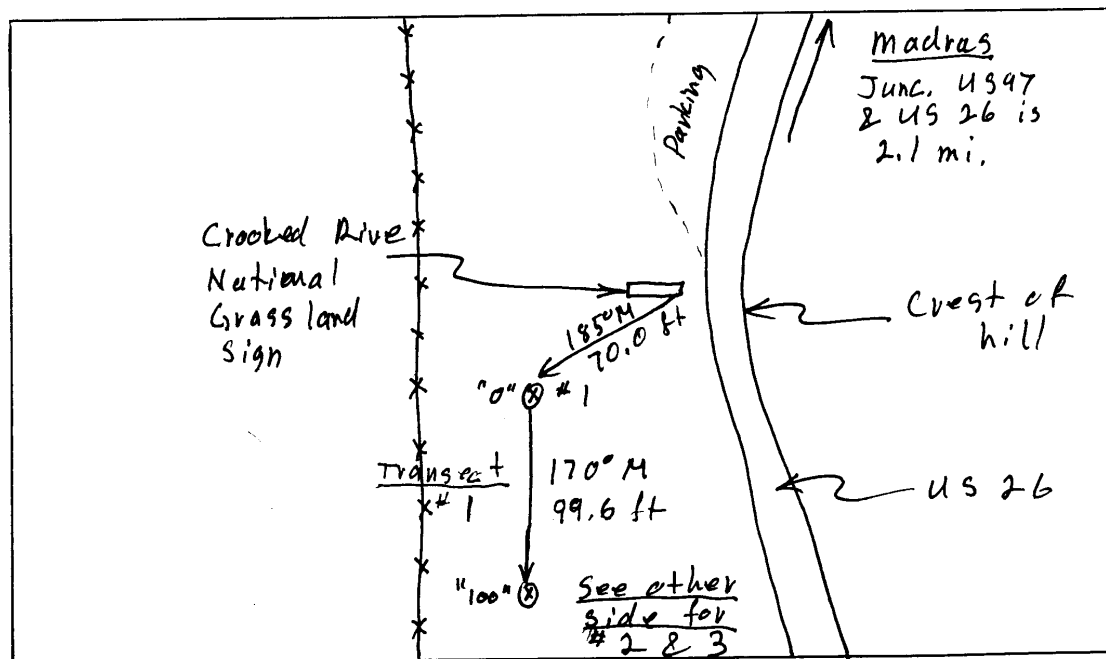
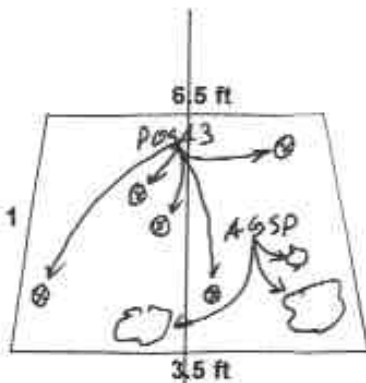


Figure 92—Filing system form "Sampling Site Description and Location" locating the 9-ft² (1-m²) transect system. It is the same location used for 1-ft² and nested frequency sampling. Circle "1 sq. m." on the top line. Fill in the rest of the information. Map the transect layout. Transects had to run end to end so the map continues on the back of the form (see fig. 74).

PHOTO TREND SAMPLE - 9 sq. ft. (1 sq. m)

Date 1947/3/22 Cluster 3 Transect ① 2 3 4 5

Area Crooked River N. G.
 Allot. Madras
 Investigator PS
 Season of use none
 % use —
 Grazing system exclosure
 Remarks Hyway exclosure



Soil surface: B G R L C

Line intercept:

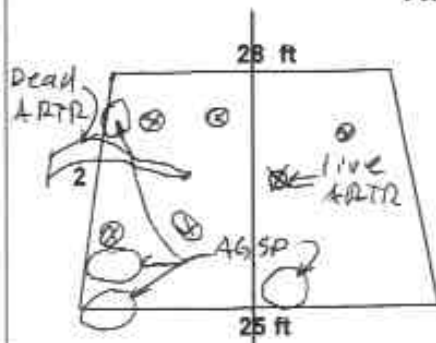
Species	From	To	Feet
<u>ABTR</u>	<u>12</u>	<u>15</u>	<u>3</u>
<u>ABTR</u>	<u>22</u>	<u>23</u>	<u>1</u>



Camera at the 0 foot mark.

Figure 93—Filing system form "Photo Trend Sample - 9 sq. ft. (1 sq. m.)" illustrating its use. Two additional forms are required: transect identification (shown in the upper picture) and plot identification (lower picture). Fill out required information on each form: CRNG (Crooked River National Grassland), Madras Exclosure, cluster 3, transect 1, date, and notes. Photograph the transect from the 0-ft (upper picture) and the 100-ft ends (fig. 95). This is the same transect shown in figures 75 and 77. Soil surface items are B = bare ground, G = gravel, R = rock, L = litter, and C = cryptogamic crust. Circle each item occurring in the plot.

PHOTO TREND SAMPLE - 9 SQ.FT. (1 SQ. M)



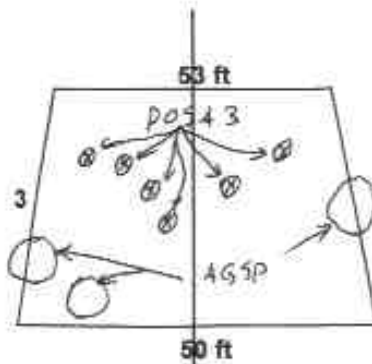
Soil surface: **B G R L C**

Line intercept:

Species	From	To	Feet
ARTR	27	28	1



Camera at the 21.5 foot mark.



Soil surface: **B G R L C**

Line intercept:

Species	From	To	Feet



Camera at the 46.5 foot mark.

Figure 94—Second page of the "Photo Trend Sample - 9 sq. ft. (1 sq. m.)" form locating plots 2 and 3. Plot location foot marks are shown on the left. Camera location foot mark is shown under the photograph. Remember to circle the soil surface items within the plot. Cross out the previous plot number and circle the current one.

PHOTO TREND SAMPLE - 9 sq.ft. (1 sq. m)

SUMMARY

Species	Frequ.	Interc.
POS43	5	
AGSP	4	
ARTM	1	6
LOMAT	2	
PHLOX	1	
BASA		
SIHY	2	

PUTR 1



ACTIVITIES

Logging _____
 Fire _____
 Revegetation _____
 Insects _____
 Wildlife Deer, rabbits
 Other _____

CLIMATE compared to Average

	This Yr.	Last Yr.	Two Yrs.	Three Yrs.	Four Yrs.
Temp	+0 -	+0 -	+0 -	+0 -	+0 -
Ppt.	+0 -	+0 -	+0 -	+0 -	+0 -

Bare soil 5
 Gravel pavement 3
 Rock 2
 Litter 5
 Cryptogams 5

Apparent range condition Good
 Apparent range trend Static

COMMENTS

A hiway enclosure

Estimated Utilization

Species % Use

Figure 95—Summary sheet of the "Photo Trend Sample - 9 sq. ft. (1 sq. m)" form with the 100-ft transect photograph. Frequency of occurrence by species is on the left. Under that is frequency of soil surface items. Fill out appropriate information on the right.

Do the same for plots 3 and 4.

Plot 5 is different. It is photographed in the opposite direction from the others, back down the transect (see number 4, above).

Summarize Data

After sampling, fill in the summary on the last page of form, "Photo Trend Sample - 9 sq. ft. (1 sq. m)" (fig. 95). It is the same summary sheet used with the 1-ft² plots, and the procedure is identical. If the site is forested, tree crown cover must be sampled as discussed below.

Trend Interpretation

Transfer summary data from the last page of the form, "Photo Trend Sample - 9 sq. ft. (1 sq. m)" (fig. 95) to the "Range Trend Rereadings" form (figs. 96 and 97). Fill out the form information and circle "5 plots 9 sq. ft. (1 sq. m)" on the top line. Enter the transect intercept data by date of rereading. Then enter the frequency data by date of rereading (fig. 96). Data were measured for 1997 and constructed for 1957 and 1982.

On the second page (fig. 97), summarize by date and frequency by decreaser, palatable increaser, unpalatable increaser, and invader. Do not add up the frequency ratings from the first page (fig. 96) because frequency of these large plots is not additive. Instead, return to the data forms (figs. 93 and 94) and count the number of plots by species. Often two species in a category, such as unpalatable increasers, will occur in the same plot. The total frequency for unpalatable increasers from figure 96 is 4 but the frequency for the category had a frequency of only 3 (LOMAT, PHLOX, ARTR).

Transfer the soil surface items. Vegetation is any plant root crown, so a frequency of 5 for a species would be a 5 for vegetation. Transfer utilization and climate information. Finally, transfer the estimated range condition and trend information.

Interpretation of change is based on professional judgment and interpretation of photos.

Tree Cover Sample

Tree cover has direct influences on ground vegetation by casting shade. Trend in density and composition of species is often as much influenced by this shade as by grazing or light disturbance. Any transect placed in a forest setting should have tree cover sampled.

Concept

Tree canopy cover significantly influences density and composition of ground vegetation (shrubs and herbs). The effect is so important that documentation of tree cover on forest land transects is strongly recommended. Tree canopies are photographed by using a camera leveling board to assure vertical orientation of the camera (fig. 98).

On a 100-ft transect used for square-foot, nested-frequency, or 9-ft² (1-m²) sampling, photograph tree cover at the 0-, 25-, 50-, 75-, and 100-ft locations. Overhead photos also may be taken with topic photography utilizing a single overhead photo (fig. 52). At 40-percent canopy cover using a 50-mm lens, trees taller than 70 ft will

Text continues on page 169.

RANGE TREND REREADINGS

Circle the sampling system: 20 plots 1 sq.ft, 100 plots Nest. Freq. 5 Plots 9 sq.ft. (1 sq. m)
Area Crooked R. N. G. Allotment Madras Cluster 3 Transect 1 2 3 4 5

<u>Species</u>	<u>Averages by Year</u>							
	1957	1982	1997					
Tree Crown Cover (in percent)								
TOTAL								
Shrub intercept (in feet)								
ARTR	5	6	6					
PATR	-	-	1					
CHNA	-	-	-					
TOTAL								
Frequency: No. plots for 1 sq.ft. & 9 sq.ft. (1 sq. m); nested frequ. value								
POSA3	5	5	5					
AGSP	3	4	4					
LOMAT	3	2	2					
PHLOX	1	1	1					
BASA								
SIHY	2	2	2					
STOC	1							
ARTR	2	1	1					

OVER FOR ADDITIONAL DATA

Figure 96—The filing system form “Range Trend Rereadings” where the transect data are compared to previous readings. Fill in the required information and circle “5 plots 9 sq. ft. (1 sq. m).” Transfer information from figure 95 to this form.

RANGE TREND REREADINGS (Continued)

Elements	Averages by Year									
	1957	1982	1997							
Range Condition Guide/date <i>none</i>	—	—	—							
Decreasers:	3	4	4							
Palatable Increases	5	5	5							
Unpalatable Increases	4	3	3							
Invaders	—	—	—							
Vegetation - (root crown)	5	5	5							
Bare Soil	4	3	5							
Gravel (1/8 to 3/4 inch)	5	5	3							
Rock (> 3/4 inch)	2	2	2							
Litter	5	5	5							
Cryptogams	4	5	5							
% Utilization by species										
<i>None - exlosure</i>										
Season of Use										
Climate										
Temp: Current	+	0	0							
Last year	0	0	0							
2 yrs. Ago	0	+	0							
3 yrs. Ago	0	0	—							
4 yrs. Ago	—	0	—							
Ppt.: Current	0	+	+							
Last year	0	+	+							
2 yrs. Ago	0	0	0							
3 yrs. Ago	—	0	0							
4 yrs. Ago	+	0	—							
Apparent range condition	P	P	F							
Apparent range trend	S	S	S							

Figure 97—Second page of the "Range Trend Rereadings" form where previous information is compared. See text for details.

appear in adjacent pictures providing a continuous 100-ft transect of tree cover. If a 35-mm lens is used, trees over 50 ft tall will provide a continuous strip. Whatever focal length is used to begin, the **same focal length** must be used for subsequent photos. Long axis of the camera should be across the transect.

Equipment

The following equipment is required for sampling tree cover:

1. Camera or cameras with both color and black-and-white film, or digital camera
2. A camera leveling board (app. C)
3. Form from appendix B for data and photo mounting: "Photo Trend Sampling - Tree Cover"
4. Meter board (app. C) to set the leveling board and camera on
5. A compass and 100-ft steel tape with clamps or vice grips to clamp onto angle iron stakes used for ground vegetation sampling
6. Fenceposts and angle iron stakes sufficient for the number of transects desired: 2 fenceposts and 3 angle iron stakes per transect and pounder (these are on the equipment list for ground vegetation sampling system)
7. Metal detector for locating transect stakes

Technique

On the 100-ft transect used for square feet, nested frequency, or 9-ft² sampling, photograph tree cover at the 0-, 25-, 50-, 75-, and 100-ft marks. Position the meter board at each of the foot marks, place the camera leveling board on top of the meter board, and set the camera on the leveling board with the long axis perpendicular to the transect and the viewfinder toward the 0-ft mark (fig. 98).

Move the meter board sideways to level the camera board cross-transect. Then level the camera board down-transect, bend down to take your head out of the picture, and photograph (fig. 98).

Important criteria—There is neither a size control (meter board) nor photo identification sheet in these pictures. Four procedures, therefore, **must** be followed:

1. The same focal length lens must be used for all subsequent photographs so images can be compared. Note the effects of focal length in figures 6 and 7.
2. The camera must be the same height aboveground. Use the meter board for consistent heights. Figures 2 and 3 illustrate the effect of change in distance using the **same focal length** lens.
3. Make sure the camera is oriented perpendicular to the transect with the viewfinder toward the 0-ft mark (fig. 98). Remember this by viewing the transect through the camera, and then rotating it 90 degrees upward to view the canopy. This camera orientation helps with placement of photos on the form. There is no "right side up" on these photos. Their orientation can be determined only by the exposure numbers at the bottom of the film.
4. Write down the film exposure number and the cluster and transect data so that negatives can be identified and picture orientation determined.



Figure 98—Tree canopy cover photography system. A meter board is placed crosswise (perpendicular) to the transect at foot marks 0, 25, 50, 75, and 100. Hold camera level board on top of the meter board and place the camera on the level board. First center the cross-transect level by moving the meter board sideways. Then tilt the camera level board so the down-transect-level is centered, move your head out of the camera view, and photograph.

Summarize Data

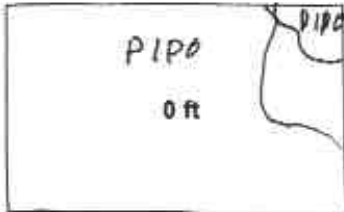
Attach crown cover photos to the filing system form, "Photo Trend Sampling - Tree Cover" (figs. 99 and 100). Fill out information on the top two lines. Roughly diagram canopy outlines and label by species for identification. Then proceed as follows to determine canopy cover on each photo (figs. 99 and 100):

1. Print on clear plastic five copies of the grid analysis outline form (fig. 54), one for each photo. Tape along one edge over a photo and enter information for the photo (fig. 101). Outline the tree canopies carefully and identify by letter or number.
2. Print (without size adjustment on white paper) a copy of the analysis grid for shrub analysis (grid with meter boards at each edge) from appendix B. Remove the outline overlay from the photo and tape onto the grid. Orient the outline overlay on the bottom line of the grid and next to the left meter board but one grid line to the right (fig. 101). The top and right edges of the outline probably will fall between grid lines.
3. Determine the total number of grid intersects on the picture. Remember to count the left and bottom grid lines to determine total number. In figure 101, there are 26 grid lines across and 17 up for a total of 442 intersects.

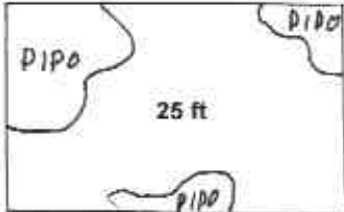
Text continues on page 174.

PHOTO TREND SAMPLING - TREE COVER

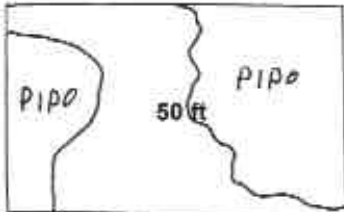
Area Prairie City Allot. Blue mtn Thin-wide Date 95/8/25
Investigator ECV Sampling system 3-step Cluster 1 Transect: (1) 2 3 4 5



Species	Cover	Species	cover
<u>PIPO</u>	<u>92%</u>	_____	_____%
_____	_____%	_____	_____%
_____	_____%	TOTAL	_____%



Species	Cover	Species	cover
<u>PIPO</u>	<u>30%</u>	_____	_____%
_____	_____%	_____	_____%
_____	_____%	TOTAL	_____%



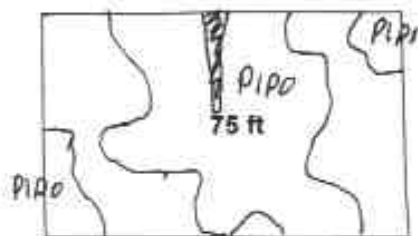
Species	Cover	Species	cover
<u>PIPO</u>	<u>64%</u>	_____	_____%
_____	_____%	_____	_____%
_____	_____%	TOTAL	_____%



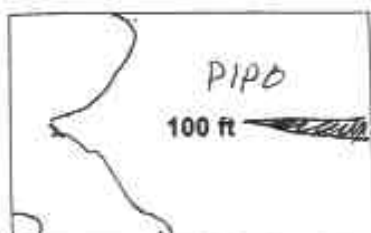


Figure 99—Filing system form "Photo Trend Sampling - Tree Cover" used to mount tree canopy cover photos and to estimate cover. Percentage of cover is determined by dot or intersect grid analysis (illustrated in fig. 101). Diagrams of cover are used to identify species, not to determine the percentage of cover (PIPO: *Pinus ponderosa* P. & C. Lawson, ponderosa pine).

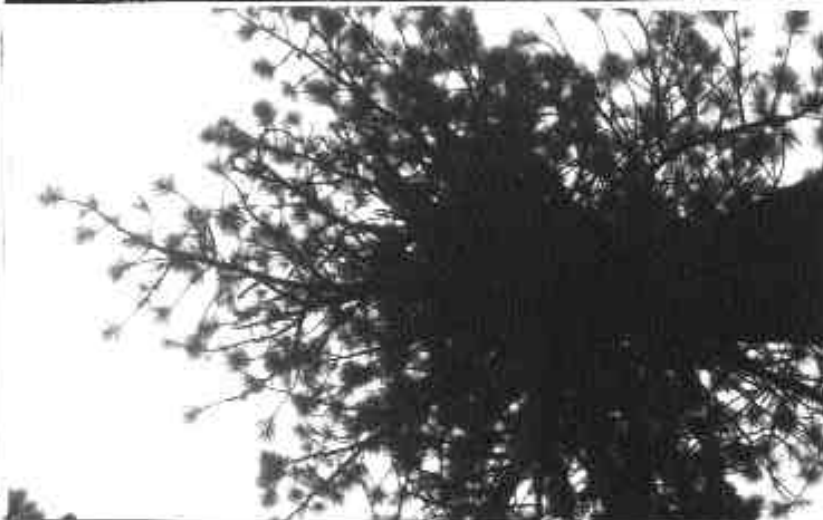
PHOTO TREND SAMPLING - TREE COVER



Species	Cover	Species	cover
PIPO	70%		%
	%		%
	%	TOTAL	%



Species	Cover	Species	cover
PIPO	74%		%
	%		%
	%	TOTAL	%



SUMMARY

Ave.

Species % cover

PIPO	66

$$SD = 22.67$$

$$SE = 10.18$$

$$CI_5 = 28.3$$

Figure 100—Second page of the "Photo Trend Sampling - Tree Cover" form with the cover summary. In this case, statistical analysis results were added: SD = standard deviation, SE = standard error, and CI_5 = the confidence interval at the 5-percent level of probability.

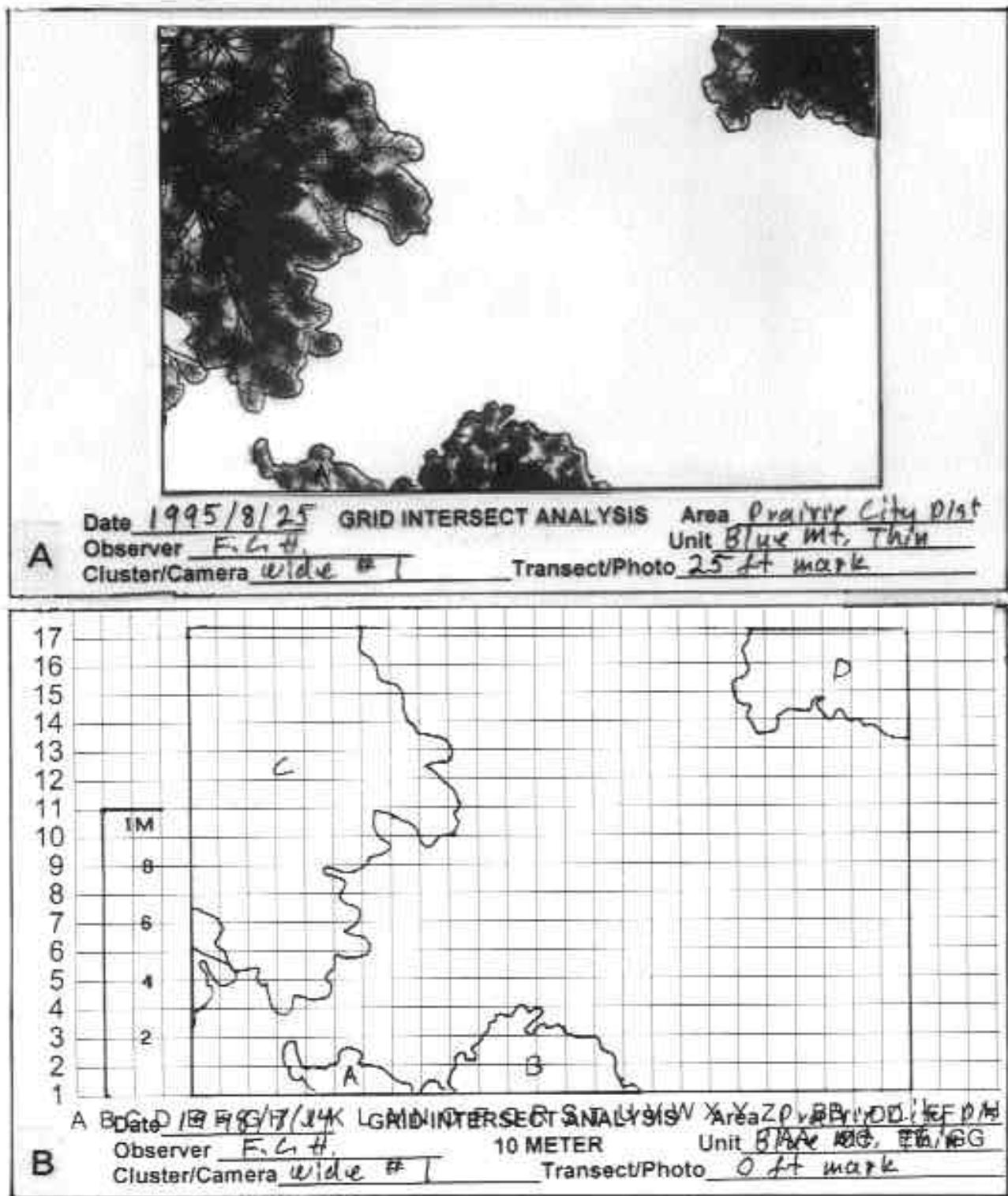


Figure 101—Determination of tree canopy cover using grid intersect. The grid intersect outline form printed on clear plastic is overlaid on photo **A** and tree canopies outlined, here for the 25-ft photo (fig. 99). Then in **B**, the outline is placed on the shrub analysis grid (with meter boards at each side) and printed on paper. Intersects within each tree canopy outline are counted (131) and divided by the total number of intersects within the photo (442, or 17×26) for 30-percent canopy cover.

4. Decide if tree canopy or open space will be counted. To ease counting, I prefer to count the item of least coverage: open space in the 0-ft picture of figure 99 and tree cover in the 25-ft picture (fig. 99). Count grid intersects on the left edge and bottom of the photograph. When counting open space, subtract the grid intersects from the total to determine canopy cover. In figure 101, the number of grid intersects falling on the tree canopy is 131. Percentage of cover is $131 \div 442 = 29.6$, or 30-percent canopy cover.
5. For each photo, list canopy cover by species on the left of the filing system form, "Photo Trend Sampling Tree Cover," under the canopy diagram. Retain each outline as a permanent data form.
6. Add canopy cover for each photo, average, and enter in the summary shown in figure 100: a total of 330 divided by 5 is an average of 66-percent canopy cover.

Trend Interpretation

If there are five samples for statistical analysis of change, the mean of 66.0 will have a standard deviation of 22.7, a standard error of 10.2, and a confidence interval at the 0.05-percent probability level of 28.3 (fig. 100). The Student's T-test may be used to evaluate significant change in tree canopy cover between two data sets.

Usage Measured by Robel Pole

Stubble height of vegetation remaining after livestock grazing indicates animal preference for certain areas, may be used to adjust animal distribution, and suggests intensity of utilization. The Robel pole system documents this stubble height.

Concept

The basic concept is to measure stubble height, or ungrazed herbaceous height, by using a pole marked in inches and photographing it (a "visual observation") from a specific distance and height aboveground. Robel and others (1970) discuss the mathematics and test results. Guenther (1998) used the same concept to estimate annual grass herbage production in California. He uses two views: one from 20 ft and another from 10 ft. A 0.96-ft² hoop is placed at the base of the pole for visual reference.

The pole is 2.5 in in diameter and marked in alternate black bands by inches (fig. 102). A 4-m-long line is attached at 1-m height on the Robel pole and connected to the top of a 1-m-tall line pole (app. C). The Robel pole is set at the sample location (station) while the line is stretched and a photograph taken (visual observation) from the top of the line pole (fig. 103). Landscape orientation seems to be better than portrait for depicting utilization, because the former broadens the view at the Robel pole.

The location of the Robel pole is termed a "station" from which two visual observations are made: one in the direction of the transect and a second 180 degrees backwards to the start of the transect.

These consistently used measurements, 4-m distance and 1-m height of camera (4-to-1 ratio), provide repeatable angles for documenting stubble height (Robel and others 1970).

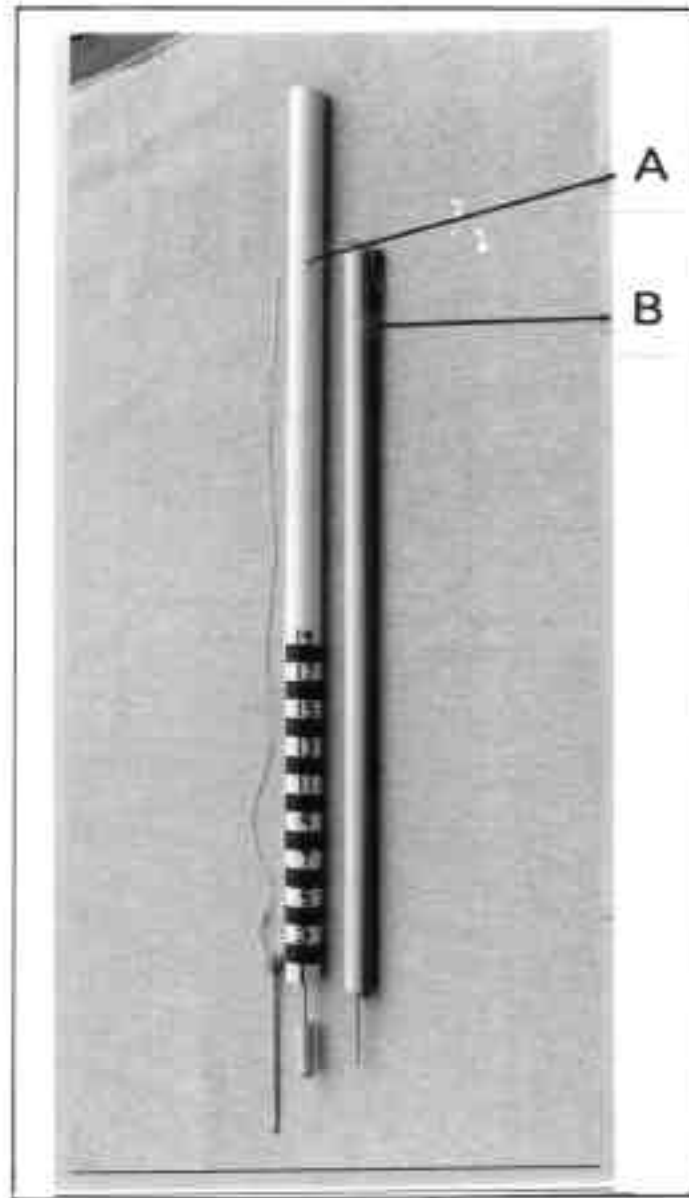


Figure 102—Robel pole has two main parts: the Robel (measuring) pole (A) and the camera height pole (B). The Robel pole is 2.5 in diameter and the camera height pole 1.5 in so the latter will fit inside the Robel pole. “A” points to an eye where a 4-m long line is attached. The line is shown wrapped around the camera height pole in B. A tent peg with 2 m of line may be used to hold the Robel pole when one person is sampling. See appendix D for details.

Transects generally are not permanently located with fenceposts and steel stakes. A fencepost marking a sampling station may significantly alter domestic livestock use owing to its physical presence. If permanent transects are desired, they should be located with fenceposts identifying the transect start and end. They may be set at visual observation camera locations with the station located by a steel stake driven flush with the ground. A metal detector is needed for relocation (White’s Electronics, Inc. 1996).

Equipment

The following equipment is required for Robel pole transect sampling:

1. Camera or cameras with both color and black-and-white film, or digital camera
2. Robel pole with its 4-m line and a line pole (fig. 102, app. C)



Figure 103—Technique for photographing the Robel pole. In this case, the camera is held in the “portrait” or vertical position. I prefer the “landscape” or horizontal camera orientation (see fig. 106) because it covers a broader area of ground at the Robel pole. Spikes on the bottom of the Robel pole and line pole (fig. 102) are 1/4-in steel rod 6 in long, which are capable of holding both poles upright.

3. Forms from appendix B for transect identification, “Cluster – Transect,” and station identification, “Utilization - Robel Pole,” both printed on medium blue paper, and data and photo-mounting form, “Utilization - Robel Pole Sampling,” printed on medium yellow paper
4. Meter board (app. C)
5. Clipboard and support for holding photo identification sheet (app.C)

Technique

Site selection is a function of animal use and management objectives. For this illustration, a moist meadow in forested rangeland was selected because it is the most palatable kind of vegetation in the area and because it is adjacent to a water hole. Provide the usual two maps: one to locate the sampling area (fig. 104) and another to map the sampling transect (fig. 105). Draw a map on the filing system form, “Sampling Site Description and Location” and fill in necessary information.

1. Determine the number of transects and number of visual observation stations per transect. Then determine the direction of each transect and the interval between stations. All are influenced by two factors: homogeneity of vegetation and uniformity of animal use. Record and map transects on the filing system form, “Sampling Site Description and Location” (fig. 105). The filing system form, “Utilization - Robel Pole Sampling,” provides for 25 stations and 50 observations (fig. 106).

LONG CREEK RANGER DISTRICT MALHEUR NATIONAL FOREST

Pacific Northwest Region

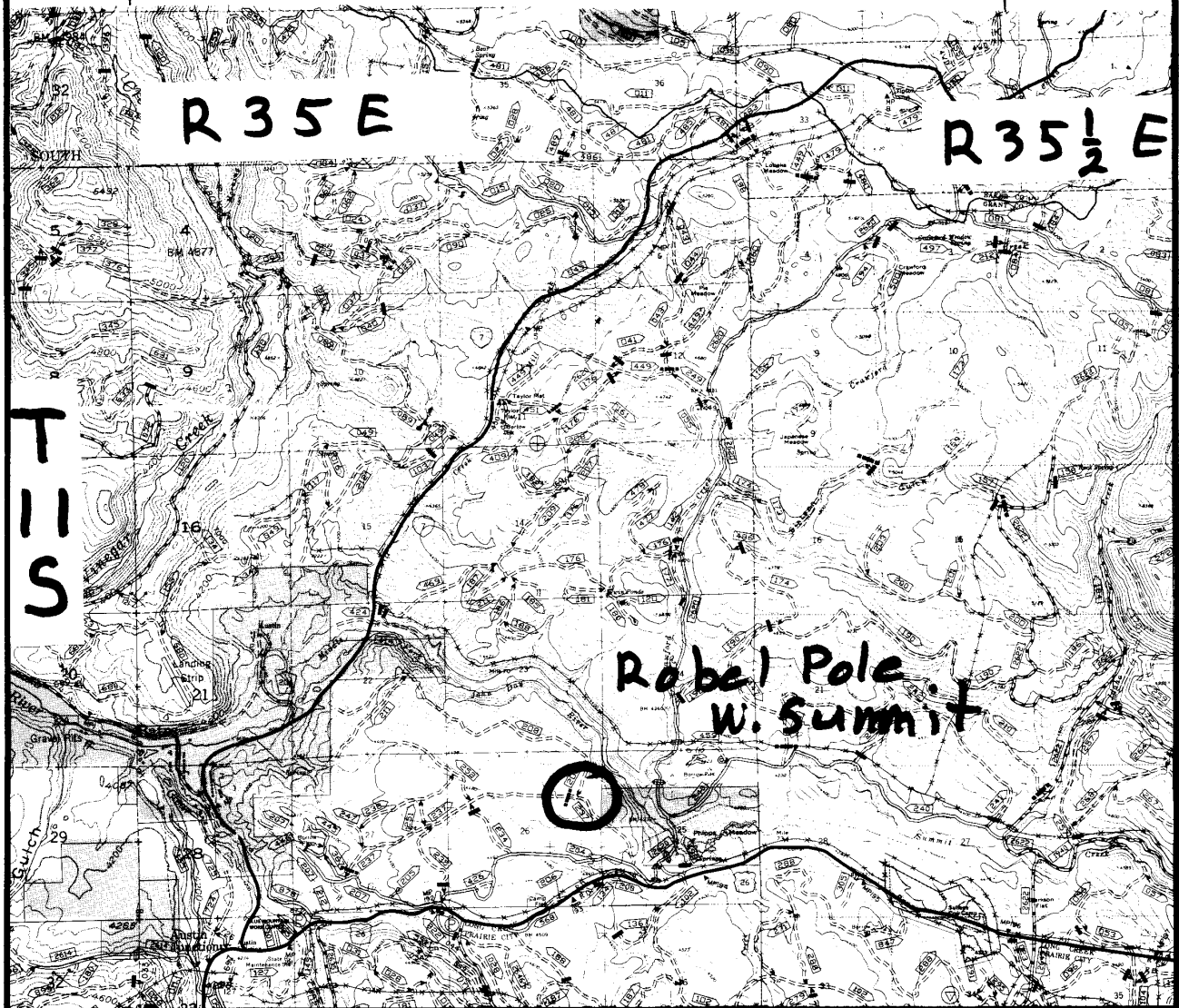


Figure 104—Ranger District map of the Robel pole utilization sampling site. It is on the West Summit Allotment at a road junction. Figure 105 shows the precise location.

SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft. Nested Freq. 1 sq.m. Robel Pole Shrub Form _____

Date 1997/7/7 Site Data: Elev. 4525 % slope 2°6
 Area Long Cr. Dist. Slope aspect: N NE E SE S SW W NW
 Allot. West Summit Slope position: top up 1/3 mid low 1/3 bottom
 Cluster No. 1 Micro topography: convex flat concave
 Transects: ① 2 3 4 5 Macro topography: flat undulating rolling
 Plant community POPR steep rough broken
meadow Geology:

Grazing system: Deposition: wind stream lake colluvial
 Type RR Date _____ residual _____
 Type _____ Date _____ Material: limestone mudstone sandstone
 Type _____ Date _____ granite serpentine diorite
 Kind of animal: cattle sheep basalt andesite rhyolite
 horses goats deer tuffaceous cinders pumice ash
 elk _____ Soil: Restrictive layer: absent clay pan bedrock
 cemented

Location: T. 11S R. 35E Surface compaction: none moderate severe
 Sec. 26 SE of NE Soil profile stone: absent gravel stony
 Description: Rd 237; 0.65 mi Soil texture: sandy loamy silty clayey ashy
from junct rd 204; at Other notes: _____
water hole; PP at rd Stations at 8 yd intervals
fork 24" DBH - tagged

MAP

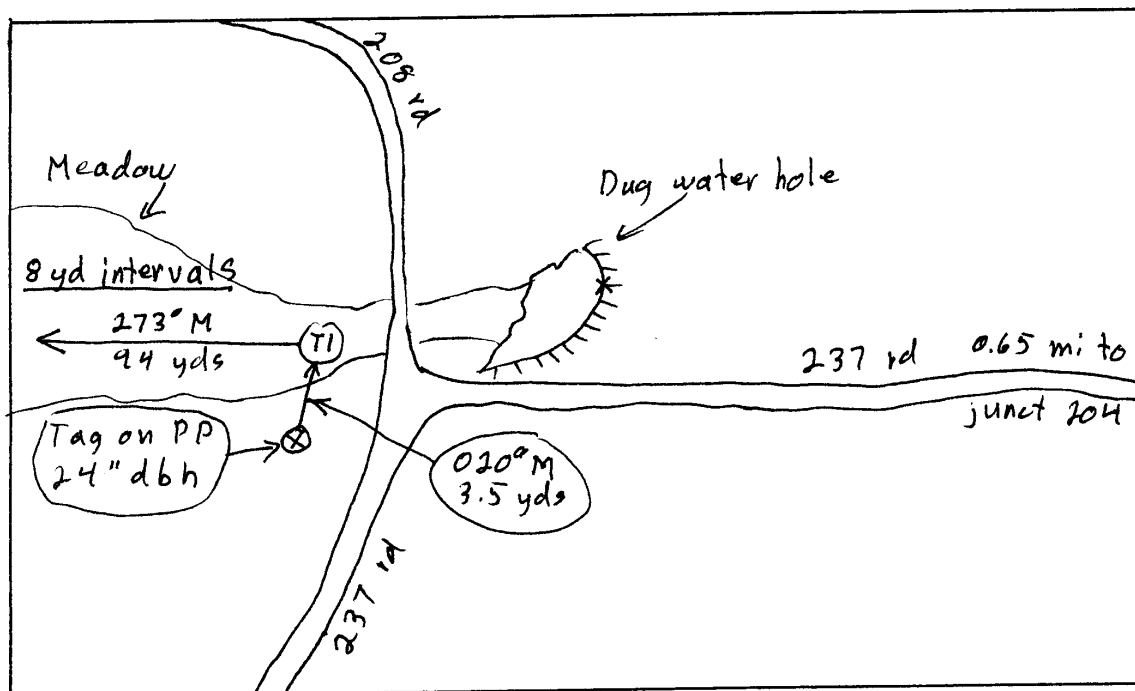


Figure 105—Filing system form "Sampling Site Description and Location" with information and transect location diagrammed. Remember to circle the sampling system, "Robel Pole," on the first line.

2. In this illustration, the meadow is small, oblong, and homogeneous. Only one transect is needed with 10 stations. The transect is oriented lengthwise and calls for a compass heading of 273 degrees magnetic and a total distance of 94 yd, which results in 8-yd intervals between stations (fig. 105).
3. Mark station 1 of the transect with the meter board. Place the camera location fencepost 10 m distant on the transect line. Fill out the transect photo identification form, circle the "0," place it at 5 m, and photograph the transect (fig. 106 A).
4. At the first station, fill out the photo identification form, "Utilization - Robel Pole Sampling," printed on medium blue paper; circle "1A," and place next to the Robel pole at the station (fig. 106 B). Extend the line its full 4 m along the transect toward the fencepost that locates the transect. Set the line pole on the transect line, and photograph the Robel pole with the bottom of the pole in the center of the photo (fig. 106B). Focus on the pole to assure the sharpest image.
5. Using the filing system form, "Utilization - Robel Pole Sampling," printed on medium yellow paper (fig. 106), fill in the first page. Then opposite "Visual Observation 1A" (station 1), record the stubble height, any comments, and the one to three species immediately in front of the pole that are being measured for stubble height. In this case, Kentucky bluegrass and analogue sedge are intermixed (fig. 106 B). Stubble is shown on the white "3" band with very little on the black "4" band. Record 3 for stubble height (3 in).
6. Next, move to the opposite side of station 1, 180 degrees, for visual observation 1B (fig. 106C). Pick up the line pole, turn the Robel pole and the photo identification paper around, cross out "1A" and circle "1B" on the identification paper, extend the line, and repeat the photography (fig. 106C). Record on the "Utilization - Robel Pole Sampling" form, in the "Visual Observation 1B" space, species being measured, the stubble height, and any comments. In this case, Kentucky bluegrass and California oatgrass are intermingled. Stubble is shown on the black "2" band and not on the white "3" band for a height of 2 in.
7. For the next station, determine direction and step off the required distance, in this case 8 yd. Forms in appendix B following the first page of "Utilization - Robel Pole Sampling" do not have visual observation (station) numbers, but a blank space instead (fig. 107). Print sufficient sheets for the number of stations. Then enter appropriate visual observation (station) numbers. Thus each station has its own page. Take photographs, data, and notes as discussed above (fig. 106).
8. Repeat for each station (figs. 107 and 108). At the end of the transect (fig. 108C), establish a fencepost 10 m beyond the last station. On the transect photo identification sheet, cross out the "0" and circle "100" to indicate the end of the transect. Photograph the transect looking toward the "0" end.

Text continues on page 184.

UTILIZATION - ROBEL POLE SAMPLING	
Date <u>1997/7/7</u> Cluster <u>1</u> Transect: <u>① 2 3 4 5</u>	
Area <u>Long Cr. Dist</u>	
Allot. <u>West Summit</u>	
Investigator <u>ECV</u>	
Season of use <u>Spring</u>	
Grazing system: <u>Rest-Rotation</u>	
Remarks: <u>moist meadow adjacent to water hole. (Spring use)</u>	
Visual Observation 1A: Stubble height: <u>3</u> Comments: <u>light use,</u>	
Species: <u>POPR, CASI</u>	
Visual Observation 1B: Stubble height: <u>2</u> Comments:	
Species: <u>POPR, DACA</u>	

Figure 106—The filing system form “Utilization - Robel Pole Sampling” is used to mount pictures, record stubble height, and identify species at the Robel pole. Only those species immediately in front of the pole, whose stubble height is being photographed, are listed. (A) Looking down the transect with station 1 at the meter board. Both visual observations of station 1 are shown: (B) down the transect, and (C) 180 degrees reversed and looking up the transect. The fencepost marks the camera location and start of the transect. Species are POPR (*Poa pratensis* L., Kentucky bluegrass), CASI (*Carex simulata* Mackenzie, analogue sedge), and DACA (*Danthonia californica* Boland, California oatgrass). Species in front of the Robel pole **must** be recorded. The line upper right in B and C is the 4-m-long line measuring distance from camera to pole.

UTILIZATION - ROBEL POLE SAMPLING

Visual Observation # 2 A
 Stubble height: 2
 Comments: POPR lowest stubble
ht.

 Species: POPR, CASI
Little use on 24B4

Visual Observation # 2 B
 Stubble height: 4
 Comments: POPR lowest stubble
ht.

 Species: POPR, CASI

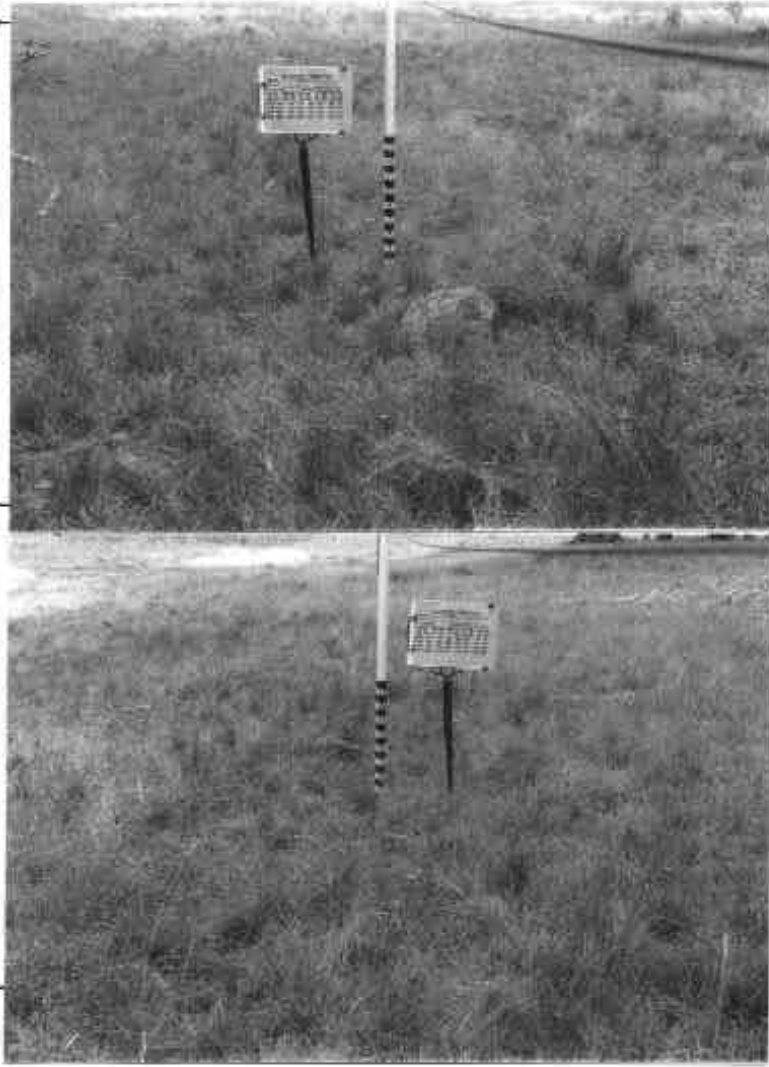


Figure 107—Second page of form “Utilization - Robel Pole Sampling” illustrating documentation and photographs of station 2. On this form at the top, enter the station number in the blank at “Visual Observation # ____ A”. Remember, on the photo identification form, to cross out “1B” and circle “2A” before photographing. Notes often are valuable in these situations.

UTILIZATION - ROBEL POLE SAMPLING

Visual Observation # 10 **A**
 Stubble height: 4
 Comments: _____

Species: DACA, JUBA

Visual Observation # 10 **B**
 Stubble height: 3
 Comments: _____

Species: CASI, JUBA

Photograph from end of transect

Comments: Cows removed at 3" stubble of DACA. All other spp with taller stubble hts.



A



B



C

Figure 108—Last page of the form "Utilization - Robel Pole Sampling" with the last station, number 10 in **A** and **B**, and a transect view toward the 0-ft end (**C**). The camera is 10 m from the last station and the photo identification sheet is halfway between camera and meter board. JUBA is *Juncus balticus* Willd., baltic rush. Remember to cross out the "0" and circle "100."

UTILIZATION - ROBEL POLE SUMMARY

Date 9/7/77 Examiner: EG Kell
 Area Long Cr. Dist. Allotment West Summit
 Cluster 1 Transect: ① 2 3 4 5 Sampling interval 8 yrd

Station	VO "A"	VO "B"	Species	
			"A" (Front)	"B" (Back)
1	3	2	POPA, CASI	POPA, DACA
2	2	4	" , "	" , "
3	2	3	" , DECE	" , DECE
4	3	3	" , "	" , "
5	6	6	" , "	" , DACA
6	4	5	DECE, DACA	DECE, JUBA
7	3	3	DACA, DECE	" , "
8	7	5	JUBA, DACA	DACA, DECE
9	3	4	DACA, JUBA	" , JUBA
10	4	3	" , "	CASI , "
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
Total	37	38		
Grand Total	75			
Average	3.75			

SD = 1.41
 SE = 0.32
 CI₅ = 0.66

Cluster Summary

Trans 1 3.75
 Trans 2 _____
 Trans 3 _____
 Trans 4 _____
 Trans 5 _____
 AVE _____

Figure 109—Filing system form "Utilization - Robel Pole Summary" with location information, stubble heights, and species taken from the transect data and photo-mounting form. Add the stubble heights in each column (37 and 38), total the columns (75), and determine the average ($75 \div 20 = 3.75$). The average stubble height is 3.75 in. Variability in stubble height may be calculated by determining the standard deviation (SD), standard error (SE), and the confidence interval at the 5-percent confidence level (CI₅). These have been entered on the form. The stubble height is 3.75 ± 0.66 in, at the 5-percent confidence level.

Summarize Data

Add each of the stubble height columns: visual observation A ("VO A") is 37 and "B" is 38; then add the column totals: $37 + 38 = 75$. Determine the average stubble height for 20 observations: $75 \div 20 = 3.75$. In this example, the standard deviation (SD) was 1.41, standard error of the estimate (SE) was 0.32, and the 5-percent confidence interval (CL_5) was 0.66, which were recorded on the form. These data also may be used to determine significant differences among transects by using the Student's t-test. In this case, the stubble height was 3.75 in ± 0.66 in at the 5-percent probability level.

Literature Cited

Guenther, Keith. 1998. Residual dry matter (RDM) monitoring photo guide. Clyde, CA: Wildland Solutions [234 Park Street, 94520].

Hall, Frederick C. 1976. Range trend sampling by photographs. R6 Regional Guide 2-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 50 p.

Parker, K.W. 1954. A method for measuring trend in range condition on National Forest ranges with supplemental instructions for measurement and observation of vigor, composition, and browse. Admin. Publ. Washington, DC: U.S. Department of Agriculture, Forest Service. 37 p.

Parker, K.W.; Harris, R.W. 1959. The three-step method for measuring condition and trend of forest ranges: a resume of its history, development, and use. In: Techniques and methods of measuring understory vegetation: Proceedings of a symposium; 1958 October; Tifton, GA. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 55-69.

Reppert, Jack N.; Francis, Richard E. 1973. Interpretation of trend in range conditions from 3-step data. Res. Pap. RM-103. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 15 p.

Robel, R.J.; Briggs, J.N.; Dayton, A.D.; Hulbert, L.C. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management. 23: 295-297.

White's Electronics, Inc. 1996. Classic II SL™. Sweet Home, OR: White's Electronics, Inc. [1011 Pleasant Valley Road, 97368].

Appendix B: Blank Forms for Photo Monitoring

This appendix contains forms for photo monitoring. To be of the most use, they need to be copied onto three paper colors or overhead projection clear plastic, depending on their use. Office forms are printed on standard white paper. Field forms are printed on either of two colors: blue paper to place in photographs to identify each photo or yellow paper to ease eye strain for field forms. Outline forms for grid analysis are printed on clear plastic. Grids and summary forms are printed on white paper. Paper colors I've found suitable for each form are shown in **bold**.

White paper is used for summary forms and for grids adjusted to size of the outline overlays.

Blue paper is Hammermill Brite Hue Blue® or Georgia Pacific Papers Hots Blue®, or equivalent, used in the actual photographs for identification. This shade of blue has proven to be least sensitive to changes in sunlight, from full sun to shade, and has the least tendency to "bleach out" in full sun.

Yellow paper is Champion Goldenrod® or Hammermill Copy Plus GOLDENROD®, or equivalent, to be used for field forms. It has proven to be the least annoying in direct sunlight for field recording data, maps, diagrams, and other descriptions.

Clear plastic sheets for printing outline overlays are 3M® or Labelon® Overhead Transparency Film. These films are specifically designed for different printers such as laser, inkjet, or plain paper.

These forms are printed here at 90 percent of their original size. To reproduce at full size on 8½- by 11-inch paper, set the copy machine for a 110-percent enlargement.

Page and figure numbers for examples of their use are given in the following list.

Paper and form	Page	Figure examples
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Shrub photo sampling	194	67-68
Square-foot frequency	195	75-77
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Utilization, Robel pole	198-199	106-108
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Photo mounting and data forms, printed on yellow paper :		
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Summary forms, printed on white paper :		
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Nested frequency transect data	255-256	86-87
Nested frequency cluster summary	256-258	88-89
Utilization - Robel pole summary	270	109

Paper color found best for photo identification forms is this color blue.

It is **Hammermill Brite Hue Blue®**

or **Georgia Pacific Papers Hots Blue®**

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Paper color that is easy on the eyes and used for transect data collection as well as photo mounting is this color.

It is **Champion Goldenrod®**

or **Hammermill Copy Plus GOLDENROD®**

/

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DATE _____ **0 100**

AREA _____

ALLOT. _____

CLUSTER _____

TRANS. **1 2 3 4 5**

DATE

AREA

UNIT

CAMERA: 1 2 3 4 5

PHOTO: A B C D

E F G H I J

DATE

AREA

UNIT

CAMERA: 6 7 8 9 10

PHOTO: A B C D

E F G H I J

SHRUB PHOTO SAMPLING

DATE _____ **0** **END** _____

AREA _____

ALLOT. _____

TRANSECT **1** **2** **3** **4** **5** _____

SHRUB **1A 1B** **2A 2B** **3A 3B**

4A 4B **5A 5B** **6A 6B** **7A 7B**

8A 8B **9A 9B** **10A 10B**

SQUARE FOOT FREQUENCY

DATE _____ AREA _____

ALLOT. _____

CLUSTER _____ TRANS: 1 2 3 4 5

PLOT	1	2	3	4	5	6	7	8	9	10
FEET	0 - 1	5 - 6	10 - 11	15 - 16	20 - 21	25 - 26	30 - 31	35 - 36	40 - 41	45 - 46
	11	12	13	14	15	16	17	18	19	20
FEET	50 - 51	55 - 56	60 - 61	65 - 66	70 - 71	75 - 76	80 - 81	85 - 86	90 - 91	95 - 96

NESTED FREQUENCY

DATE _____ AREA _____

ALLOT. _____

CLUSTER _____ TRANS: 1 2 3 4 5

PLOT 1 2 3 4 5 6 7 8 9 10
FEET 0 - 1.6 5 - 6.6 10 - 11.6 15 - 16.6 20 - 21.6 25 - 26.6 30 - 31.6 35 - 36.6 40 - 41.6 45 - 46.6

11 12 13 14 15 16 17 18 19 20
FEET 50.- 51.6 55 - 56.6 60 - 61.6 65 - 66.6 70 - 71.6 75 - 76.6 80 - 81.6 85 - 86.6 90 - 91.6 95 - 96.6

9 SQ.FEET – 1 SQ. METER

DATE

AREA

ALLOT.

CLUSTER

TRANSECT: 1 2 3 4 5

PLOT:

1 2 3 4 5

FEET

3.5-6.5 25-28 50-53 75-78 96.5-93.5

METERS

1-2 7-8 15-16 22-23 29-28

UTILIZATION - ROBEL POLE

Date _____ Cluster _____

Area _____

Allot. _____

Transect: 1 2 3 4 5

1A 1B 2A 2B 3A 3B 4A 4B

5A 5B 6A 6B 7A 7B 8A 8B

9A 9B 10A 10B 11A 11B

12A 12B 13A 13B 14A 14B

UTILIZATION - ROBEL POLE

Date _____ Cluster _____

Area _____

Allot. _____

Transect:	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
15A 15B	16A	16B	17A	17B	
18A 18B	19A	19B	20A	20B	
21A 21B	22A	22B	23A	23B	
24A 24B	25A	25B			

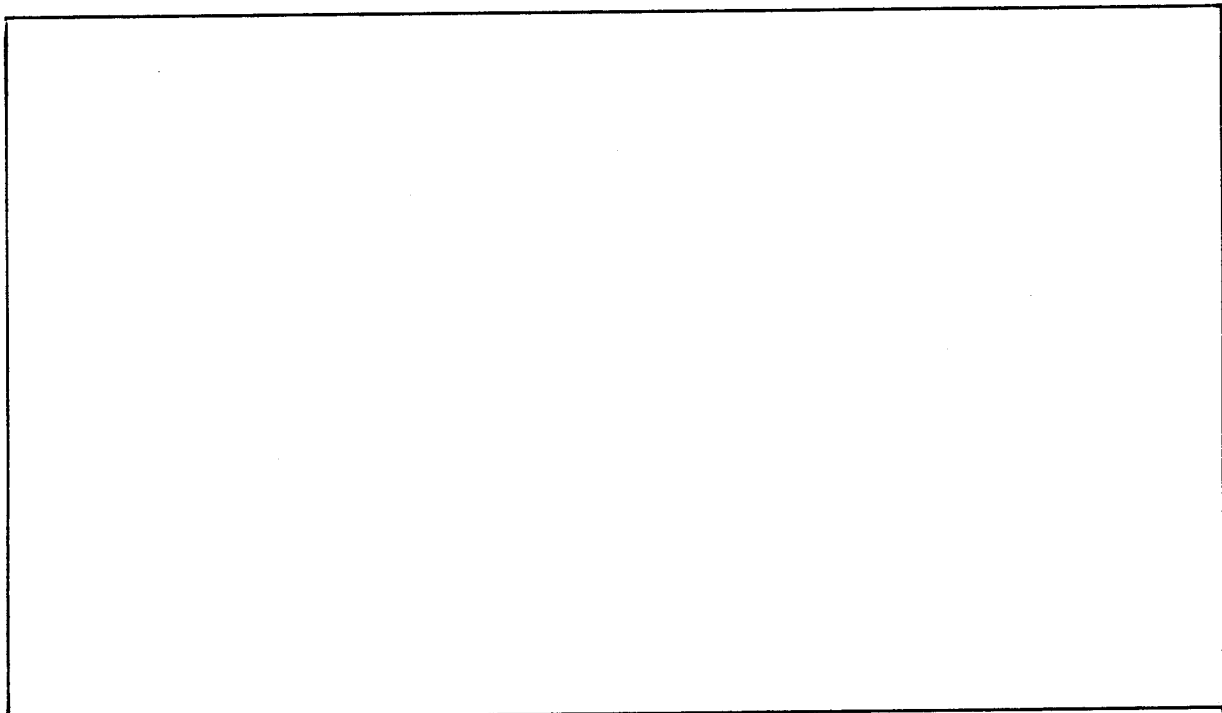
SAMPLING SITE DESCRIPTION AND LOCATION

Circle: 1 Sq.Ft. **Nested Freq.** 1 sq.m. **Robel Pole** **Shrub Form** _____

Date _____ Area _____ Allot. _____ Cluster No. _____ Transects: 1 2 3 4 5 Plant community _____ Grazing system: Type _____ Date _____ Type _____ Date _____ Type _____ Date _____ Kind of animal: cattle sheep horses goats deer elk _____	Site Data: Elev. _____ % slope _____ Slope aspect: N NE E SE S SW W NW Slope position: top up 1/3 mid low 1/3 bottom Micro topography: convex flat concave Macro topography: flat undulating rolling steep rough broken Geology: Deposition: wind stream lake colluvial residual _____ Material: limestone mudstone sandstone granite serpentine diorite basalt andesite rhyolite tuffaceous cinders pumice ash Soil: Restrictive layer: absent clay pan bedrock cemented _____ Surface compaction: none moderate severe Soil profile stone: absent gravel stony Soil texture: sandy loamy silty clayey ashy Other notes: _____ _____ _____
--	---

Location: T. _____ R. _____
 Sec. _____
Description: _____

MAP



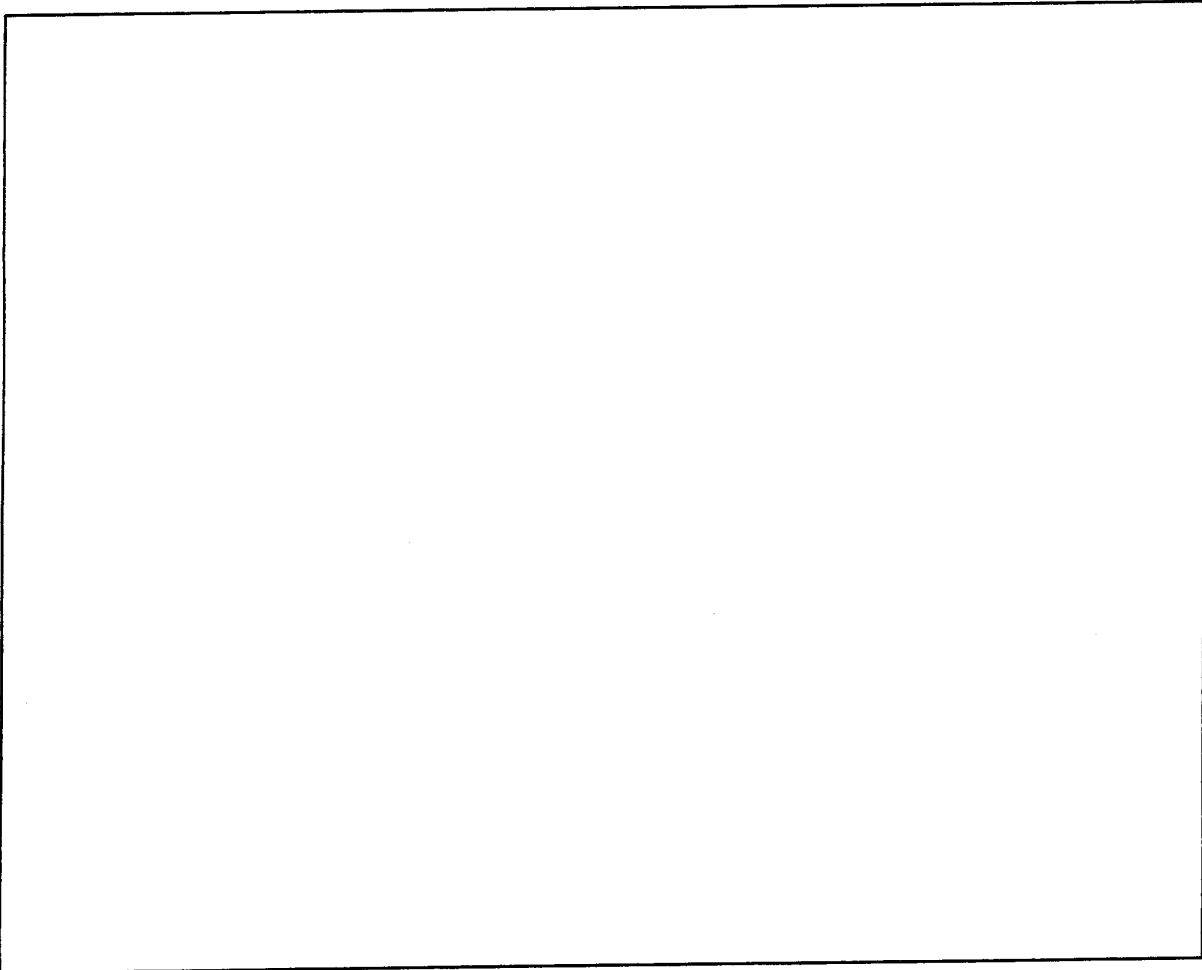
PHOTOGRAPHIC SITE DESCRIPTION AND LOCATION

Date _____ Area _____
Unit _____ Observer: _____
No. of Camera locations: _____ No. of Photo points: _____
Plant community _____
Location: T. _____ R. _____ Sec. _____
Location description _____

Photo purpose: _____

Discussion: _____

MAP



Use back of sheet for additional details.

CAMERA LOCATION AND PHOTO POINTS

Date _____ Camera Location _____
Area _____ Number of Photo points: _____
Unit _____ Observer _____
Comments _____

Slope _____ Aspect _____ Slope position _____

Photo point A:
Compass bearing: _____
Distance: _____

Photo Point A

Photo point B:
Compass bearing: _____
Distance: _____

Photo Point B

CAMERA LOCATION AND PHOTO POINTS

Photo point C _____
Compass bearing: _____
Distance: _____

Photo point C

Photo Point D: _____
Compass bearing: _____
Distance: _____

Photo point D

Photo Point E: _____
Compass bearing : _____
Distance: _____

Photo point E

CAMERA LOCATION AND PHOTO POINTS

Photo Point F: _____
Compass bearing: _____
Distance: _____

Photo point F

Photo Point G: _____
Compass bearing: _____
Distance: _____

Photo point G

Photo Point H: _____
Compass Bearing: _____
Distance: _____

Photo point H

CAMERA LOCATION AND PHOTO POINTS

Photo Point I: _____

Compass bearing: _____

Distance: _____

Photo point I

Photo Point J: _____

Compass bearing: _____

Distance: _____

Photo point J

PHOTO POINTS AND CLOSE PHOTOS

Date _____ Camera _____

Area _____

Unit _____

Photo point: A

Observer _____

Remarks _____

General photograph of point A

Photo point A:

Left of meter board

Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point A:

Right of meter board

Species/cover: _____

Close photo to right of meter board

Comments: _____

PHOTO POINTS AND CLOSE PHOTOS

Date _____
Area _____
Unit _____
Camera _____
Photo point: B
Observer _____
Remarks _____

General photograph of point B

Photo point B
Left of meter board
Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point B
Right of meter board
Species/cover: _____

Close photo to right of meter board

Comments: _____

PHOTO POINTS AND CLOSE PHOTOS

Date _____
Area _____
Unit _____
Camera _____
Photo point: C
Observer _____
Remarks _____

General photograph of point C

Photo point C
Left of meter board
Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point C
Right of meter board
Species/cover: _____

Close photo to right of meter board

Comments: _____

PHOTO POINTS AND CLOSE PHOTOS

Date _____
Area _____
Unit _____
Camera _____
Photo point: D
Observer _____
Remarks _____

General photograph of point D

Photo point D
Left of meter board
Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point D
Right of meter board
Species/cover: _____

Close photo to right of meter board

Comments: _____

PHOTO POINTS AND CLOSE PHOTOS

Date _____
Area _____
Unit _____
Camera _____
Photo point: E
Observer _____
Remarks _____

General photograph of point E

Photo point E
Left of meter board
Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point E
Right of meter board
Species/cover: _____

Close photo to right of meter board

Comments: _____

PHOTO POINTS AND CLOSE PHOTOS

Date _____
Area _____
Unit _____
Camera _____
Photo point: _____
Observer _____
Remarks _____

General photograph of point _____

Photo point _____
Left of meter board
Species/cover: _____

Close photo to left of meter board

Comments: _____

Photo point _____
Right of meter board
Species/cover: _____

Close photo to right of meter board

Comments: _____

PHOTO POINTS WITH OVERHEAD VIEWS

Date _____ Camera _____
Area _____ Number of Photo points: _____
Unit _____ Observer _____
Comments _____
Slope _____ Aspect _____ Slope position _____ Topography _____

Photo Point A
Compass bearing: _____
Distance _____
Photo comments: _____

Photo point A

Overhead of Photo Point A
Photo comments: _____

Overhead of photo point A

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point B

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point B

Overhead of Photo Point B

Photo comments: _____

Overhead of Photo point B

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point C

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point C

Overhead of Photo Point C

Photo comments: _____

Overhead of Photo point C

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point D

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point D

Overhead of Photo Point D

Photo comments: _____

Overhead of Photo point D

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point E

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point E

Overhead of Photo Point E

Photo comments: _____

Overhead of Photo point E

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point F

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point F

Overhead of Photo Point F

Photo comments: _____

Overhead of Photo point F

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point G

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point G

Overhead of Photo Point G

Photo comments: _____

Overhead of Photo point G

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point H

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point H

Overhead of Photo Point H

Photo comments: _____

Overhead of Photo point H

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point I

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point I

Overhead of Photo Point I

Photo comments: _____

Overhead of Photo point I

PHOTO POINTS WITH OVERHEAD VIEWS

Photo Point J

Compass bearing: _____

Distance _____

Photo comments: _____

Photo point J

Overhead of Photo Point J

Photo comments: _____

Overhead of Photo point J

SHRUB PHOTO TRANSECT

Date _____ Cluster _____ Transect 1 2 3 4 5

Area _____

Allot. _____

Investigator: _____

Season of use _____

Grazing system: _____

Animals _____

Direction _____

Distance _____

General photograph down the transect

Shrub 1A

Direction _____

Distance _____

Comments _____

Shrub 1A

Shrub 1B

Direction _____

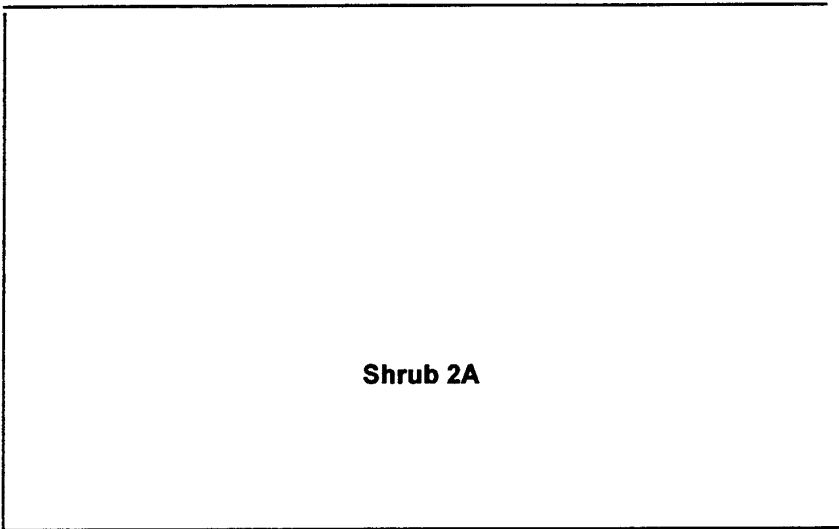
Distance _____

Comments _____

Shrub 1B

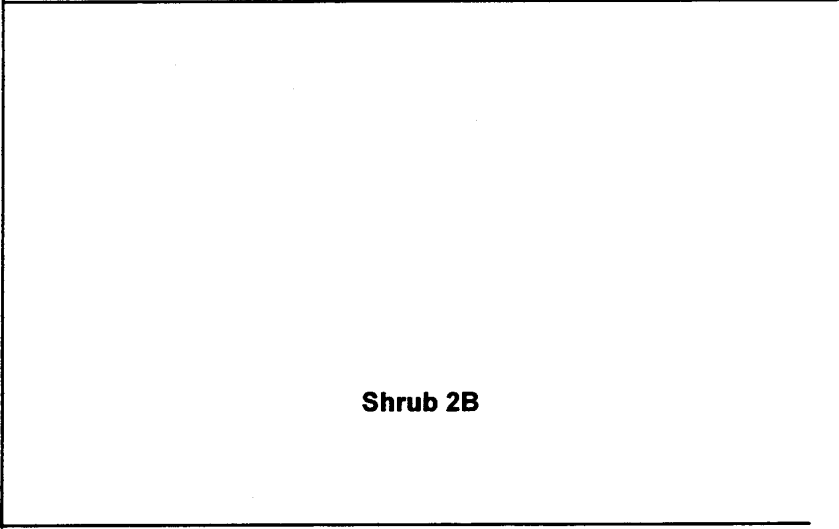
SHRUB PHOTO TRANSECT

Shrub 2A
Direction _____
Distance _____
Comments _____



Shrub 2A

Shrub 2B
Direction _____
Distance _____
Comments _____



Shrub 2B

SHRUB PHOTO TRANSECT

Shrub 3A

Direction _____

Distance _____

Comments _____

Shrub 3A

Shrub 3B

Direction _____

Distance _____

Comments _____

Shrub 3B

SHRUB PHOTO TRANSECT

Shrub 4A

Direction _____

Distance _____

Comments _____

Shrub 4A

Shrub 4B

Direction _____

Distance _____

Comments _____

Shrub 4B

SHRUB PHOTO TRANSECT

Shrub 5A

Direction _____

Distance _____

Comments _____

Shrub 5A

Shrub 5B

Direction _____

Distance _____

Comments _____

Shrub 5B

SHRUB PHOTO TRANSECT

Shrub 6A

Direction _____

Distance _____

Comments _____

Shrub 6A

Shrub 6B

Direction _____

Distance _____

Comments _____

Shrub 6B

SHRUB PHOTO TRANSECT

Shrub 7A

Direction _____

Distance _____

Comments _____

Shrub 7A

Shrub 7B

Direction _____

Distance _____

Comments _____

Shrub 7B

SHRUB PHOTO TRANSECT

Shrub 8A

Direction _____

Distance _____

Comments _____

Shrub 8A

Shrub 8B

Direction _____

Distance _____

Comments _____

Shrub 8B

SHRUB PHOTO TRANSECT

Shrub 9A

Direction _____

Distance _____

Comments _____

Shrub 9A

Shrub 9B

Direction _____

Distance _____

Comments _____

Shrub 9B

SHRUB PHOTO TRANSECT

Shrub 10A

Direction _____

Distance _____

Comments _____

Shrub 10A

Shrub 10B

Direction _____

Distance _____

Comments _____

Shrub 10B

Up transect photograph:

Direction _____

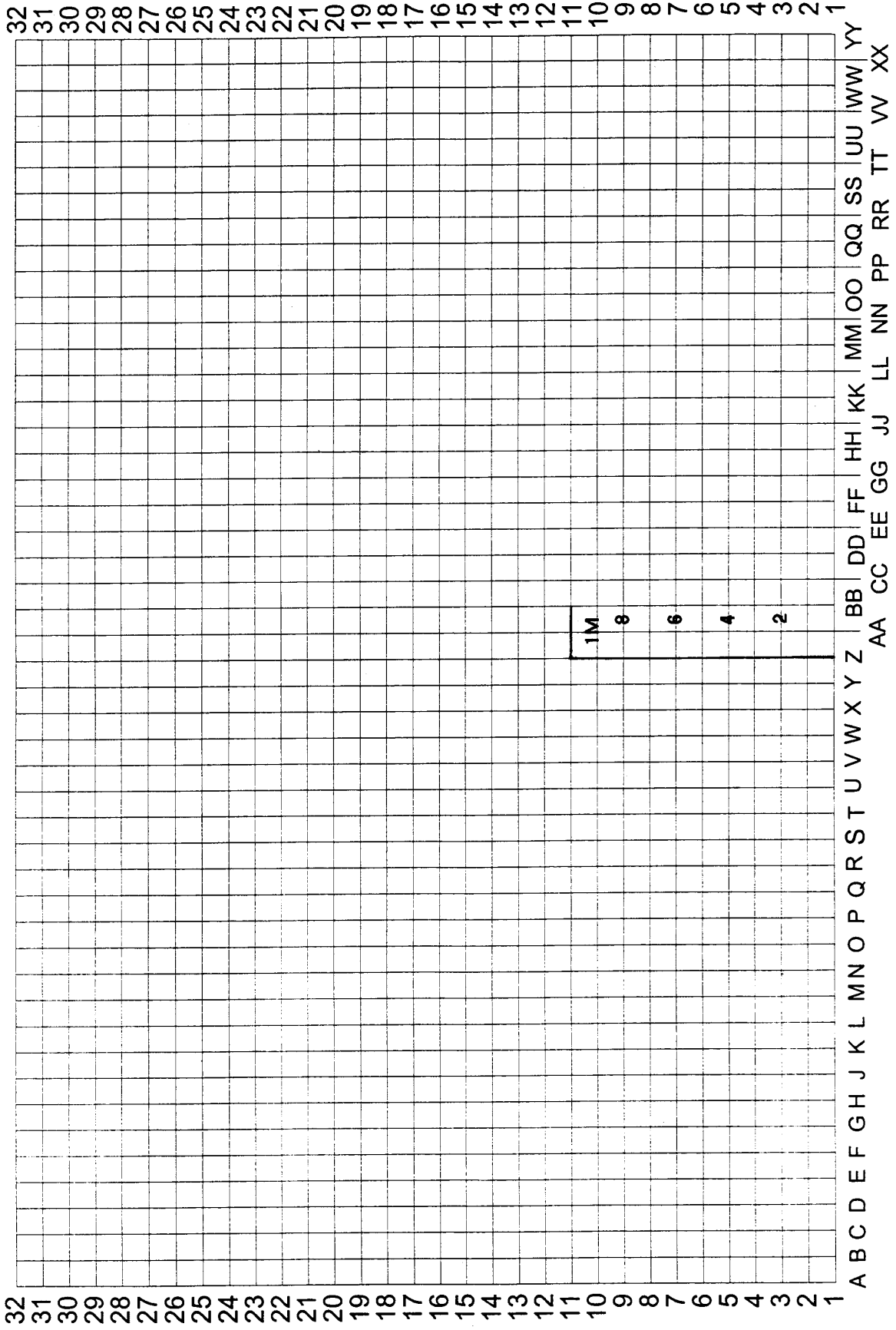
Distance _____

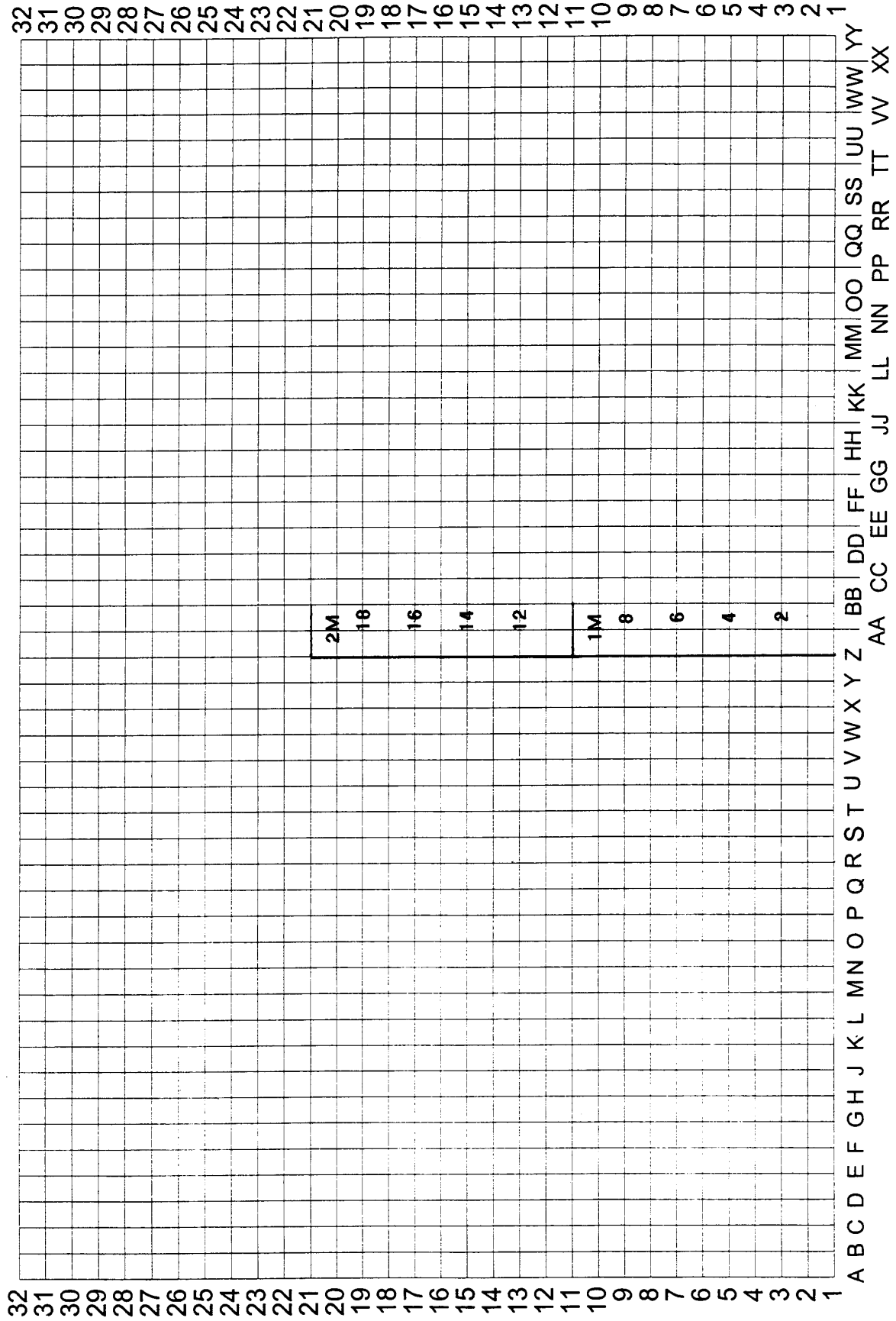
Comments: _____

General photograph up the transect

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Date _____ GRID ANALYSIS OUTLINE Area _____
 Observer _____ Unit _____
 Cluster/Transect _____ Transect/Photo _____





1999/2/19

PHOTO GRID SUMMARY

Date _____ **Observer** _____

Area _____ **Unit** _____

Cluster/Camera _____ Transect/Photo _____

[illegible]

PHOTO TREND SAMPLE – 1 SQ.FOOT

Date _____ Cluster _____ Transect 1 2 3 4 5

Area _____

Allot. _____

Investigator _____

Season of use _____

% use _____

Grazing system _____

Remarks _____

General photograph down the 100 ft. (30 m)

tape from the 0 end

Size control board at 33 ft (10 m)

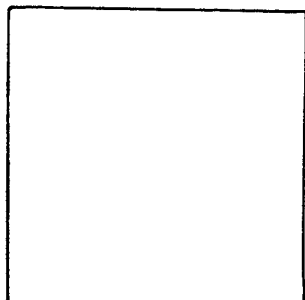
Photo identification paper at 15 ft (5 m)

Photograph of plot 1

Photograph of plot 2

PHOTO TREND SAMPLE – 1 SQ.FOOT

3



10 ft

11 ft

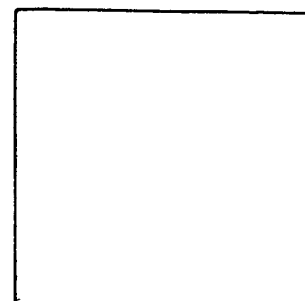
Soil surface: B G R L C

Line intercept

Species	From	to	feet

Photograph of plot 3

4



15 ft

16 ft

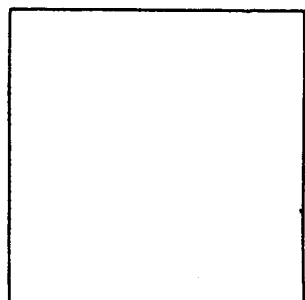
Soil surface: B G R L C

Line intercept

Species	From	to	Feet

Photograph of plot 4

5



20 ft

21 ft

Soil surface: B G R L C

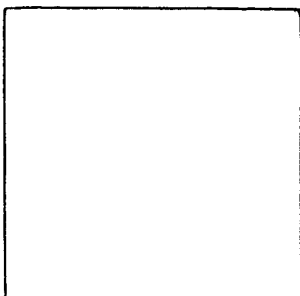
Line intercept:

Species	From	To	Feet

Photograph of plot 5

PHOTO TREND SAMPLE – 1 SQ.FOOT

6



25 ft

26 ft

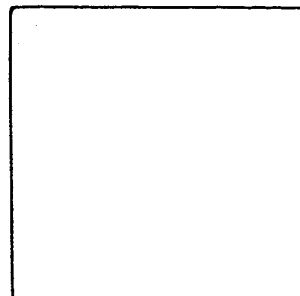
Soil surface: B G R L C

Line intercept

Species	From	to	feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 6

7



30 ft

31 ft

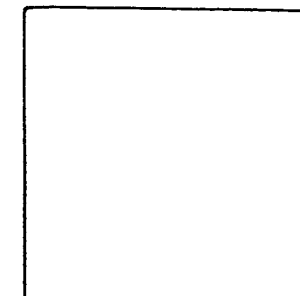
Soil surface: B G R L C

Line intercept

Species	From	to	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 7

8



35 ft

36 ft

Soil surface: B G R L C

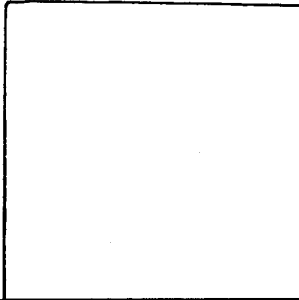
Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 8

PHOTO TREND SAMPLE – 1 SQ.FOOT

9



40 ft

41 ft

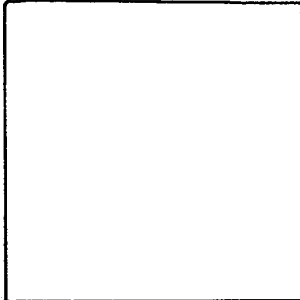
Soil surface: B G R L C

Line intercept

Species	From	to	feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 9

10



45 ft

46 ft

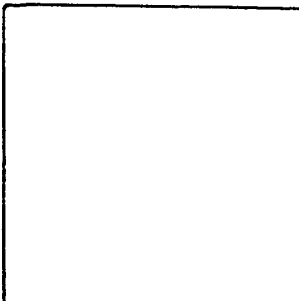
Soil surface: B G R L C

Line intercept

Species	From	to	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 10

11



50 ft

51 ft

Soil surface: B G R L C

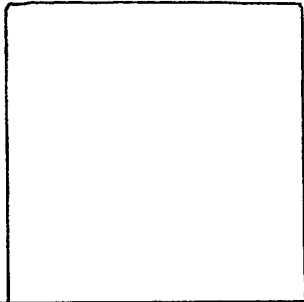
Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 11

PHOTO TREND SAMPLE - 1 SQ.FOOT

12



55 ft

56 ft

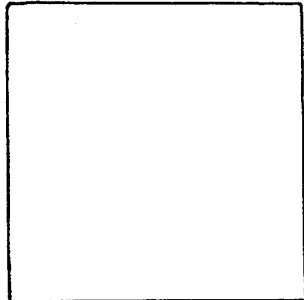
Soil surface: B G R L C

Line intercept

Species	From	to	feet

Photograph of plot 12

13



60 ft

61 ft

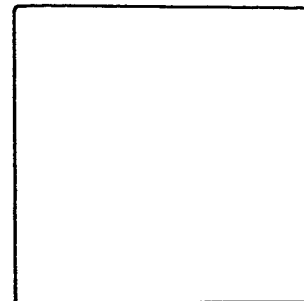
Soil surface: B G R L C

Line intercept

Species	From	to	Feet

Photograph of plot 13

14



65 ft

66 ft

Soil surface: B G R L C

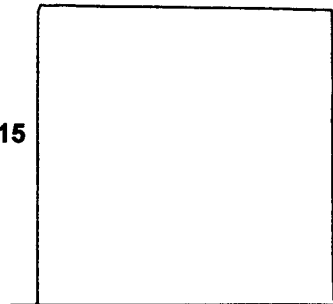
Line intercept:

Species	From	To	Feet

Photograph of plot 14

PHOTO TREND SAMPLE – 1 SQ.FOOT

15



70 ft

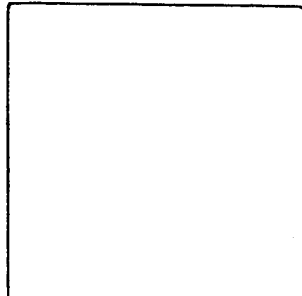
71 ft

Soil surface: B G R L C

Line intercept

Species	From	to	feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

16



75 ft

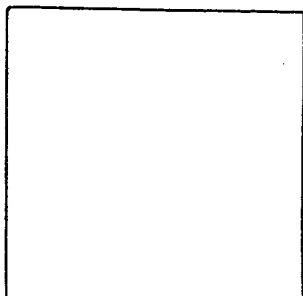
71 ft

Soil surface: B G R L C

Line intercept

Species	From	to	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

17



80 ft

81 ft

Soil surface: B G R L C

Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

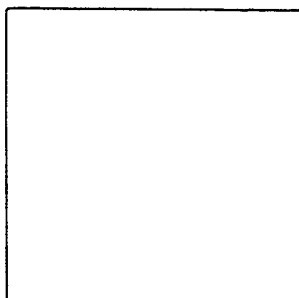
Photograph of plot 15

Photograph of plot 16

Photograph of plot 17

PHOTO TREND SAMPLE – 1 SQ.FOOT

18



85 ft

86 ft

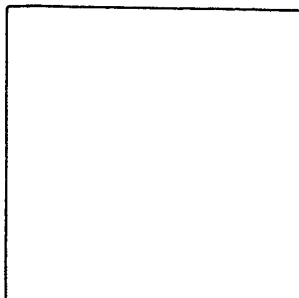
Soil surface: B G R L C

Line intercept

Species	From	to	feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 18

19



90 ft

91 ft

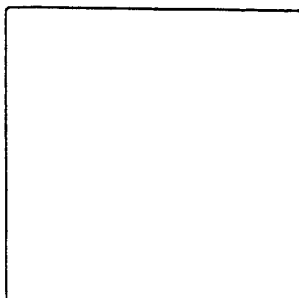
Soil surface: B G R L C

Line intercept

Species	From	to	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 19

20



95 ft

96 ft

Soil surface: B G R L C

Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 20

PHOTO TREND SAMPLE – 1 SQ.FOOT

SUMMARY

[illegible]

General photograph up the 100 ft (30 m)

tape from the 100 (30m) end

Size control board at 67 ft (20 m)

Photo identification paper at 85 ft (26 m)

ACTIVITIES

Logging _____

Fire _____

Revegetation _____

Insects _____

Wildlife _____

Other _____

CLIMATE compared to Average

	<u>This Yr.</u>	<u>Last Yr.</u>	<u>Two Yrs.</u>	<u>Three Yrs</u>	<u>Four Yrs.</u>
Temp	+ 0 -	+ 0 -	+ 0 -	+ 0 -	+ 0 -
Ppt.	+ 0 -	+ 0 -	+ 0 -	+ 0 -	+ 0 -

Apparent range condition _____
Apparent range trend _____

COMMENTS

Estimated Utilization

<u>Species</u>	<u>% Use</u>
----------------	--------------

PHOTO TREND SAMPLE – NESTED FREQUENCY

Date _____ Cluster _____ Transect 1 2 3 4 5

Area _____

Allot. _____

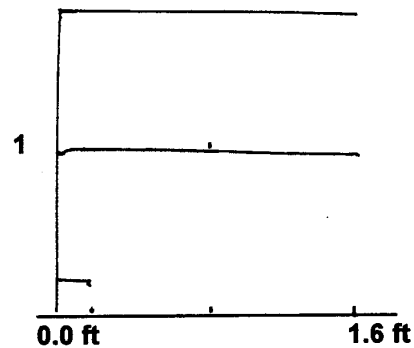
Investigator _____

Season of use _____

% use _____

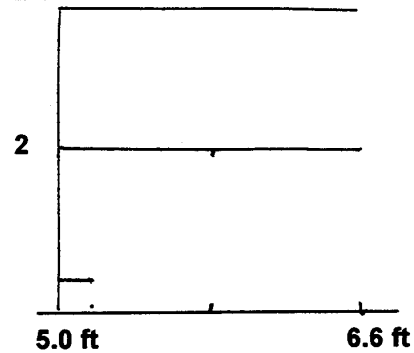
Grazing system _____

Remarks _____



Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____



Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

General photograph down the 100 ft. (30 m)

tape from the 0 end

Size control board at 33 ft (10 m)

Photo identification paper at 15 ft. (5 m)

Photograph of plot 1

Photograph of plot 2

PHOTO TREND SAMPLE – NESTED FREQUENCY

3

10.0 ft 11.6 ft

Line intercept

Species From to feet

Photograph of plot 3

4

15.0 ft 16.6 ft

Line intercept

Species From to Feet

Photograph of plot 4

5

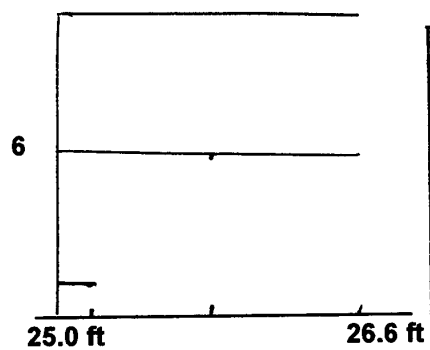
20.0 ft 21.6 ft

Line intercept:

Species From To Feet

Photograph of plot 5

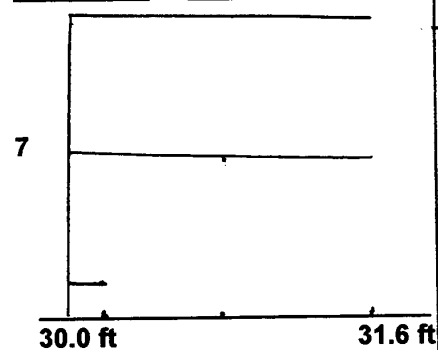
PHOTO TREND SAMPLE – NESTED FREQUENCY



Photograph of plot 6

Line intercept

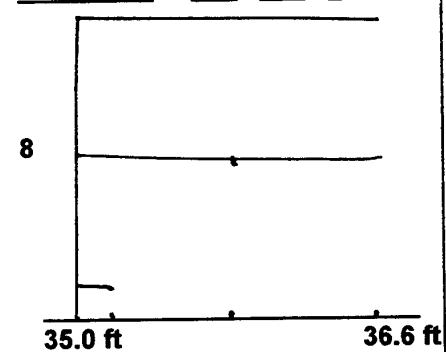
Species	From	to	feet



Photograph of plot 7

Line intercept

Species	From	to	Feet



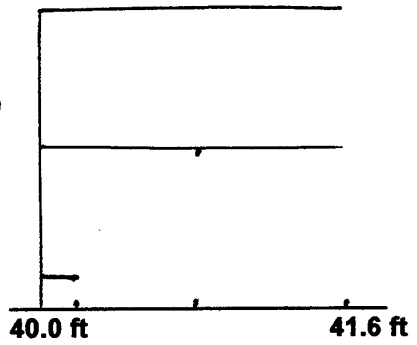
Photograph of plot 8

Line intercept:

Species	From	To	Feet

PHOTO TREND SAMPLE – NESTED FREQUENCY

9



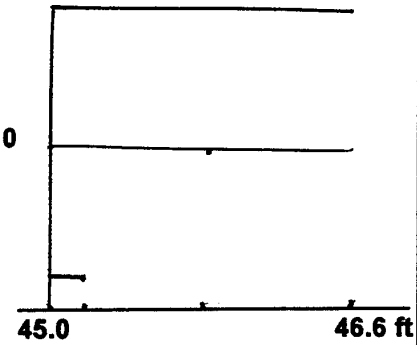
Photograph of plot 9

Line intercept

Species From to feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

10



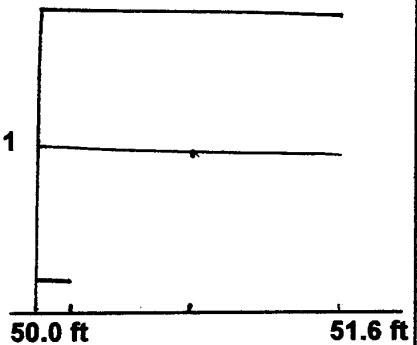
Photograph of plot 10

Line intercept

Species From to Feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

11



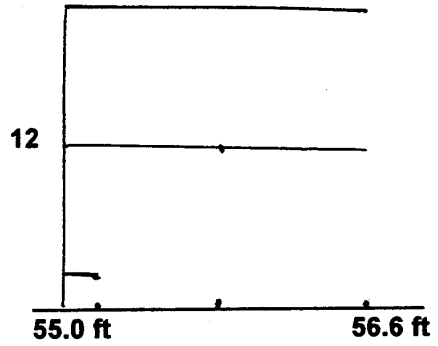
Photograph of plot 11

Line intercept:

Species From To Feet

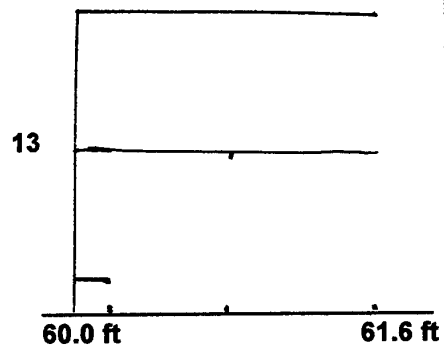
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

PHOTO TREND SAMPLE - NESTED FREQUENCY



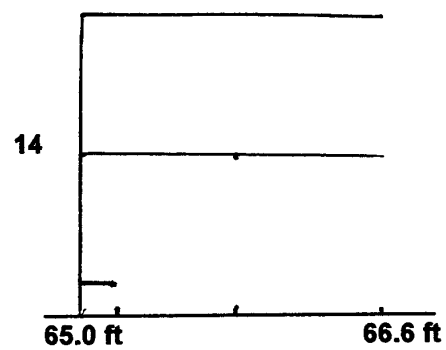
Photograph of plot 12

Line intercept
Species From to feet



Photograph of plot 13

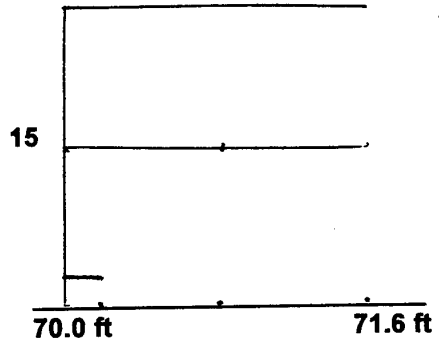
Line intercept
Species From to Feet



Photograph of plot 14

Line intercept:
Species From To Feet

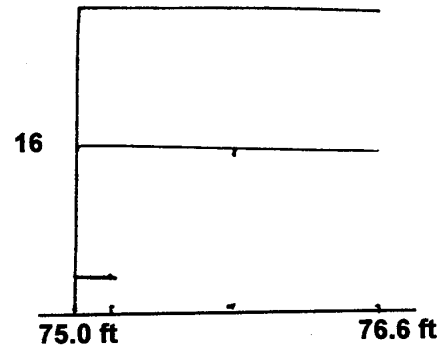
PHOTO TREND SAMPLE – NESTED FREQUENCY



Line intercept
Species From to feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

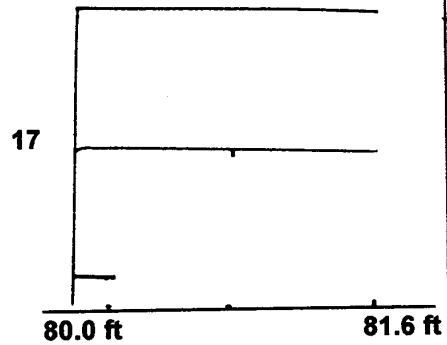
Photograph of plot 15



Line intercept
Species From to Feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 16

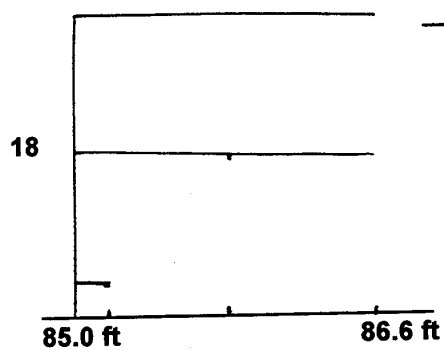


Line intercept:
Species From To Feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 17

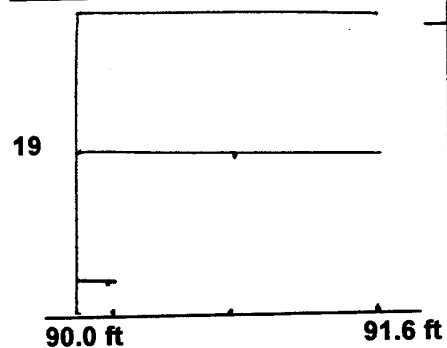
PHOTO TREND SAMPLE – NESTED FREQUENCY



Photograph of plot 18

Line intercept
Species From to feet

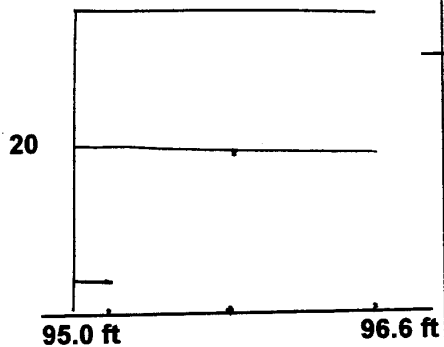
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____



Photograph of plot 19

Line intercept
Species From to Feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____



Photograph of plot 20

Line intercept:
Species From To Feet

_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

PHOTO TREND SAMPLE – NESTED FREQUENCY SUMMARY

NOTE: use the nested frequency data forms on the next two pages.

General photograph up the 100 ft (30 m)
tape from the 100 ft (30m) end

Size control board at 67 ft (20 m)
Photo identification paper at 85 ft (26 m)

ACTIVITIES

Logging _____
 Fire _____
 Revegetation _____
 Insects _____
 Wildlife _____
 Other _____

CLIMATE compared to Average

	<u>This Yr.</u>	<u>Last Yr.</u>	<u>Two Yrs.</u>	<u>Three Yrs</u>	<u>Four Yrs.</u>
Temp	+ 0 -	+ 0 -	+ 0 -	+ 0 -	+ 0 -
Ppt.	+ 0 -	+ 0 -	+ 0 -	+ 0 -	+ 0 -

Apparent range condition _____
 Apparent range trend _____

COMMENTS

Estimated Utilization Species	% Use	
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

NESTED FREQUENCY TRANSECT DATA

Area: _____ Allotment: _____ Date: _____
Investigator: _____ Cluster: _____ Transect: 1 2 3 4 5
Plant community: _____

[illegible]

POINT SAMPLING

POINT SAMPLING							
Ground cover	Veg.	Soil	Gravel	Rock	Litter	Crypt.	Total
Dot tally							
Totals							80

NEXT SHEET FOR LINE INTERCEPT OF SHRUBS AND TREES

NESTED FREQUENCY TRANSECT DATA (Continued)

Line intercept of trees and shrubs

Shrub species	Line Intercept								Total	Percent
Totals										

[illegible]

NESTED FREQUENCY CLUSTER SUMMARY

Area: _____ Allotment: _____ Date: _____
Investigator: _____ Cluster: _____
Plant community: _____

[illegible]

OVER FOR LINE INTERCEPT AND POINT SAMPLING

NESTED FREQUENCY CLUSTER SUMMARY (Continued)

LINE INTERCEPT

Shrub species	Transect Number					(To trend summary)	
	1	2	3	4	5	Total	Percent
Tree Species							

POINT SAMPLING

Ground Item	Transect Number					(To trend summary)	
	1	2	3	4	5	Total Hits	Percent
Vegetation (root crown) _____							
Bare soil _____							
Gravel (1/8 to ¼ in.) _____							
Rock (> ¼ in.) _____							
Litter _____							
Cryptogams _____							
Totals:	80	80	80	80	80	400	100

Table 5. Significant change table for nested frequency.

Using 100 nested frequency plot frames, the table below shows a significant change in frequency value at the 80% probability level. Enter the table at "Initial value" with the *previous* frequency value for the 5 transects (100 plot frames). Compare the *previous* value with the *current* value to determine if a significant change has occurred. A change is significant if the *current* value is smaller than the "Less than" value or greater than the "More than" value.

Less than	<u>Initial value</u>	More than	Less than	<u>Initial value</u>	More than	Less than	<u>Initial value</u>	More than
17	25	31	137	155	171	257	280	301
21	30	37	142	160	176	261	285	307
25	35	43	147	165	181	266	290	312
30	40	48	151	170	176	271	295	317
35	45	55	<u>156</u>	<u>175</u>	<u>192</u>	<u>276</u>	<u>300</u>	<u>322</u>
<u>39</u>	<u>50</u>	<u>59</u>	161	180	197	281	305	327
43	55	65	166	185	202	285	310	333
48	60	70	170	190	208	290	315	338
53	65	75	175	195	213	295	320	343
57	70	81	<u>180</u>	<u>200</u>	<u>218</u>	<u>300</u>	<u>325</u>	<u>348</u>
<u>62</u>	<u>75</u>	<u>86</u>	185	205	223	307	330	353
67	80	91	189	210	229	309	335	359
71	85	97	194	215	234	314	340	364
76	90	102	219	220	239	319	345	369
81	95	107	<u>204</u>	<u>225</u>	<u>244</u>	<u>324</u>	<u>350</u>	<u>374</u>
<u>85</u>	<u>100</u>	<u>113</u>	209	230	249	329	355	379
90	105	118	213	235	255	334	360	384
95	110	123	218	240	260	339	365	389
99	115	129	223	245	265	343	370	395
104	120	134	<u>228</u>	<u>250</u>	<u>270</u>	<u>348</u>	<u>375</u>	*
<u>109</u>	<u>125</u>	<u>139</u>	233	255	275	353	380	*
113	130	145	237	260	281	358	385	*
118	135	150	242	265	286	363	390	*
123	140	155	247	270	291	368	395	*
128	145	160	<u>252</u>	<u>275</u>	<u>296</u>	<u>372</u>	<u>400</u>	*
<u>132</u>	<u>150</u>	<u>166</u>						

PHOTO TREND SAMPLE – 9 sq.ft. (1 sq. m)

Date _____ Cluster _____ Transect 1 2 3 4 5

Area _____

Allot. _____

Investigator _____

Season of use _____

% use _____

Grazing system _____

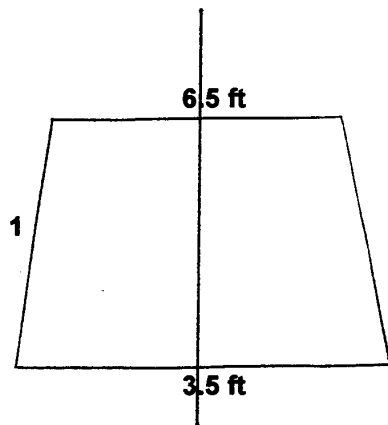
Remarks _____

General photograph down the 100 ft. (30 m)

tape from the 0 end

Size control board at 33 ft (10 m)

Photo identification paper at 15 ft (5 m)



Soil surface: B G R L C

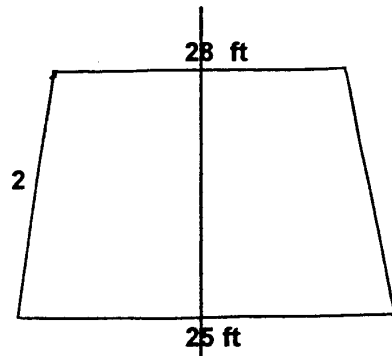
Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 1

Camera at the 0 foot mark.

PHOTO TREND SAMPLE – 9 SQ.FT. (1 SQ. M)



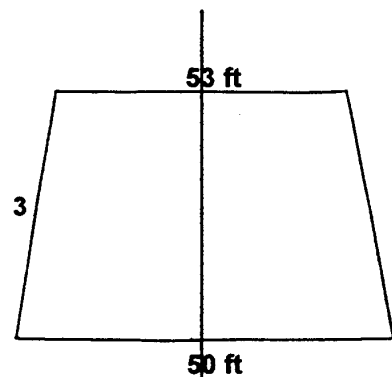
Soil surface: B G R L C

Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 2

Camera at the 21.5 foot mark.



Soil surface: B G R L C

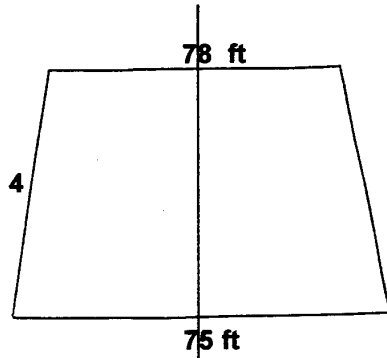
Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 3

Camera at the 46.5 foot mark.

PHOTO TREND SAMPLE – 9 SQ.FT. (1 SQ. M)



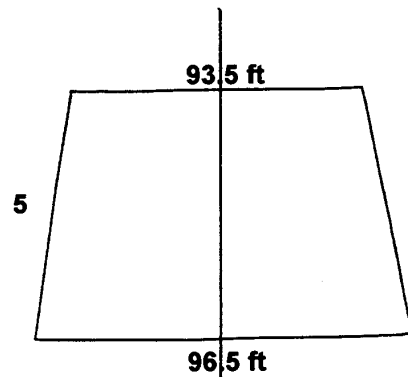
Soil surface: B G R L C

Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 4

Camera at the 71.5 foot mark



Soil surface: B G R L C

Line intercept:

Species	From	To	Feet
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Photograph of plot 5

STOP: Change camera direction - photo from the 100 ft end

Camera at the 100 foot mark.

PHOTO TREND SAMPLE – 9 sq.ft. (1 sq. m)
SUMMARY

[illegible]

ACTIVITIES

			Logging	
			Fire	
			Revegetation	
			Insects	
			Wildlife	
			Other	

CLIMATE compared to Average

	<u>This Yr.</u>	<u>Last Yr.</u>	<u>Two Yrs.</u>	<u>Three Yrs</u>	<u>Four Yrs.</u>
Temp	+ 0 -	+ 0 -	+ 0 -	+ 0 -	+ 0 -
Ppt.	+ 0 -	+ 0 -	+ 0 -	+ 0 -	+ 0 -

Bare soil

Gravel pavement _____

condition_____

Rock

trend _____

Litter

Cryptogams

Apparent range

Apparent range

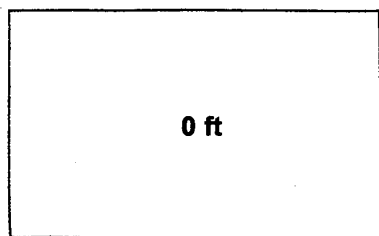
COMMENTS

Estimated Utilization

<u>Species</u>	<u>% Use</u>

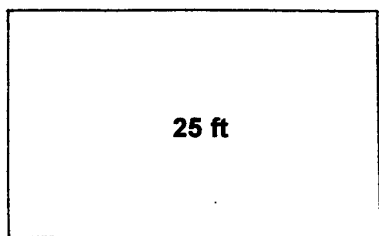
PHOTO TREND SAMPLING – TREE COVER

Area _____ Allot. _____ Date _____
 Investigator _____ Sampling system _____ Cluster ____ Transect: 1 2 3 4 5



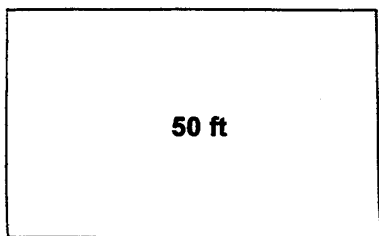
Species	Cover	Species	cover
_____	_____%	_____	_____%
_____	_____%	_____	_____%
_____	_____%	TOTAL	_____%

Vertical photo of tree cover above 0 foot mark



Species	Cover	Species	cover
_____	_____%	_____	_____%
_____	_____%	_____	_____%
_____	_____%	TOTAL	_____%

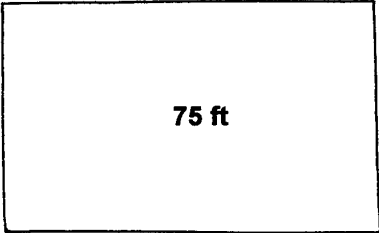
Vertical photo of tree cover above 25 foot mark



Species	Cover	Species	cover
_____	_____%	_____	_____%
_____	_____%	_____	_____%
_____	_____%	TOTAL	_____%

Vertical photo of tree cover above 50 foot mark

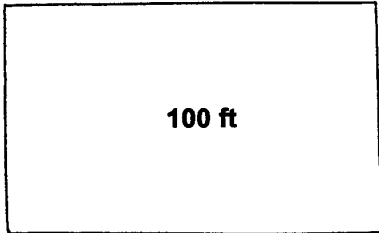
PHOTO TREND SAMPLING – TREE COVER



75 ft

Vertical photo of tree cover above 75 foot mark

Species	Cover	Species	cover
_____	____%	_____	____%
_____	____%	_____	____%
_____	____%	TOTAL	____%



100 ft

Vertical photo of tree cover above 100 foot mark

Species	Cover	Species	cover
_____	____%	_____	____%
_____	____%	_____	____%
_____	____%	TOTAL	____%

SUMMARY

Species	Ave. % cover
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

RANGE TREND REREADINGS

Circle the sampling system: 20 plots 1 sq.ft, 100 plots Nest. Frequ. 5 Plots 9 sq.ft.(1 sq. m)
Area Allotment Cluster Transect 1 2 3 4 5

[illegible]

OVER FOR ADDITIONAL DATA

RANGE TREND REREADINGS (Continued)

<u>Elements</u>	<u>Averages by Year</u>									
Range Condition Guide/date										
Decreasers:										
Palatable Increasesers										
Unpalatable Increasesers										
Invaders										
Vegetation - (root crown)										
Bare Soil										
Gravel (1/8 to ¼ inch)										
Rock (> ¼ inch)										
Litter										
Cryptogams										
<u>% Utilization by species</u>										
<u>Season of Use</u>										
<u>Climate</u>										
Temp: Current										
Last year										
2 yrs. Ago										
3 yrs. Ago										
4 yrs. Ago										
Ppt.: Current										
Last year										
2 yrs. Ago										
3 yrs. Ago										
4 yrs. Ago										
Apparent range condition										
Apparent range trend										

UTILIZATION - ROBEL POLE SAMPLING

Date _____ Cluster _____ Transect: 1 2 3 4 5

Area _____

Allot. _____

Investigator _____

Season of use _____

Grazing system: _____

Remarks: _____

Visual Observation 1A:

Stubble height: _____

Comments: _____

Species: _____

Visual Observation 1B:

Stubble height: _____

Comments: _____

Species: _____

General photograph down the transect from the start

**Size control board at 33 ft (10 m)
Photo identification paper at 15 ft (5 m)**

Photograph of observation 1A forward on contour

Photograph of observation 1B backward on contour

UTILIZATION - ROBEL POLE SAMPLING

Visual Observation # ____ A

Stubble height: _____

Comments: _____

Species: _____

Photograph of observation ____ A forward on contour

Visual Observation # ____ B

Stubble height: _____

Comments: _____

Species: _____

Photograph of observation ____ B backward on contour

UTILIZATION - ROBEL POLE SAMPLING

Visual Observation # ____ A

Stubble height: _____

Comments: _____

Species: _____

Photograph of observation ____ A forward on contour

Visual Observation # ____ B

Stubble height: _____

Comments: _____

Species: _____

Photograph of observation ____ B backward on contour

Photograph from end of
transect

Comments: _____

General photograph up the transect from the end

Six control board at 33 ft (10M)
Photo identification paper at 15 ft (5 m)

UTILIZATION - ROBEL POLE SUMMARY

Date _____ Examiner: _____

Area _____ Allotment _____

Cluster _____ Transect: 1 2 3 4 5 Sampling interval _____

Station	VO "A"	VO "B"	Species "A" (Front)	"B" (Back)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
Total				
Grand Total				
Average				

Cluster Summary

Trans 1 _____

Trans 2 _____

Trans 3 _____

Trans 4 _____

Trans 5 _____

AVE _____

Appendix C: Photo Monitoring Equipment

Contents	273	Meter Boards
	273	One-Meter Board
	274	Two-Meter Folding Board
	279	One-Meter Folding Board
	279	Photograph Identification-Sheet Holder
	284	One-Square-Foot Sampling Frame
	286	Nested Frequency Sampling Frame
	288	One-Square-Meter Sampling Frame
	290	Robel Pole Sampling System
	293	Camera Leveling System
	294	Double-Camera Bracket
	296	Fenceposts
	296	Identification Tags

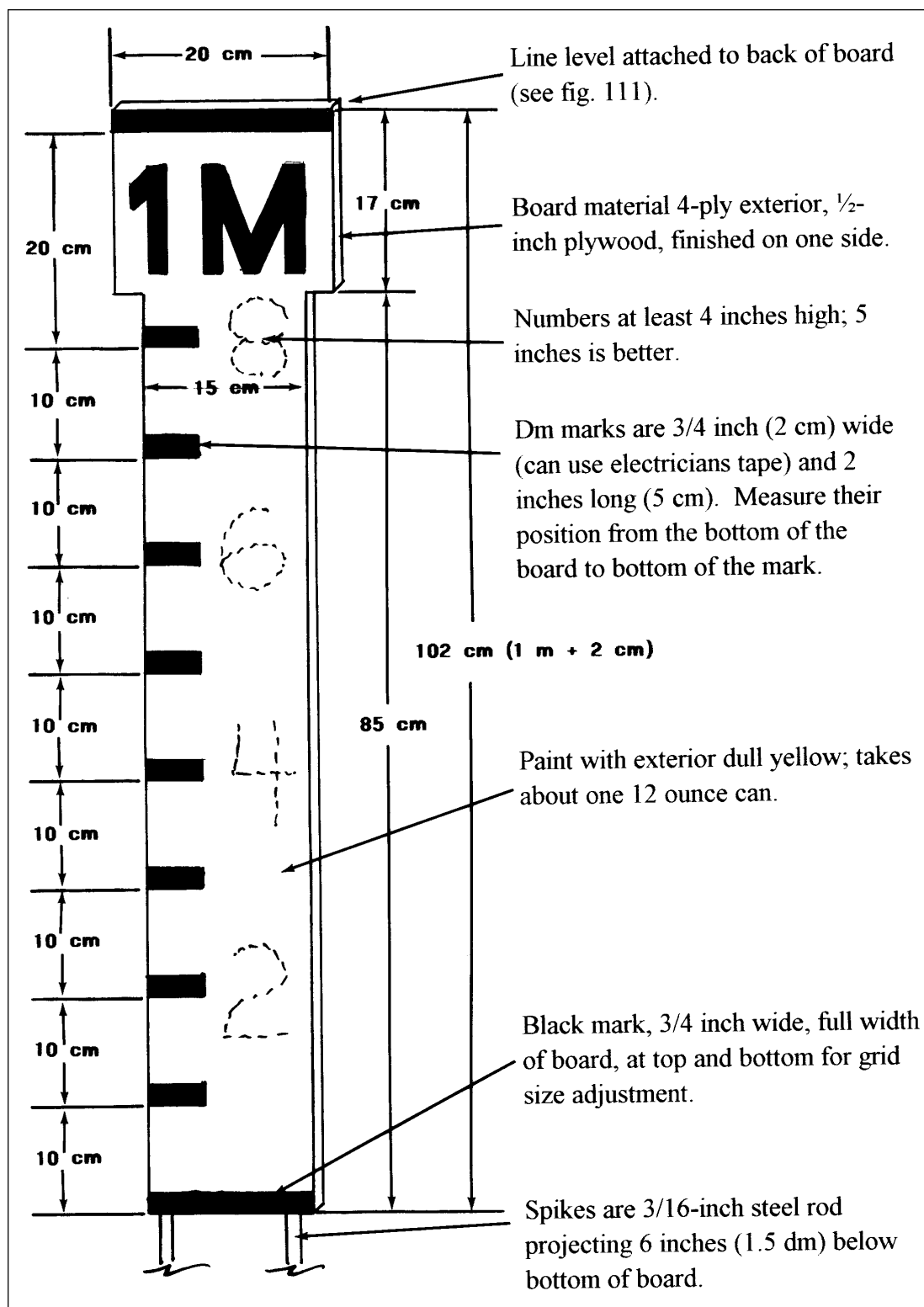


Figure 110—Construction details of a 1-m-tall meter board. The same measurements are used for the 1-m-tall folding board and for the 2-m folding board.

Meter Boards

Meter boards are used to mark photo points. They help in taking consistent repeat photographs if the camera is oriented on the “1M” of the board. Sharp exposure at the meter board is assured by focusing the camera on the “1M.” Meter boards also provide a size control in photographs that can be used to adjust the analysis grids when measuring the attributes shown in a photo. This section described how to construct meter boards.

One-Meter Board

Materials	Cost ¹
	<i>Dollars</i>
1 piece 1/2-in 4-ply exterior or marine plywood, finished on one side, 1 by 4 ft @ \$20/sheet	3
1 steel rod 3/16-in diameter, 36 inches long	1
Numerals:	
1 packet adhesive-backed numerals, 5-1/4 in tall, on a reflector, (need numbers 1, 2, 4, 6, 8)	4
(Alternative is 4-in nail-on numbers, 5 @ \$2/numeral)	(20)
1 4- to 5-in-long line or pocket level	4
1 16-oz can dull yellow spray paint, exterior	4
Screws:	
2 #4 5/8-in line level screws	
9 #6 3/4-in spike plate screws	1
A few feet of black electricians tape	1
Total	18

Meter boards are constructed from 1/2-in, 4-ply plywood, at least exterior quality and preferably marine quality (waterproof glue). Waterproof glue is desirable when sampling riparian areas because the meter board often will be placed in water. (Dimensions and layout are shown in fig. 110). Cut out according to the measurements shown in figure 110.

Prime the front of the board before painting. Then apply two coats of dull, textured, yellow paint to reduce reflection from the sun. Yellow is used for visibility. If dull yellow paint is not available, do not sand or smooth the front of the board. Unsanded roughness causes the paint to be rough, thus reducing glare. Most of the 12-oz pressure can will be required for two coats.

¹ Prices given are approximate as of 2000.

The numerals 2, 4, 6, and 8 should be black and at least 4 in tall. For good readability in projected slides, 5 in is even better. All illustrations in this publication show 5-in numbers. There are many sources for these, including paste-on numbers, numbers on a card that must be cut out, and nail-on numbers. I use 5-1/4-in-tall numbers on a reflective card with adhesive back. Each number must be cut out and applied to the painted surface. The "M" in "1M" is made from electricians tape, or it may be painted on.

Black marks at each decimeter and bands at top and bottom may be applied in one of two ways: paint them on at 2 cm wide or use black electricians tape, which is 3/4 in wide (1.8 cm). The top, bottom, and decimeter marks are used to adjust grid size before grid analysis of items in the photographs. Location of the marks on the meter board therefore must be positioned precisely (fig. 110).

A line level is attached to the back of the board at the top (fig. 111). This allows the board to be oriented vertically, which is essential for grid analysis, and it makes pictures look good.

Steel spikes are attached to the bottom of the board (fig. 112) to hold it in the ground. Steel rod, 3/16-in diameter, works well because it is strong enough to hold the board upright and small enough in diameter to be pushed into rocky soil. Spikes should extend 6 in below the bottom of the board (fig. 112). Rods come in 36-in lengths. About 30 in is required. Bend the rod into a "U" shape to match the dotted outline in figure 112.

For convenience, a carrying handle may be attached to the edge of the board near the 5-dm position.

Two-Meter Folding Board

Two-meter boards are used when shrubs or other vegetation exceeds the height of a 1-m board (fig. 113). They are, very simply, two single-meter boards attached by hinges and a barrel bolt so that either the 1-m or 2-m length may be used.



Figure 111—A line level is used to orient the board vertically. Obtain a 4- to 5-in-long line level and drill a hole in each end for a screw. Attach one end of the line level to the back of the meter board $\frac{1}{2}$ in (1 cm) from the top. Then orient the board vertically by using a carpenter's level along one side. Hold the board in position, adjust the line level to horizontal, and carefully screw in the other end.

Materials

Cost
(see footnote 1)

	<i>Dollars</i>
2 pieces 1/2-in 4-ply exterior or marine plywood, finished on one side, 1 by 4 ft @ \$20/sheet	6
1 steel rod 3/16-in diameter, 36 in long	1
Numeralals:	
2 packets adhesive-backed numeralals, 5¼ in tall, on a reflector, (need 2 each of 1, 2, 4, 6, 8)	8
1 4- to 5-in-long line or pocket level	4
2 16-oz cans dull yellow spray paint, exterior	8
2 strap hinges, 4-in size, heavy duty	5
1 barrel bolt, 5-in size, heavy duty	8
Screws:	
2 wood screws, #4 5/8-in line level screws	
9 #6 3/4-in spike plate screws	
1 #10 1/2-in sheet metal screw, for below the barrel bolt (sheet metal needed for hardness); 2¾-in washers	
10 #10 1-in hinge wood screws	2
8 #10 1/2-in barrel bolt wood screws	1
Several feet of black electricians tape	
Total	43

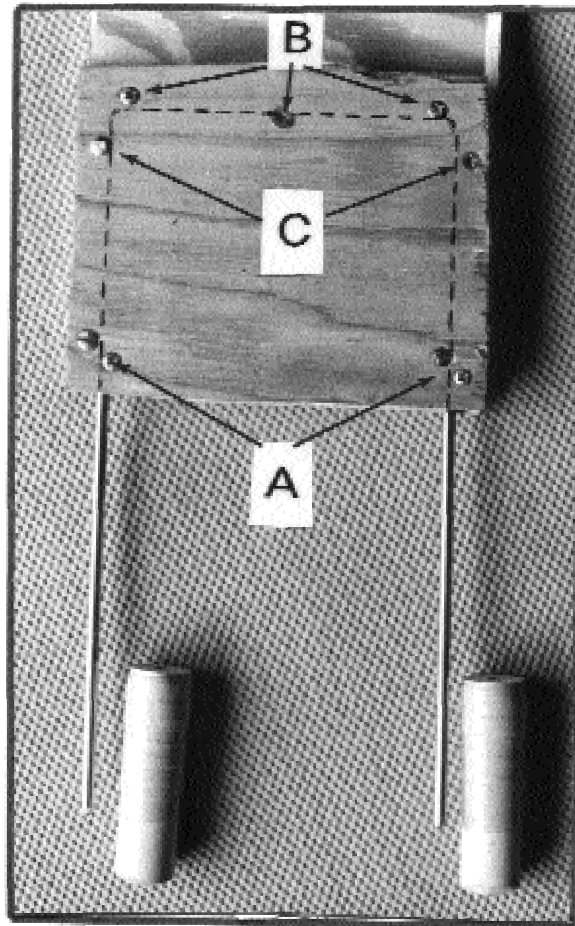


Figure 112—Spikes in the bottom of the board are pushed into the ground to hold the board upright. Use a 3/16-in diameter steel rod about 30 in long. Bend it into a U-shape as shown by the dotted line. It is placed under a plywood plate and held in place by nine screws. Leave about 6 in (1.5 dm) of rod below the board. Screws are positioned to hold the rod in place. (A) Insert a screw on each side of the rod at the bottom. (B) Insert three at the top to prevent upward and downward movement of the rod. (C) Place one at each side at top to prevent sideways movement. Drill out doweled to fit over the spikes for safety.



Figure 113—Use of a folding 2-m board to document height and growth of tall shrubs. This board is hinged in the middle and held upright by a barrel bolt. When folded together (fig. 109), it functions as a 1-m board. Here, the board has been unfolded to 2 m.



Figure 114—The 2-m board system. (A) Standard 1-m board with the top half folded underneath. (B) The folded board has been turned over to show the 2-m section.

Construct two 1-meter boards as discussed previously. On the first, construct with spikes at the bottom and numerals as shown. On the second, use “2M” at the top instead of “1M,” and add numeral “1” to each of the decimeter numbers as shown in figures 113 and 114. The numeral “1” can be made from electricians tape.

Figure 115 illustrates the hinge, barrel bolt, and position of the line level between the two halves of the meter board. Proceed as follows:

1. Refer to figure 115. Attach hinges (A) to plywood the same thickness as the barrel bolt and glued to both halves of the meter board. The 5-in bolt shown in figure 115 required 3/8-in plywood. These plywood blocks raise the meter board halves so that the barrel bolt will clear both its connecting strap (B) and the line level (D) when folded. Attach the hinge straps to the top board first. Then use a straight edge to align both halves in a straight line. Finally, attach the bottom straps to the bottom board while firmly holding both halves together.
2. Install the barrel bolt next. Position the barrel bolt at the very bottom of the upper meter board so the bolt drops down when the boards are erected. Place the barrel bolt strap (B) as close to the top of the bottom board as possible without the screws splitting the wood. The bolt should protrude about 3/8 in below the strap (figs. 115C and 116A). Insert a sheet metal screw and sufficient washers under the bolt end to hold it firmly against the strap to prevent flexing when the boards are unfolded (fig. 116B).
3. Position the line level on the bottom (1-meter) board where it can be seen from above when the boards are folded for 1-meter use, and from the back when unfolded for 2 meters (fig. 115D). The line level can be seen when the boards are folded by looking down through the strap holding the barrel bolt when it drops.

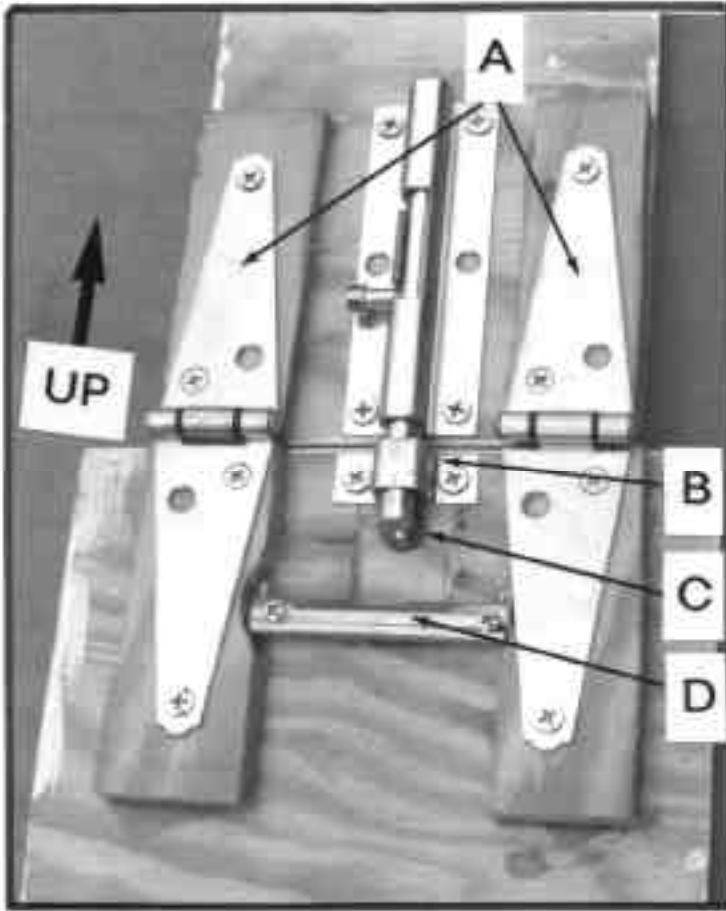


Figure 115—Hinges and a barrel bolt connect the halves of the 2-m board. (A) When installing hinges, attach to the top board first, and then align the boards in a straight line, and then attach the lower straps of the hinges. (B) The barrel bolt should be oriented to fall down when the board is unfolded. Position the bolt and its strap at the edges of the board halves so that the bolt protrudes about $\frac{3}{8}$ in below the strap. (C) Install an adjusting screw (fig. 116) to tighten the barrel bolt against its strap and stiffen the two boards when unfolded. (D) A line level is placed an inch half such that it can be viewed from above when folded and from behind when unfolded, as shown.



Figure 116—Adjusting screw and washer used to remove play between the barrel bolt and its strap, which will stiffen the two halves when unfolded. (A) Measure the distance between the bolt and the board. (B) Insert a round-headed sheet metal screw with enough washers to make the bolt fit firmly under the flange. Sheet metal screws are preferred because of their hardness. Pound the flange down if necessary.



Figure 117—Folding 1-m board specifications. (A) Cut a standard 1-m board at 4 dm and install hinges and a barrel bolt. This offset is used to protect the spikes (B). Assemble the board before painting and application of decimeter marks to assure correct measurements.

One-Meter Folding Board

If field transportation of a meter board is a concern, the 1-meter board can be made to fold. The hinge system is described and shown in figures 115 and 116. Figure 117 illustrates dividing the board at 4 dm to provide protection for the spikes.

Photograph Identification-Sheet Holder

Each photograph taken in photo monitoring should be identified. Plot photographs are identified by a form attached to a clipboard and placed within view of the plot form. General and topic photos taken of the meter board are identified by a form attached to a clipboard and positioned between the camera and meter board. Making the clipboard and a post to hold it are described.

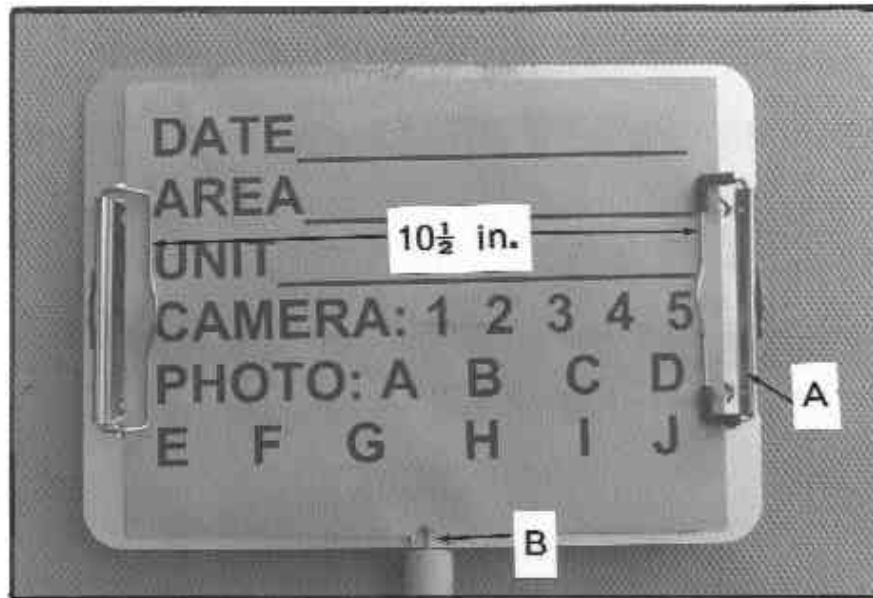


Figure 118—Clipboard for displaying photo identification forms. A second clip (A) is taken from another clipboard and either screwed or riveted to this clipboard. Distance between the clipboard clips should be 10 ½ in to do two things: (1) hold the sheet in windy conditions and (2) not cover essential information. The clipboard is placed on the ground for plot photos or on top of a clipboard post (see fig. 119) to be set in front of the camera. When placed on the post, a screw (B) is inserted into the wooden block holding the ¼-in rod behind the clipboard (see figs. 119 and 121) to prevent the clipboard from rotating in the wind.

The clipboard is shown in figure 118. It is a standard 12-in clipboard with the addition of a second clip removed from another clipboard and attached by rivets or screws as shown. The critical factor is to place the clips no closer than 10 ½ in to avoid covering any information on the identification paper. Two clips are required to prevent the identification sheet from blowing in the wind.

Materials (see footnote 1)	Cost
	<i>Dollars</i>
2 clipboards 12 in long @ \$4.50/each;	
second clipboard for its clip	9
6 1/8-in diameter bolts or rivets to attach the second	
clipboard clip and straps for the clipboard post	1
2 1/4-in line guides or straps	<u>1</u>
Total	11

Remove the clip from the second clipboard and attach it to the first board with either two bolts or two rivets.

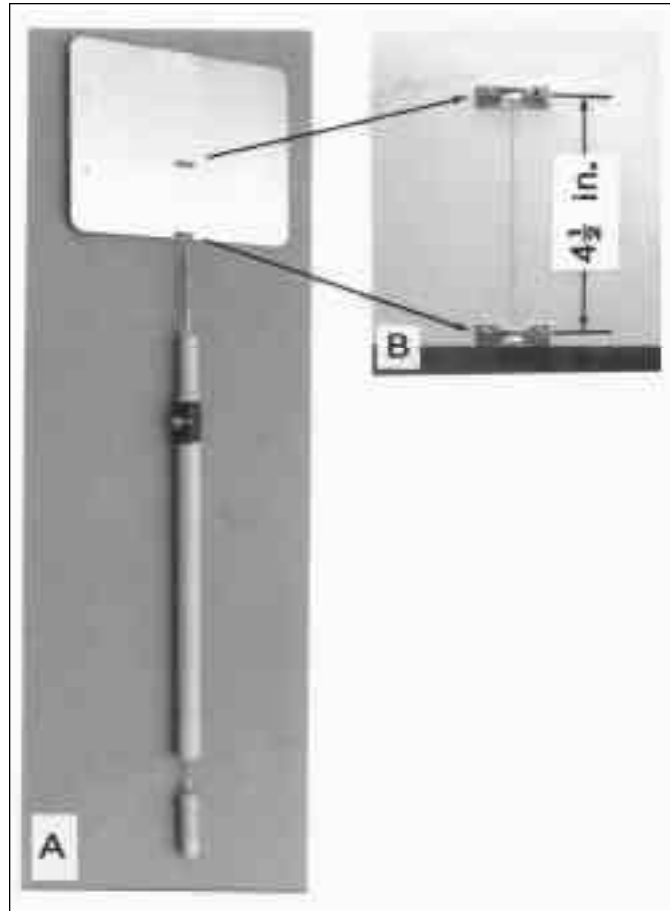


Figure 119—The clipboard post (A) in its compressed position ready to be inserted into the straps behind the clipboard. The 1/4-in rod slides into two 1/4-in straps on the clipboard. (B) These straps are positioned 4½ in apart and riveted (as shown) or bolted to the clip board with 1/8-in rivets or bolts.

Figure 119 shows the clipboard post in its compressed position. Two straps capable of having a 1/4-in diameter rod inserted are attached to the back of the clipboard in the middle, as shown. They are centered 6 in from each end and placed 4½ in apart so that the 5-in rod will engage each (fig. 119B).

The clipboard post is an adjusted pole, 1 in in diameter, with a spike on one end to push in the ground and a telescoping inside pole with a rod at the other end to which the clipboard is attached (fig. 119A). It is composed of telescoping plastic pipes each 18 in long (fig. 120A). It is 22 in long when compressed and 32 in long when extended (fig. 120B). An adjustable hose clamp is attached to the upper end of the larger pipe so that it may be compressed around the inside pipe to hold it in place (fig. 120).

Materials

Cost
(see footnote 1)

	<i>Dollars</i>
1-in CL 200 PVC pipe @ \$1/10 ft	1
3/4-in CL 200 PVC pipe @ \$1/10 ft	1
1-in diameter hose clamp	1
1/4-in diameter, 36-inch steel rod; piece, cut two 7-in pieces`	1
Several feet of black electricians tape	4
Total	8

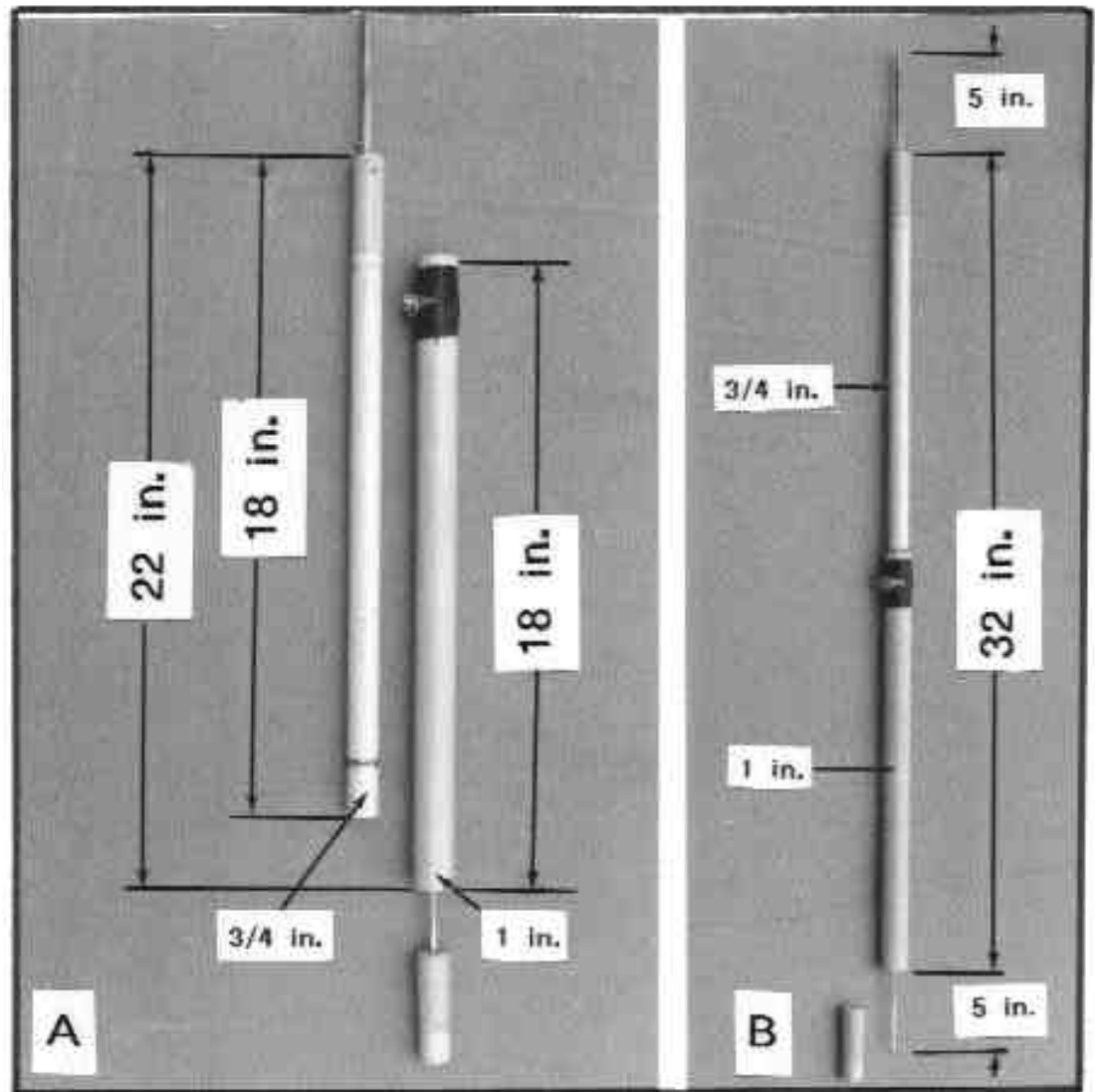


Figure 120—Details for constructing the clipboard post. (A) The 1-in PVC pipe CL200 and 3/4-in PVC pipe CL200, which fits inside the 1-in pipe, are each 18 in long. When the 3/4-in pipe is inserted into the 1-in pipe and compressed, they are 22 in long. (B) The 18-in inside pipe has been extended 14 of its 18 in, for 32 in. The 3/4-in diameter spikes at the bottom and top both extend 5 in beyond the pipe and are imbedded into doweling inserted in the pipe.

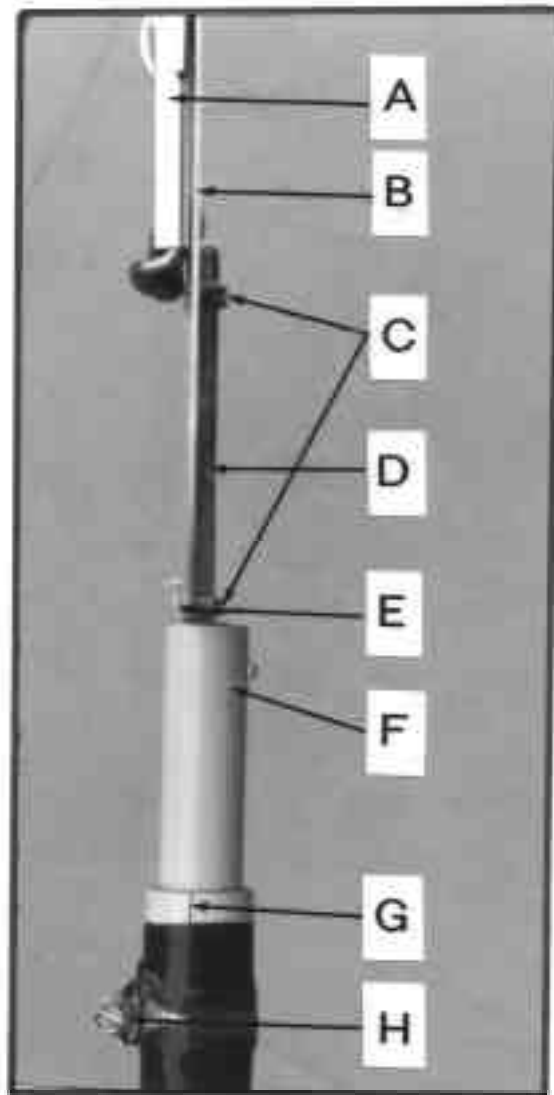


Figure 121—Details of how the clipboard is placed over the rod as viewed from the edge of the clipboard. (A) The clip of the clipboard. (B) The edge of the clipboard, in this case an aluminum board. (C) The $\frac{1}{4}$ -in straps into which the $\frac{1}{4}$ -in rod of the post is inserted. (D) The $\frac{1}{4}$ -in rod of the post inserted into the clipboard straps. (E) A screw inserted into the wood doweling to hold the $\frac{1}{4}$ -in rod, which prevents the clipboard from rotating in the wind (see fig. 118). (F) A piece of doweling fitted inside the $\frac{3}{4}$ -in PVC pipe, which is drilled out for a $\frac{1}{4}$ -in steel rod and held in place by a screw. (G) A sawcut 2 in into the 1-in PVC pipe so that the pipe can be compressed by the hose clamp (H) to hold the inside pipe at the desired height. At H, the hose clamp is secured with electricians tape.

The clipboard post is composed of two parts (fig. 121). One is 1-in CL 200 PVC pipe and the other is $\frac{3}{4}$ -in CL 200 PVC pipe, both 18 in long. The $\frac{3}{4}$ -in pipe fits inside the 1-in pipe with some slack. If pipe specifications other than these are used, be sure that one pipe will fit inside the other. When compressed, the clipboard holder is 22 in tall. When extended with 4 in of pipe inside, it is 32 in tall (fig. 120B).

To make the clipboard post adjustable, saw down 2 in into the end of the 1-in pipe (fig. 121G). Attach a 1-in hose clamp an inch below the top of the pipe and secure it with electricians tape (fig. 121H). Tighten the hose clamp so that the inside $\frac{3}{4}$ -in pipe can just be moved up and down to adjust height of the clipboard above vegetation or other obstructions.

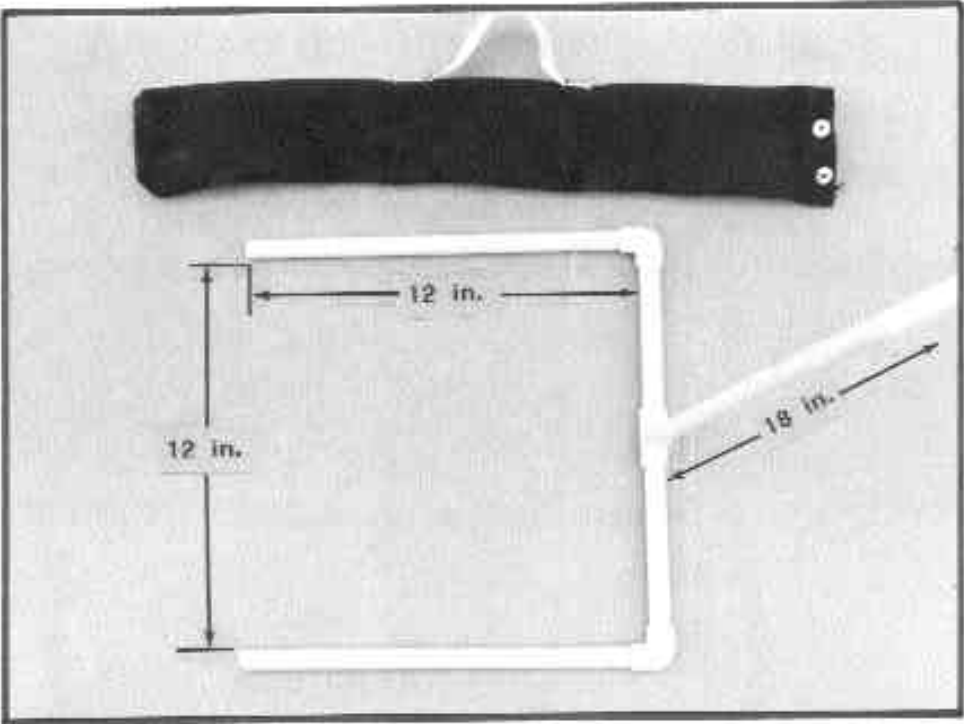


Figure 122—The 1-ft² sampling frame is made from 1/2-in PVC pipe. Inside measurement is 12 in square. The side opposite the handle is open to facilitate placement in shrubby vegetation. An 18-in-long handle facilitates placement of the frame.

**One-Square-Foot
Sampling Frame**

The 1-ft² sampling frame is used with stereo photographic sampling. It is constructed from 1/2-in-diameter PVC pipe and measures 12 in square (fig. 122). An 18-in-long handle reduces effort when placing the frame.

Materials	Cost
	(see footnote 1)
	Dollars
1/2-in-diameter PVC pipe, 10 ft long @ \$3/piece	3
2 90-degree, 1/2-in PVC elbows; 1 1/2-in PVC "T"	1
Total	4

Consider not cementing the elbows to the pipe so that the frame can be taken apart to transport. Figure 123 shows the frame disassembled with its carrying case. The case is made from canvas with a handle and two snaps at the open end.

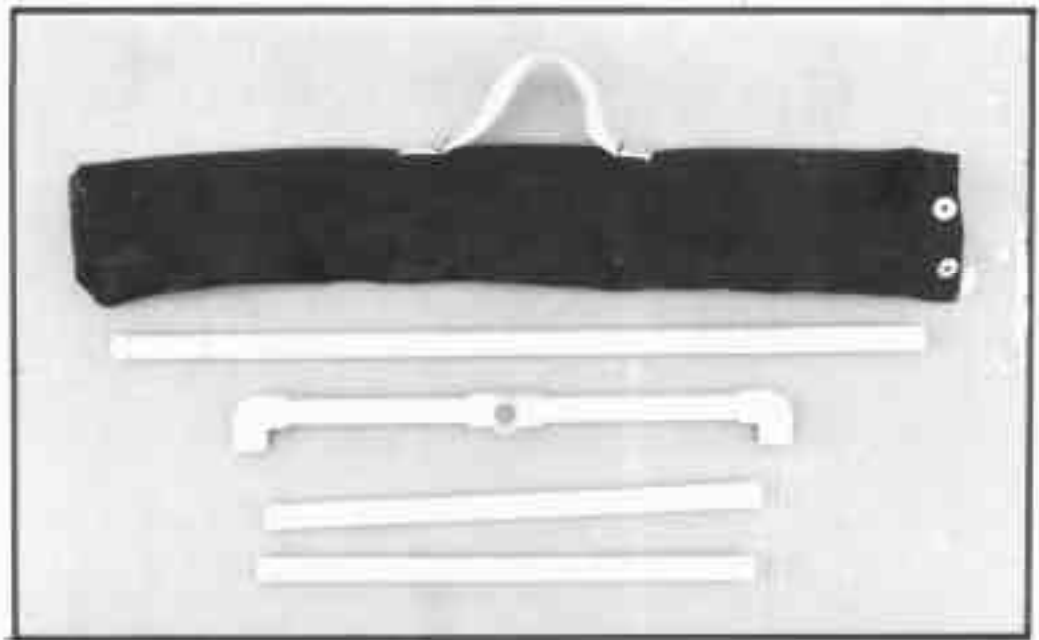


Figure 123—A1-ft² sampling frame disassembled with its carrying case. The case is made from canvas with a handle and two snaps at the open end.

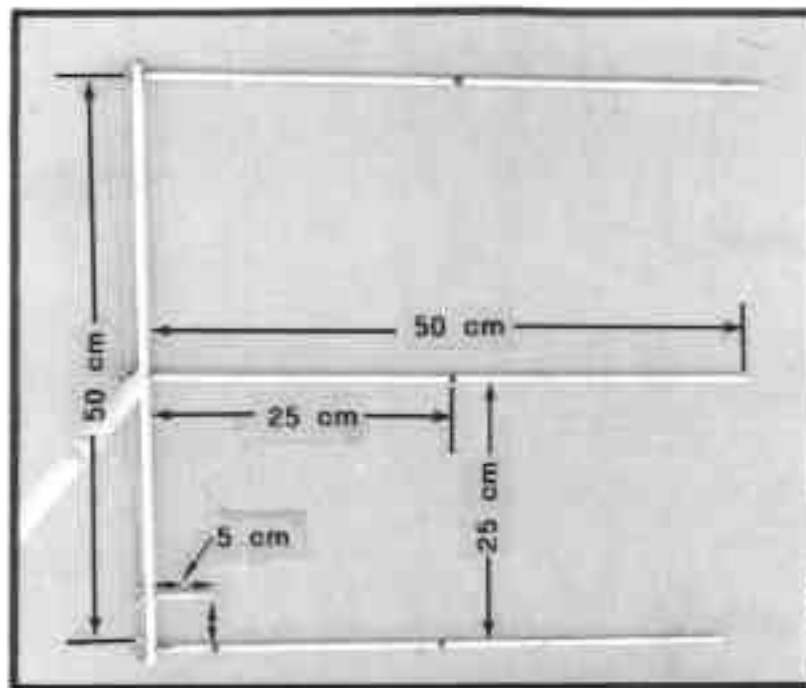


Figure 124—Nested frequency plot frame specifications. Measurements shown are inside dimensions. The four prongs must be cut 2 cm longer to provide for threading the ends and the aluminum back piece must be cut 2 cm longer to provide for 1/4-in tapped drill holes for the edge prongs.

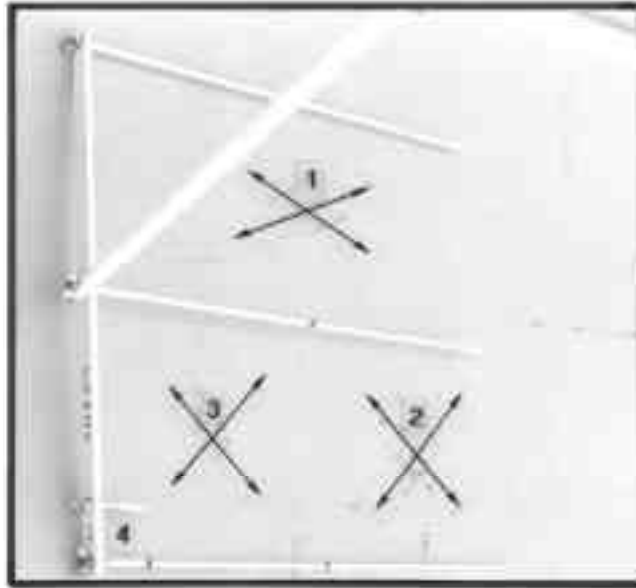


Figure 125—Plot locations in the nested frequency plot frame. The smallest is rated “4,” next largest a “3,” half the plot frame is rated “2,” and the rest a “1.” Plants rooted in each section are given the assigned rating, which is recorded by species.

Nested Frequency Sampling Frame

Nested frequency is a sampling system designed for low variability rates among observers; it is based on statistical analysis to detect change. A plot frame, 1/2-m square, with four sizes of nested plots is used (fig. 124). Species are recorded and given a value when rooted within any of the four subplots.

Values are assigned based on plot size (fig. 125). Species numerous enough to fall within the smallest subplot are rated highest to reflect their greater density. Species are recorded starting with the smallest subplot (4) and proceeding to larger subplots. Once a species is recorded, do not repeat its presence in a larger subplot.

Figure 124 specifies plot dimensions. Please note length requirements in the materials list below. The steel rods must be cut 2 cm longer so they can be threaded and screwed into the aluminum back piece. The aluminum back piece must be 2 cm longer than the dimensions shown in figure 124 to accommodate tapped holes for the outside rods.

Materials

Cost
(see footnote 1)

	<i>Dollars</i>
1 tap and die set for 1/4-in steel rod	(borrowed)
3 1/4-in steel rods, 36 in long:	
3 pieces cut 52 cm long, threaded for 2 cm (effective length 50 cm)	
1 piece cut 7 cm long, threaded for 2 cm (effective length 5 cm)	3
1-in by 1/4-in aluminum bar stock cut 52 cm long @ \$10/6 ft (drill and tap 4 holes, each 1/4-in diameter, at 1, 6, 26, 51 cm)	4
5 wing nuts for 1/4-in threaded steel rod	1
PVC pipe 1/2-in diameter SCH40 cut 50 cm long, @ \$3/10 ft	1
Total	9

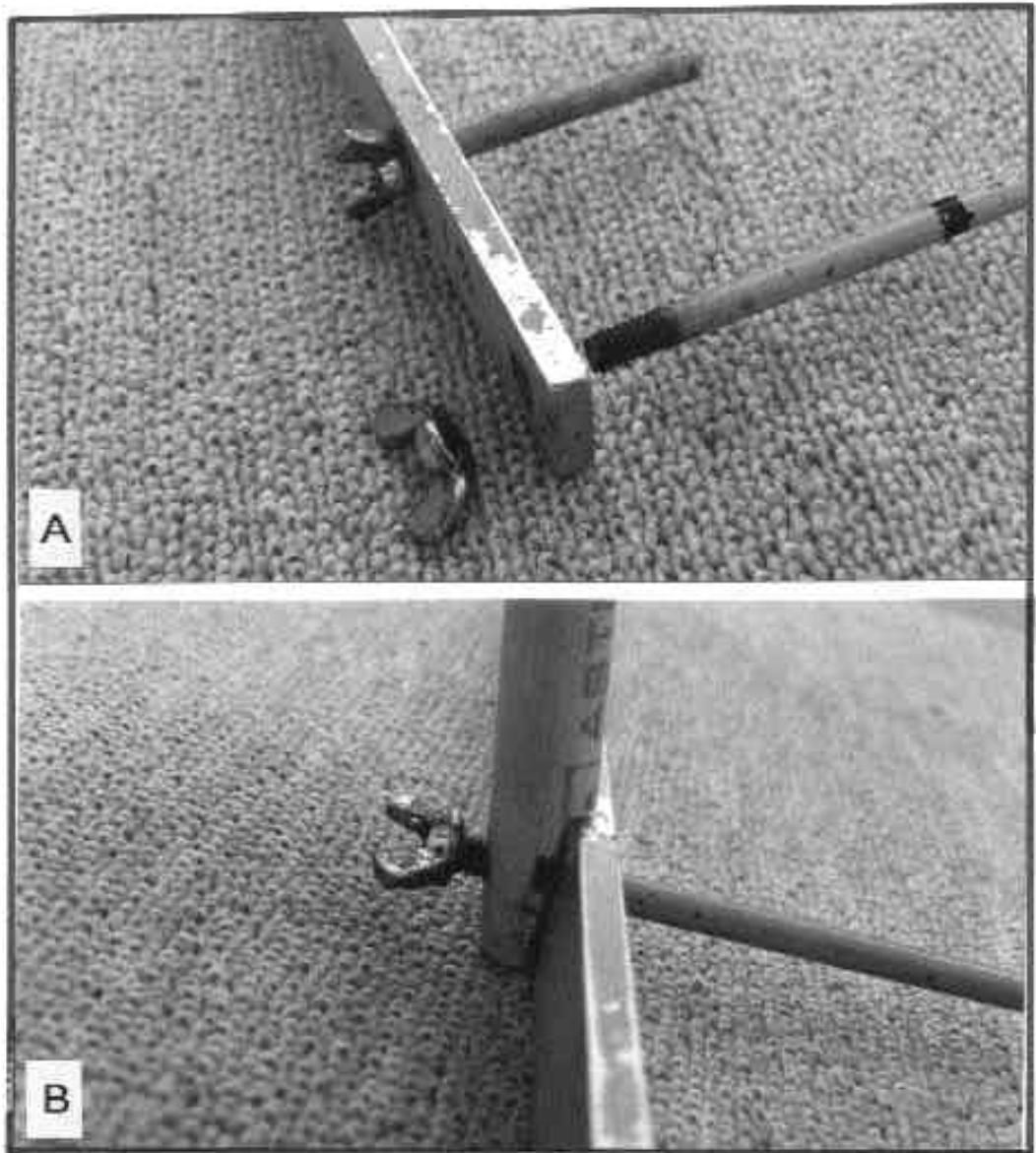


Figure 126—Method for attaching the nested frequency prongs to the 1-in by 1/4-in aluminum back piece. (A) A 50-cm prong is shown threaded and ready to screw into the aluminum back piece. Next to it is the 5-cm-long prong attached. The 5-cm subplot is identified by the black mark on the 50-cm prong and the end of the 5-cm prong. (B) The center 50-cm prong is shown screwed into the aluminum back piece and through the 50-cm handle, with a wing nut ready to tighten the handle to the back piece.

Sharpen the ends of the four prongs to a 45-degree angle. These points are where ground cover items are recorded, such as bare ground, gravel, or rock.

Screw the threaded rods into the aluminum back piece (fig. 126A). Secure the rods with wing nuts. Be sure the measurements shown in figure 124 are met.

The 50-cm PVC handle is cut out and attached (fig. 126B). Cut one-third of the way through the pipe 1 in above its end to fit over the aluminum back piece. Then, from the bottom and starting in the center, cut at an angle to the upper cut. Finally, drill a 1/4-in hole to match the hole at 26 cm in the aluminum back piece (fig. 126B). Assemble as shown in figure 126B.

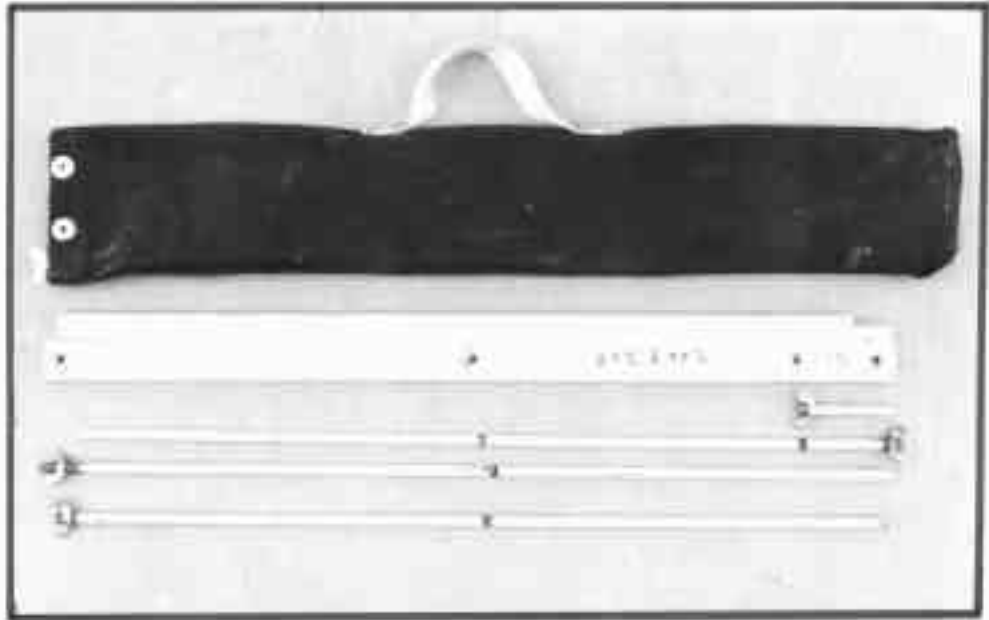


Figure 127—The disassembled nested frequency plot frame is shown with its carrying case. Notes on the aluminum back piece show percentage of the plot frame occupied by the 25- by 25-cm subplot (25 percent), 25- by 50-cm subplot (50 percent), and the 5- by 5-cm subplot (1 percent).

Paint the frame with dull yellow paint. When dry, paint the black marks at 5 and 25 cm on one prong and at 25 cm on the other prongs. These marks identify the various subplots sizes shown in figures 124 and 125.

The plot frame may be disassembled for carrying as shown in figure 127.

One-Square-Meter Sampling Frame

One-square-meter photo plot frames are designed to replace Parker's (1954) three-step method using a 3-ft by 3-ft plot frame. Both are used in photographs taken at an oblique angle. His plot frames were made from two 6-ft folding rulers, the joints of which could be used to draw a grid on a photograph. This 1-m² frame is marked off in 2-dm increments (fig. 128).

Materials

Cost
(see footnote 1)

	<i>Dollars</i>
3/4-in SCH40 PVC pipe @ \$2/10 ft, 2 required	4
90-degree 3/4-in PVC corners SCH40, 4 required	2
4 by 8 inch, 1/2-inch thick scrap plywood	(scrap)
2 screws #6, 1 in long	
Several feet of black electricians tape	4
Total	10

Cut the 3/4-in PVC pipe into four 1-m lengths (fig. 128A). Be precise because the pipes, when inserted into the elbows, fit at exactly the elbow corner. Do not glue the pipes to the elbows. The frame will be adequately stable with the pipes simply pushed into the elbows and then can be broken down for transport (fig. 128B).

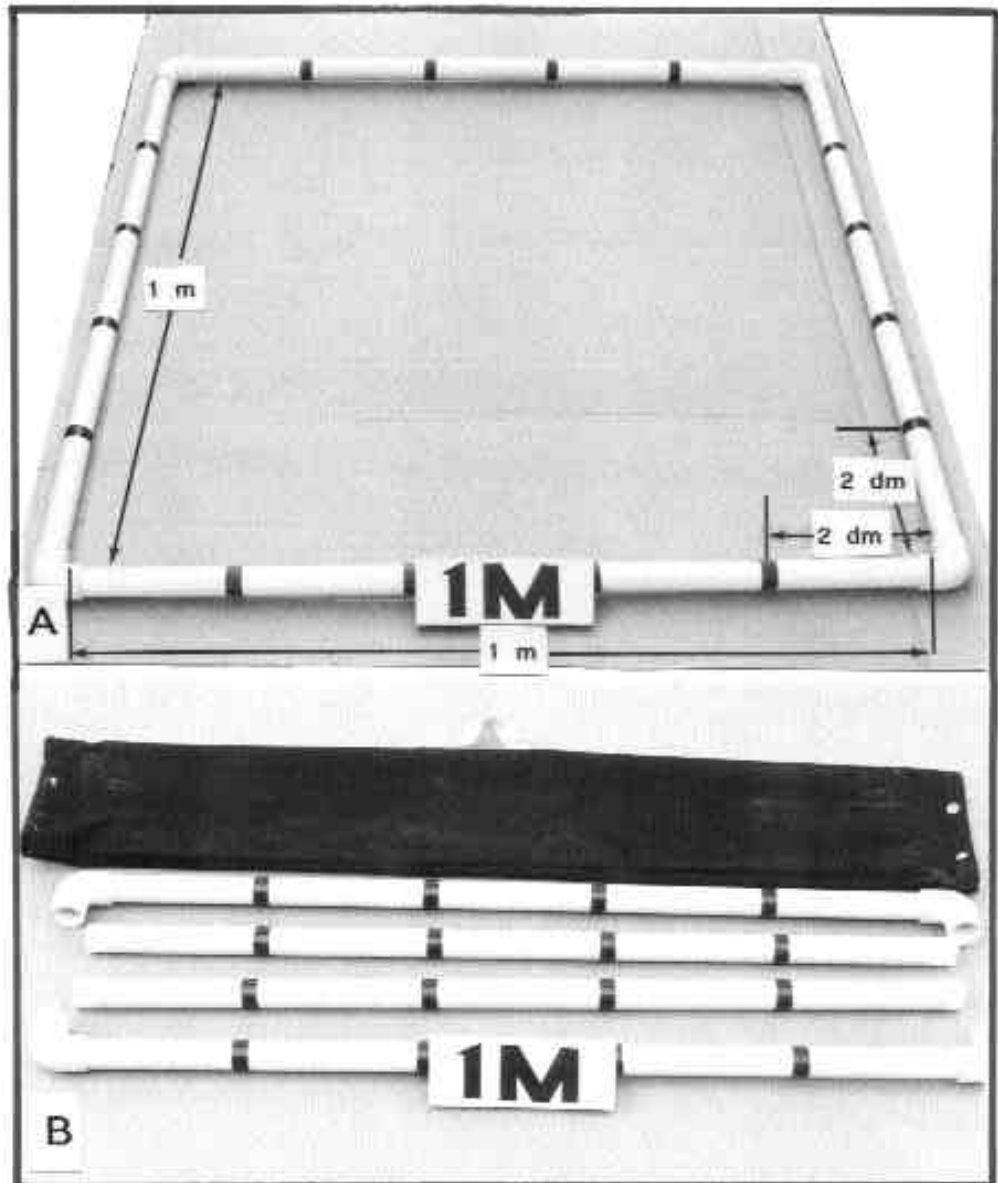


Figure 128—The 1-m² plot frame (A) is marked off in 2-dm increments. Inside measurements are 1-m per side. The ¾-in pipe may be measured precisely and inserted into the elbows because the elbows have a stop at the exact position of the elbow bend. Do not cement the elbows to the pipe because the plot frame can be disassembled for easy transport in its canvas carrying case (B).

Next, measure out 2 dm on all four pipes and circle the pipe at these locations with electricians tape to mark a 2-dm grid system (fig. 128).

In figure 128, a 1/2-in-thick piece of plywood measuring 4 by 8 in (1 by 2 dm) has been attached to identify the meter plot frame. The “1” and “M” are made with 3/4-in-wide electricians tape. The plywood is attached with two screws through the board and into the PVC pipe. I use the identification for slide talks to quickly identify the size of plot frame.

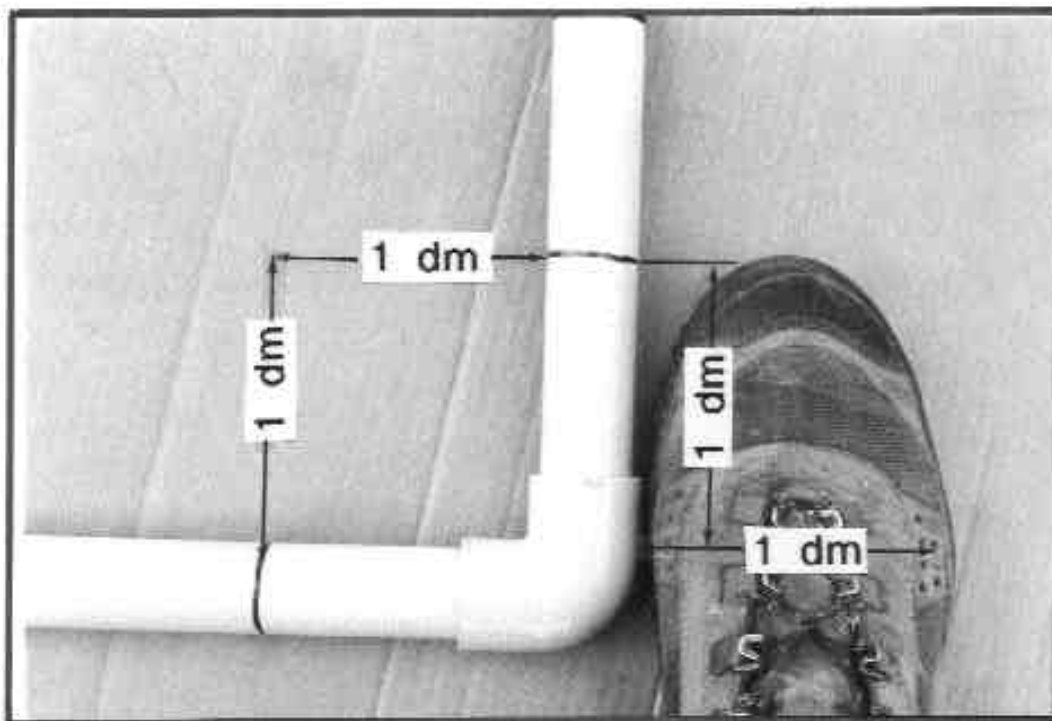


Figure 129—A method is shown for estimating small increments of cover. In a 1-m² plot frame, 1 dm² is 1 percent cover. This represents about the front one-third of my foot. Because a 1-m² plot is 3.4 feet on a side, each large step represents 1 percent cover so long as the cover is represented by each and every step. An area 2 by 2 dm is 4 percent cover, about 1.3 of my foot. I now have a measuring system for estimating cover of items I encounter while walking across an area.

Figure 129 reflects a system I have found useful in estimating cover of vegetation or soil surface items. An area 1 dm by 1 dm is 1 percent of a square-meter plot. A square-meter plot, being 3.4 ft on a side, is a little longer than the stride of a person about 6 ft tall. The front one-third of my foot is about 1 by 1 dm (fig. 129). Therefore, each time I take a long step, any vegetation that covers the front one-third of my foot is 1 percent of the cover. But the vegetation must approximate that area for *each and every step*. If it does not, then canopy cover of that item is less than 1 percent.

Each 2-dm area is 4-percent cover, a little more than one of my whole feet. Thus, when walking through an area, I have some reasonably firm idea of how to estimate cover of various items.

Robel Pole Sampling System

The Robel pole (Robel and others 1970) offers a way to document stubble height of herbaceous vegetation. They tested various systems for observing stubble height and settled on a pole marked in 1-in increments and set 4 m from an observation position 1 m high. Figure 130 shows specifications for making the Robel pole system.

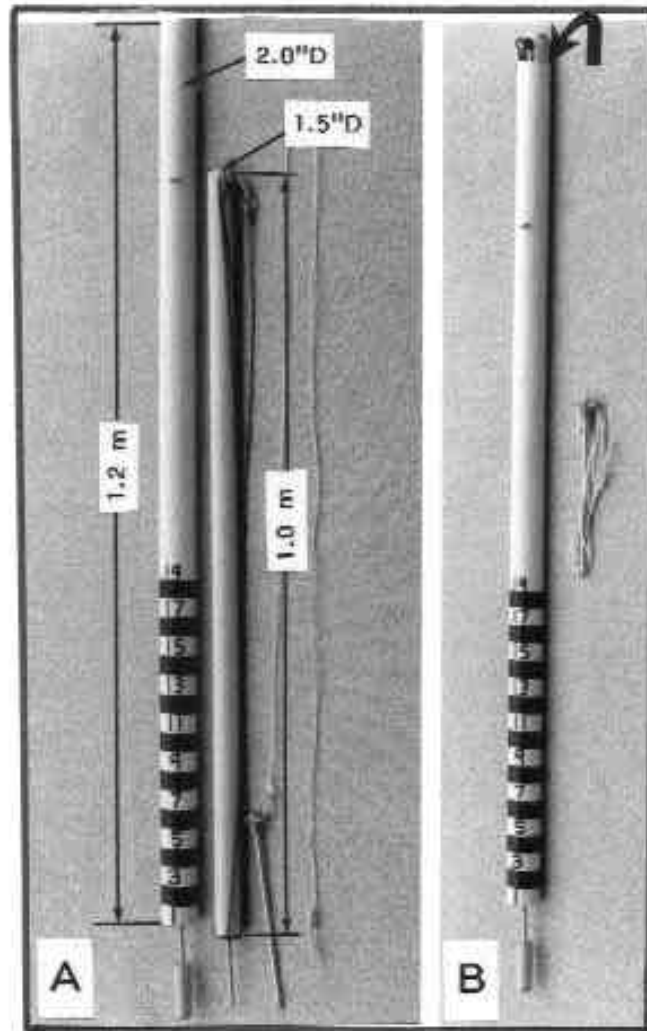


Figure 130—Robel pole specifications and criteria are shown. (A) A 2.0-in diameter PVC pipe is used for the Robel pole and 1½-in pipe for the camera height pole. These diameters permit the camera height pole to be inserted into the Robel pole (B) for carrying. A tent stake for supporting the Robel pole is carried in a person's pocket. In A, the Robel pole is 1.2 m tall with an eye at 1.0 m. The camera height pole is 1 m tall to which is fastened a 4-m measuring line. When working alone, use a tent stake with 2 m of line to hold the Robel pole vertically while pulling the 4-m line taut.

Materials

Cost
(see footnote 1)

	Dollars
2-in diameter CL200 PVC pipe @ \$3/10 ft (cut 1 piece 1.2 m for the Robel pole)	3
1.5-in diameter CL200 PVC pipe @ \$3/10 ft (cut 1 piece 1.0 m for the camera-height pole)	3
20 ft 1/8-in diameter nonstretch rope	1
1½-ft 1/4-in diameter steel rod (cut 2 pieces 8 in long)	1
2 #6 size eye screws; 1 6-in tent stake	2
1 snap with ring; several feet of black electricians tape	3
Total	13

The Robel pole system consists of two poles and a 4-m section of line attached between the poles. Figure 130 lists the specifications permitting the camera-height pole to be placed inside the Robel pole for carrying. Figure 131 illustrates construction and marking of the Robel pole and details.

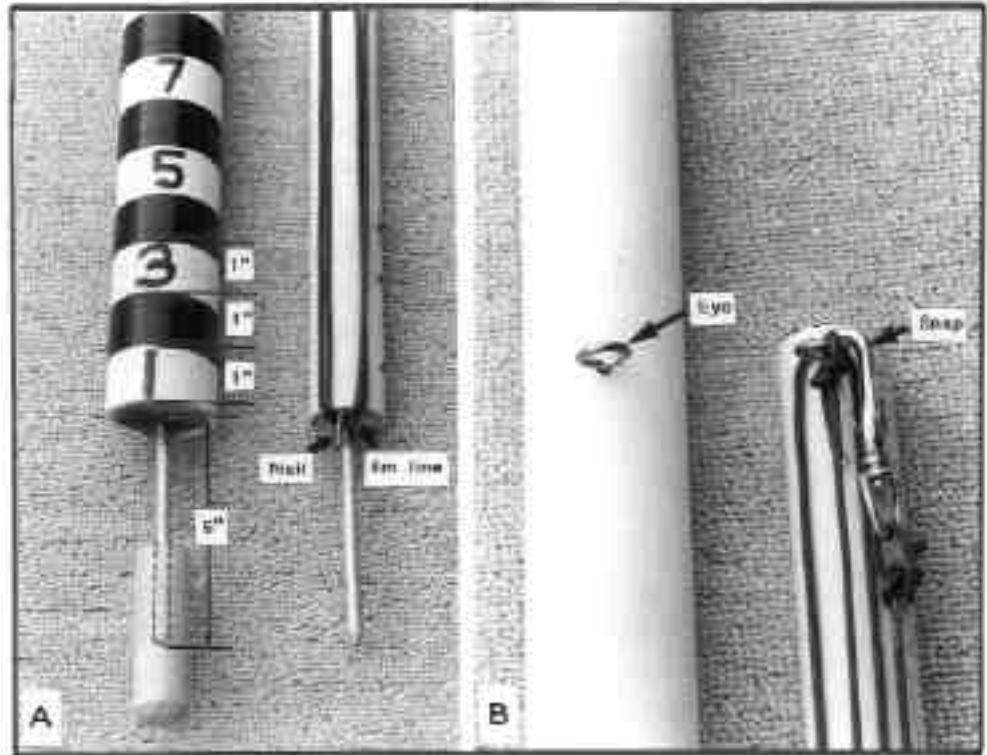


Figure 131—(A) The Robel pole is marked at 1-in increments with black electricians tape. Alternate inch increments are inscribed with permanent black markers for every odd-numbered inch. Steel rods $\frac{1}{4}$ -in diameter extend 6 in below the Robel pole and the line pole. The Robel pole rod is protected by doweling drilled out for $\frac{1}{4}$ -in steel rod. Steel rods are secured inside the PVC pipe by doweling. (B) An eye is attached to the Robel pole 1 m aboveground. After screwing in the eye, remove it and cut off the sharp end, then replace the eye. Cutting off the sharp end provides room for the camera height pole to be inserted into the Robel pole (fig. 130B). A 4-m line, secured by a nail, is wrapped around the camera height pole. It is snapped to the eye on the Robel pole to measure consistent distance between Robel pole and the camera. The camera height pole, 1 m tall, provides a consistent camera height when the camera is positioned at the top of the pole.

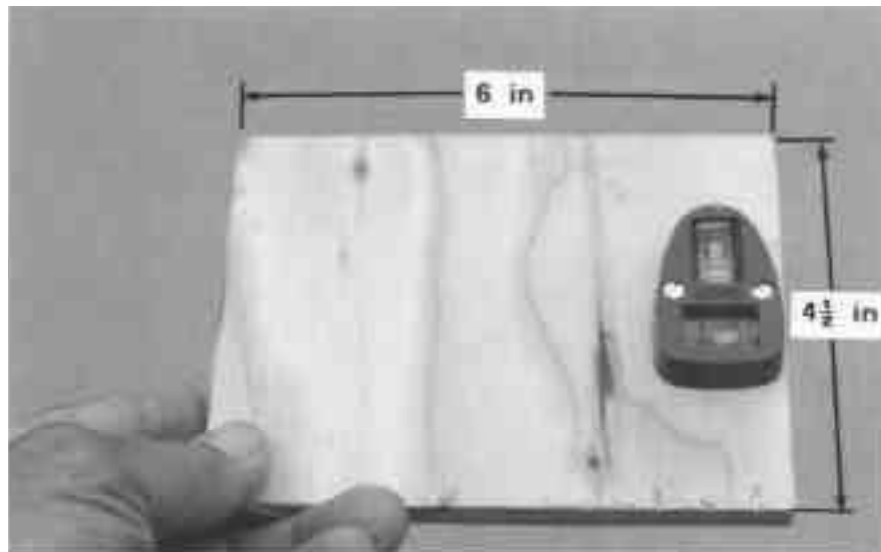


Figure 132—A leveling board for taking overhead photos of tree canopy cover measures $4\frac{1}{2}$ in by 6 in and has a two-way level attached. It is made from scrap $\frac{1}{2}$ -in plywood.



Figure 133—The camera leveling board is used to consistently rephotograph the tree canopy. Place the leveling board on top of the meter board for consistent height above the ground. Place the meter board at a right angle to the transect line. Move the meter board sideways to center the cross-transect bubble, then tilt the level board to center the down-transect bubble, and photograph.

Camera Leveling System

Photographs taken looking up at the tree canopy require a camera leveling system for consistent rephotography. The system described here uses the meter board top as one axis for consistently orienting the camera and a leveling board for the other axis (figs. 132 and 133).

Materials	Cost (see footnote 1)
	<i>Dollars</i>
1 2-way level or 2 line levels	4
4½- by 6-in, 1/2-in thick, scrap plywood	(scrap)
Total	4

Figure 132 illustrates the camera leveling board's dimensions and placement of the two-way level. Figure 133 illustrates uses of the leveling board. Place it on the top edge of the meter board, move the meter board left or right to center on the cross-transect level, then tilt the board to center the down-transect level. Move your head out of the way and photograph.



Figure 134—Double camera bracket for use when photographing in both color and black and white. The bracket is made from 1- by 1/8-in stock aluminum bar with holes drilled to mount the cameras. Identical cameras are recommended to simplify camera adjustment. Figures 135 and 136 illustrate construction details.

Double-Camera Bracket

Two cameras usually are needed to photograph in both color and black and white. A bracket holding both cameras together provides for simple and effective manipulation of the cameras (fig. 134). Identical cameras simplify adjustment. When ready to photograph, simply shoot with the top camera, then the bottom, and advance the films.

Materials

Cost (see footnote 1)

	Dollars
1 6-ft piece aluminum bar stock, 1 in wide by 1/8 in thick (cut a piece 18 in long)	8
Instant thumb screws:	
2 1/4-in diameter standard 20 thread, 3/8-in shank screws	1
2 instant thumb screws	1
Total	10

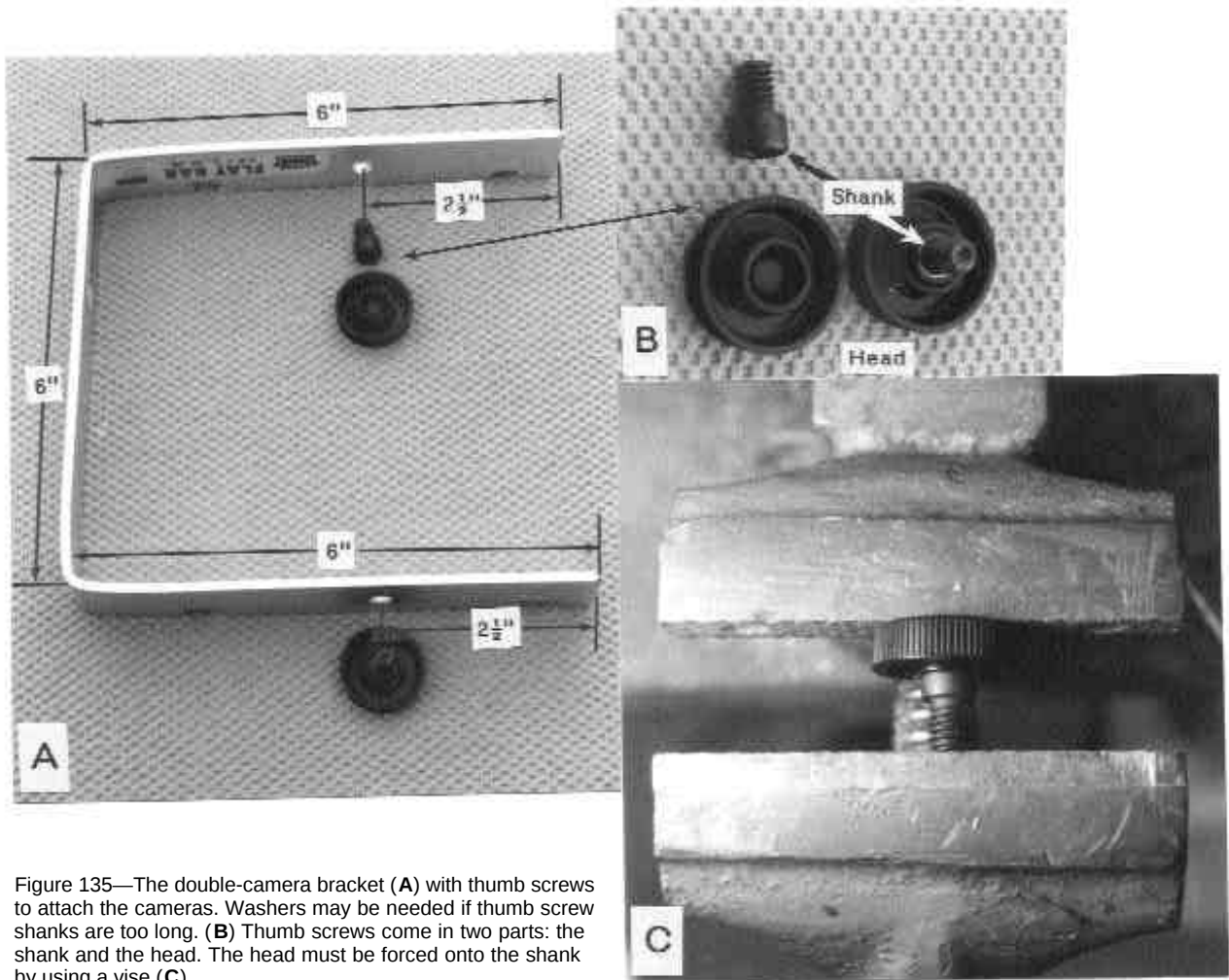


Figure 135—The double-camera bracket (A) with thumb screws to attach the cameras. Washers may be needed if thumb screw shanks are too long. (B) Thumb screws come in two parts: the shank and the head. The head must be forced onto the shank by using a vise (C).

The aluminum bar stock, cut to 18 in, is bent into equal 6-in segments to form a “U” (fig. 135A). Then, 1/4-in holes are drilled 2 1/2 in from the ends (fig. 135A) to hold the cameras. Be sure the holes will place the cameras where the rewind buttons will be accessible (fig. 136B). Next, on the aluminum bar make two 1/4-in cuts, 1/2 in apart, into the aluminum toward the front of the camera and bend the 1/2-in piece upward to about a 30-degree angle (fig. 136A). Do not bend more than 30 degrees or the aluminum will break. These tabs will prevent the cameras from rotating on the bracket.

Assemble the thumb screws, which come in two parts — the shank and the thumb head (fig. 135B). Be sure the shank will fit the camera mounting socket. A 1/4-in diameter, 20-thread shank 3/8 in long will work. Press the head onto the shank as shown in figure 135C using a vise. Heavy pliers usually do not apply sufficient force to seat the thumb head.

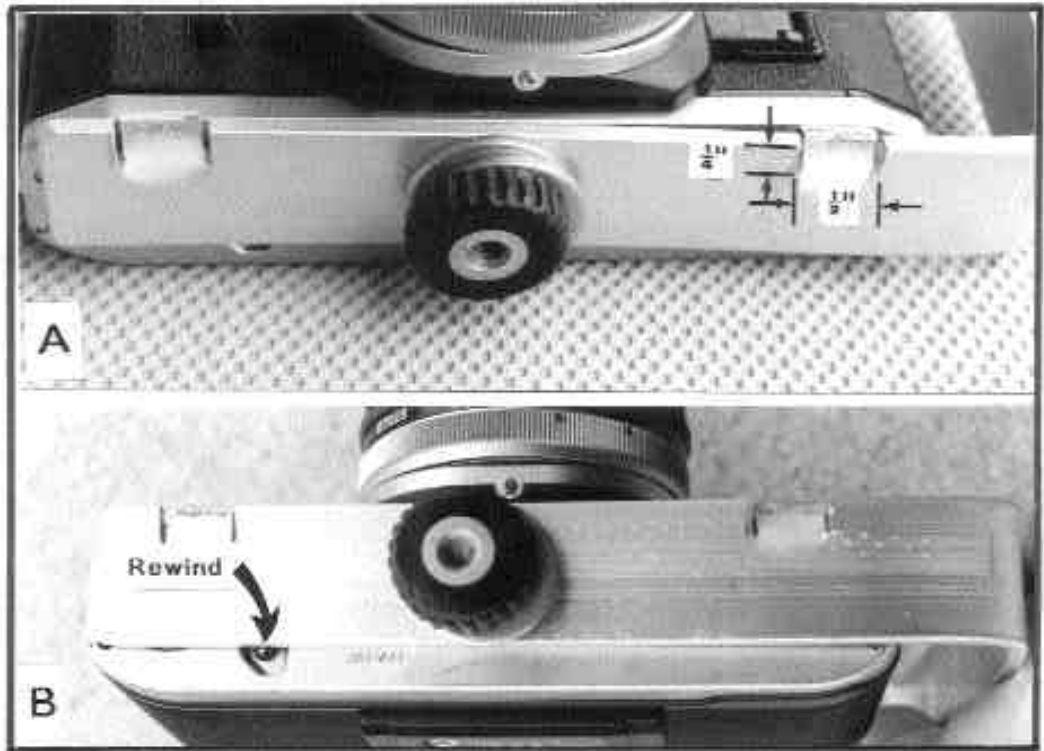


Figure 136—Two factors are important in attaching the camera to the bracket. (A) Make two ¼-in cuts into the front of the bracket, ½ in apart, and bend upward no more than 30 degrees to prevent rotation movement of the camera. (Bending them farther may break them off.) (B) Be sure the bracket clears the rewind button so that film may be changed while the camera is attached to the bracket.

Fenceposts

Flimsy fenceposts are available at builders supply outlets such as Home Depot®. They are listed as “light duty” stamped metal fenceposts. Measured across the top, the long axis is 1¼ in. Medium duty stamped fenceposts measure 2 in. Light duty posts may have to be ordered.

Identification Tags

Orange colored, aluminum tags suitable for installing on witness sites to identify a monitoring location may be obtained from:

Dixie Steel and Sign Co.
P.O. Box 54616
Atlanta, GA 30308
Phone: 404-875-8883
Fax: 404-872-5423

Obtain a tool-steel inscriber to inscribe directions and distances to camera locations and photo points directly on the tags. The tags are about 12 gauge thickness with black and orange paint.

Appendix D: Photo Monitoring Filing System

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	299	Topic Being Monitored
	299	Geographic Location of the Study
	300	File Contents
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	301	Photo-Mounting Forms
	301	Summary Forms
	301	Envelopes for Negatives
	302	Slide Files

Introduction

The concept of photo monitoring implies repeat photography, which in turn suggests the need for a filing system where, over the years, one can regularly deposit their photographs and data. This appendix describes some attributes of filing systems I've found useful over the last 40 years.

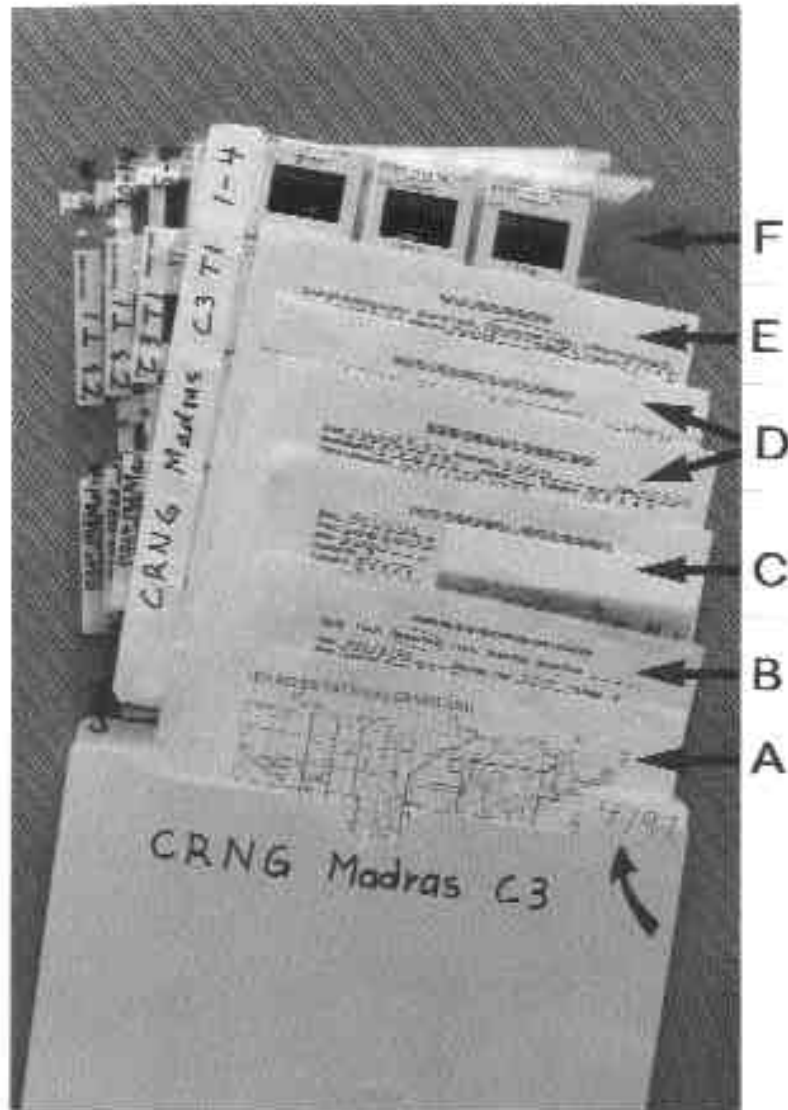


Figure 137—File folder contents for the Crooked River National Grassland trend cluster C3. I use several sizes of expanding folders: 2-fold shown here, 4-fold, and 8-fold to fit the file size. Each folder is labeled and the last date of sampling is attached to the upper right corner (arrow). All items pertaining to the sample location are included in the file: (A) general area map (fig. 72), (B) the form "Sampling Site Description and Location" for a plot layout map (fig. 82), (C) a form for attaching photographs and recording data shown here as the "Photo Trend Sample - Nested Frequency" (figs. 83-85), (D) data summary forms shown here as "Nested Frequency Transect Data" (figs. 86 and 87) and "Nested Frequency Cluster Summary" (figs. 88 and 89), (E) trend interpretation using "Range Trend Rereadings" (figs. 90 and 91), and (F) clear plastic holders for slides (fig. 139). Not shown are black-and-white negatives in their envelopes identified by date, cluster, and transect.

Office Filing System

Office organization of the filing system presumes that each monitoring location is completely contained in its own folder (fig. 137). Consider three alternatives for filing these folders: by (1) date of rephotography, (2) topic of the study, or (3) geographic location of the study.

Date of Photography

Date of photography may be season of year, such as Pole Camp in spring, summer, and fall (fig. 20); once each year at a specific date, such as herbage production (fig. 22); irregularly based on disturbance such as logging (figs. 29, 50, and 51); or at specified intervals, such as every 5 years—the three intervals between 1977 in figure 46 and 1991 in figure 48.

An advantage of organizing by date is having files immediately available each year according to their schedule. This means that topics of sampling and geographic locations are interspersed requiring search of all files. I place the date information on the upper right corner of the file rather than file by date.

Topic Being Monitored

The topic being monitored determines the purpose for monitoring and the kind of vegetation under consideration. Topics may be exclosures (fig. 137), livestock trend sampling (figs. 75, 83, and 92), sagebrush-grass (figs. 75, 83, and 92), logging effects (figs. 21, 50, and 51), herbage production (fig. 22), or livestock utilization (figs. 20 and 106-108).

Similar topics are filed together, such as logging with overstory removal (fig. 21) and a single light thinning (figs. 50 and 51) in ponderosa pine. All logging may be put together or all ponderosa pine may be located together. If logging is the topic, salvage of beetle-killed lodgepole pine (figs. 46-48) would be filed with it. Decisions must be made on organizing the files by topic, none of which will prove wholly satisfactory.

Geographic Location of the Study

Geographic location is determined by the closest available motel, access by major road, or distance to travel. My work from Portland, Oregon, covering two states, is organized by towns that gave good access and an acceptable motel. When going to an area on other work, I look in its geographic file to determine if any photo monitoring locations are due for sampling. What might be combined between current work activity and photo monitoring? Are there any monitoring sites in the neighborhood of the work area or on the route? Dates on the files are the first consideration. Is the work activity occurring about the same date as required for sampling? Consider organizing files by date and then by topic within a geographic file. Another approach is to allot several days for monitoring. Having files by location greatly facilitates travel planning and might save considerable time in visiting each site. Filing by location has been my choice for many years.

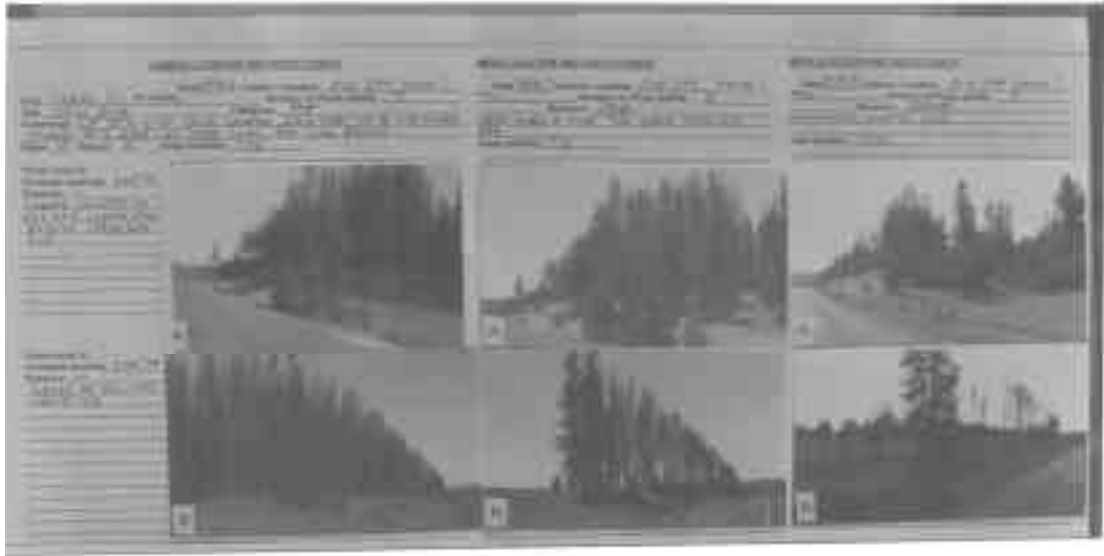


Figure 138—Three pages of filing system form “Camera Location and Photo Points” overlapped to compare changes between three dates. These are figures 46, 47, and 48 located by the map in figure 45. Essential information for making comparisons is in the upper right portion of the form: date and camera location. Overlay the forms so that photographs can be compared as shown. Camera orientation in close landscape photography can be a problem resulting from no meter board or permanent item on which to orient the camera. Compare photo B for 1977 and 1978 with B for 1991. The horizon is similar for the first two but quite different for 1991, a situation to be avoided. Also notice the variation in the road crest in the A photos.

File Contents

All information pertaining to a photo monitoring project should be placed in a single file. This may entail duplicate copies of some items, such as a request and authorization for a study, which might require filing in an office administration folder as well as in the project folder. Long-term investigation, like photo monitoring, is significantly enhanced when historical documents are included in the file.

Consider six kinds of items to include: (1) authorization, approval, or justification for the project; (2) maps to find the monitoring location—a general map noting the location and a site-specific map diagramming the sampling layout; (3) photo-mounting forms that also may be used to record data, such as transect sampling systems; (4) envelopes for negatives, either color or black-and-white, or both, digital memory cards, or compact discs (CDs); (5) summary forms when data are collected; and (6) plastic sheets for holding slides.

Authorization, Approval, or Justification

Document initiation of the photo monitoring project. This may entail copying instructions or policy from an organization, a written request to monitor and subsequent approval, or those parts of an environmental impact statement requiring monitoring of specific activities. If an environmental impact statement, or similar document, is required, include it. Assume that someone totally unfamiliar with your organization's policy, protocol, or operational procedures may pick up the file and will have everything they need to understand and use the monitoring system. This has proven invaluable in monitoring projects older than 20 years because policy, protocol, and operational procedures change.

Maps

Two maps always should be included in the monitoring file (fig. 137): a general map showing how to find the monitoring site (fig. 72), and a detailed site map of the monitoring system (fig. 73). These maps should be in such detail that a person new to the area can find the monitoring location and do the rephotography.

Photo-Mounting Forms

Effective use of photographs in monitoring suggests that they should be mounted to facilitate comparison. The filing system forms in appendix B are organized so that photos are mounted on the right, underneath the date and camera location. Pages may be overlapped to compare any number of photos by date (fig. 138).

Two kinds of photo-mounting forms are provided: those for topic or landscape photography where measurements are not made (figs. 44, 45, 46-48, and 138), and those for transect sampling where measurements are recorded in the field (figs. 67-69, 75-77, 83-85, 93-95, 99-100, and 106-108). The form shown in figure 137 is a transect form (figs. 83-85). These forms have space for 3- by 5-inch photos.

Summary Forms

Summary forms are used with transect sampling to summarize and interpret the data. One important form is "Range Trend Rereadings," used to compare data among years (figs. 79-80 and 90-91). It may be used with several of the sampling systems. Other forms are designed for a specific system, such as nested frequency (figs. 86-89; tables 2 and 3) or Robel pole utilization (fig. 109).

A different kind of summary form is used with grid analysis. It is a piece of clear plastic (fig. 54) labeled with sampling date, site name, and item, on which outlines of items (shrubs in this illustration) are drawn (figs. 55-56, 60, and 68-69). The outlined sheet is placed on a grid (figs. 58 and 70), which is adjusted in size to the outline, and the number of intersects within each outline are recorded on a summary form (figs. 59 and 71). The photograph, sized grid, outline sheet, and summary form are all filed.

**Envelopes for
Negatives**

Negatives, color or black-and-white, should be kept in the monitoring file. I find that keeping them in the envelopes from processing is quite satisfactory; there is a compartment for the negatives and one for the pictures. I routinely have two prints made: one for mounting and another as a spare. The envelope is labeled with date of photography, monitoring location, and camera-photo point identification.

Each picture on the negative should be identified by a photo identification sheet placed within the camera's view. After several sessions of rephotography, identifying which negative was taken in what year can be impossible. This becomes a serious threat to integrity of the project when prints are made simultaneously from several years of rephotography of the same photo point. How might the various negatives be returned to their proper envelope?

Digital images may be stored in the file by any of three methods: (1) memory cards with their containers, (2) transferred to a CD, or (3) stored on the hard drive of a computer with essential identifying information. Directions to find the computer filing system should be placed in the file.

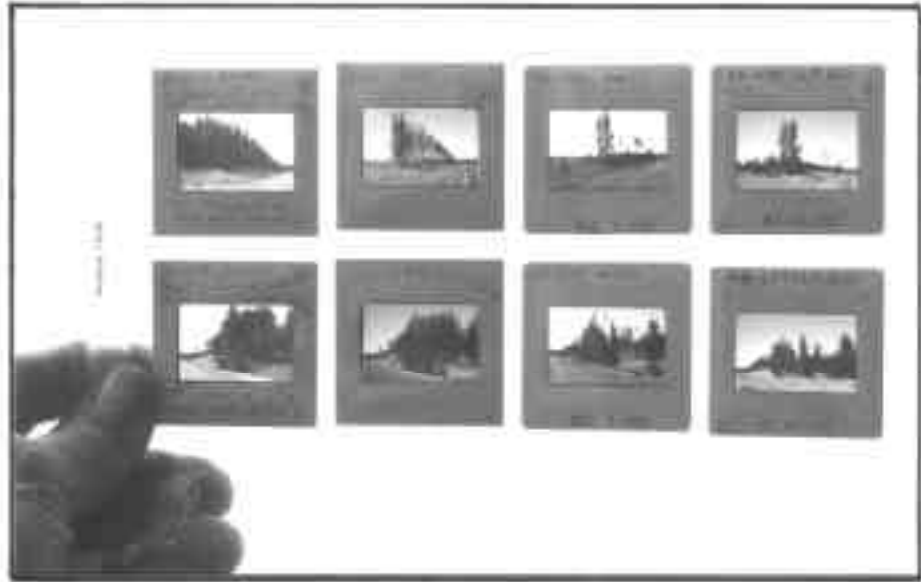


Figure 139—Slides filed in clear plastic sheets facilitate comparison among years. I use either of two systems: four columns by date using the slide holder in portrait view (shown here) or five columns by date using the slide holder in landscape view where five sets of slides are compared. Shown here are slides of figures 46 through 48 and 138. This system of four dated columns also was used in figure 137, where four sheets were required to hold slides for each date.

Slide Files

Slides may be filed in two kinds of holders: rigid opaque plastic or flexible clear plastic sheets. Rigid holders protect the slides on only one side, the other is open. Clear plastic have pockets (2 by 2 in) into which slides are placed (fig. 139). They are protected on both sides. A product **not** having PVC in its makeup will not damage the slide itself (for example, ClearView™). Some flexible pocket sheets will adhere to the slide and damage the emulsion. Slides do not fall out of rigid holders but they do tend to fall out of flexible pocket holders. Even so, my preference is for flexible pocket holders because they take only one-third the filing space of rigid ones.

Slides may be returned to you from processing in either paper or plastic mounts. Paper is less rigid and easier to write on but will hang up in projectors more often and is useless if ever dampened. Plastic requires felt-tip pens for effective writing such as Sanfords Sharpie® Ultra Fine Point Marker, the same one used for drawing outlines on clear plastic sheets. I specify “plastic mounts,” “number only,” and “do NOT date” when I have slide film processed.

All my slides are dated by when they were taken, not when processed. I use a “000” size date stamp with year, month, and day. A stamp significantly reduces time handling the slides. Each should be identified by a “photo identification” form within the view (figs. 26, 33, 67-68, 75, 83, 93, and 106). In addition, I label each slide for easy recognition and add any pertinent information (fig. 139).

Consider filing slides in columns by date (figs. 137 and 139). If there are five slides for a photo point, I file them in landscape orientation (horizontal) in the slide holder. This permits comparing five sets of slides from five different dates on one sheet. If there are four or less slides, I use columns in portrait (vertical) orientation (fig. 139) where four columns may be compared. Using a light table, one can view a number of photo points over considerable time. In figure 139, only photos A and B are shown covering a time span from 1977 to 1997.

Appendix E: Photo Techniques

Contents	303	Introduction
	305	Composition of Photographs
	313	Light
	323	Relocation of Photographs

Introduction

This appendix is devoted to several topics with much of the discussion occurring in the figure captions.

Hedgecoe (1994) introduces his treatise on landscape photography by discussing learning how to see. What the eye transmits to the brain is not what the camera records. The eye scans a topic for several seconds while the brain filters out the surroundings. Our eyes perceive fine detail over just a small area in the middle of the view. The camera records a fixed rectangular part of the scene with no overt identification of a topic. The view recorded has constrained edges, unlike the movement of eyes. A photograph, therefore, must be purposely oriented to record what the eye and brain see.

Johnson (1991) suggests asking several questions to help resolve eye and camera relations: Why am I taking this picture? What is the purpose of this picture? What will the picture demonstrate? What appeals to me in this scene? and What am I looking for? "Looking for," the topic of interest, might occur in one of three planes: foreground, middle distance, and far distance. These are relative distances between the camera and the horizon. Close photography might have only 200 yards from the camera to the horizon or back of the scene (fig. 26), in contrast to 10 miles in a general landscape view (fig. 16). Composing the picture to focus on the topic is an important objective.

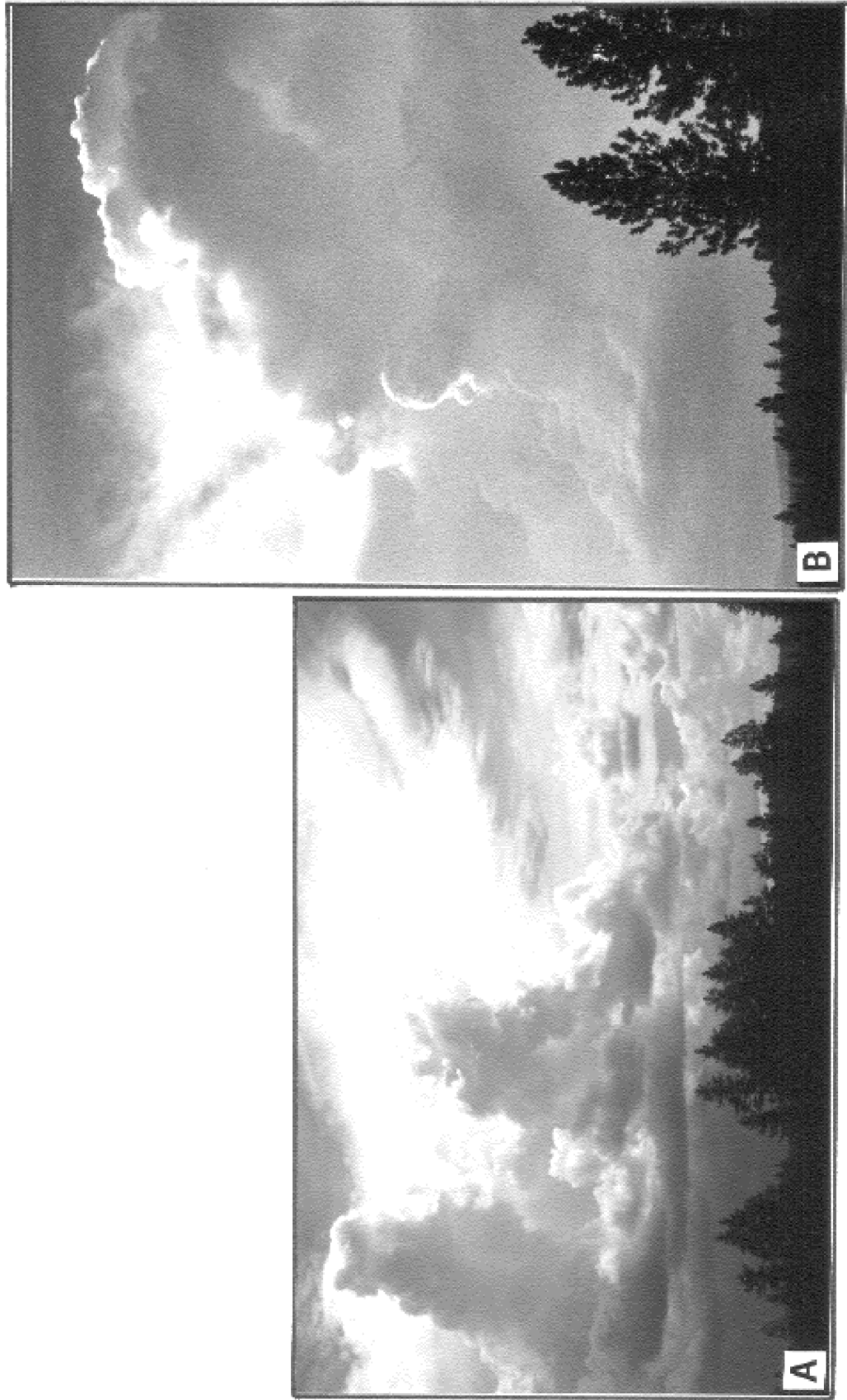


Figure 140—Comparison of (A) landscape and (B) portrait camera orientation. Hedgecoe (1994) considers landscape camera orientation as peaceful and stable and portrait orientation as active and unstable. Do you agree?

Composition of Photographs

Hedgecoe (1994) suggests that camera orientation helps to convey a message. Landscape (horizontal) orientation suggests peaceful and stable conditions, and portrait (vertical) orientation connotes active and unstable situations. Figure 140 compares these orientations.

Mobility of camera location is more valuable than a battery of lenses for photographic composition (Hedgecoe 1994). By moving around to view the topic, one can totally change the composition of the picture. Different foreground and background elements may be aligned, or detail close to the camera may be avoided or included. The point is to make the picture emphasize the chosen topic.

The next consideration is composition: First identify the topic of interest, and then position the camera to enhance the topic. Hedgecoe clearly discusses the “rule of thirds,” which is based on the golden mean, a 1:1.62 ratio, about the dimensions of a 35-mm image, which seems to be the ratio most pleasing to people from western cultures (fig. 141). It suggests that about 33 percent is a valuable percentage to use for positioning the topic. In landscape photography, it is used to position the horizon: one-third sky to two-thirds land, or as shown in figure 135, one-third land and two-thirds sky. The next “third” is to frame the picture on at least one side with something. And the last “third” is to divide the land (or sky) into thirds by use of an angle. The angle may be a road, change in vegetation, crest of a hill, cloud formation (fig. 140), or other item. Perhaps the mnemonic “one-SAT” will help recall “one side, one angle, one-third.”

Figure 142 begins a series illustrating this adage. Figure 143 is a broad view of the landscape used for illustration. Figure 144 is a common type of camera orientation, placing the horizon in the center of the picture. Lowering the camera, as in figure 145, illustrates a one-third horizon; in figure 146, the camera moves to the right to frame the scene. One angle is represented by the slope. Figure 147 is the actual scene taken near the Snake River in Oregon, showing the topic of terracing on the near slope resulting from livestock grazing and no terracing on gentler slopes.

Figure 148 illustrates the “thirds” concept but reverses one-third sky for one-third land to emphasize the topic of spring rain showers in the Great Basin. (In reality, only one-fourth is land.) In photo (B) the camera was repositioned to frame the picture with sagebrush and to include a fence for the “angle” and as a perspective on scale.

Pattern is use of contrasting objects such as a house in a field, row of trees, hills and a valley, or dramatic differences in vegetation as shown in figure 149. The topic was a meadow and its adjacent forest. Pattern also is illustrated in figure 150 but in a dramatically different way. Here pattern is related to texture of the siding compared to the roof and ground.

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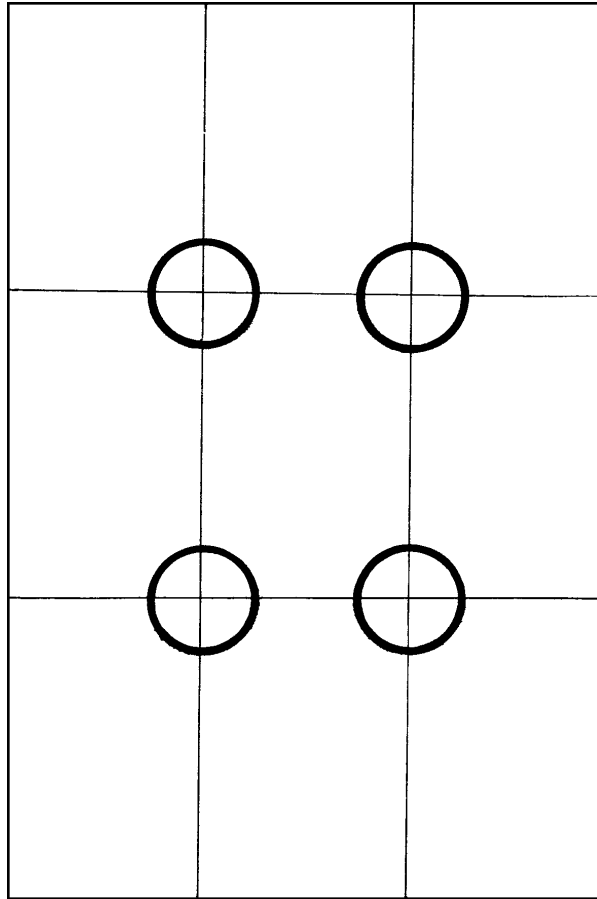


Figure 141—The “rule of thirds” depicted with a 35-mm image. Divide the image into thirds and use the intersection of the lines as a guide for topic location. In portrait photography, a person’s face or other item of interest is located at one of the circles. Landscape photography uses a modification as shown in figure 142.

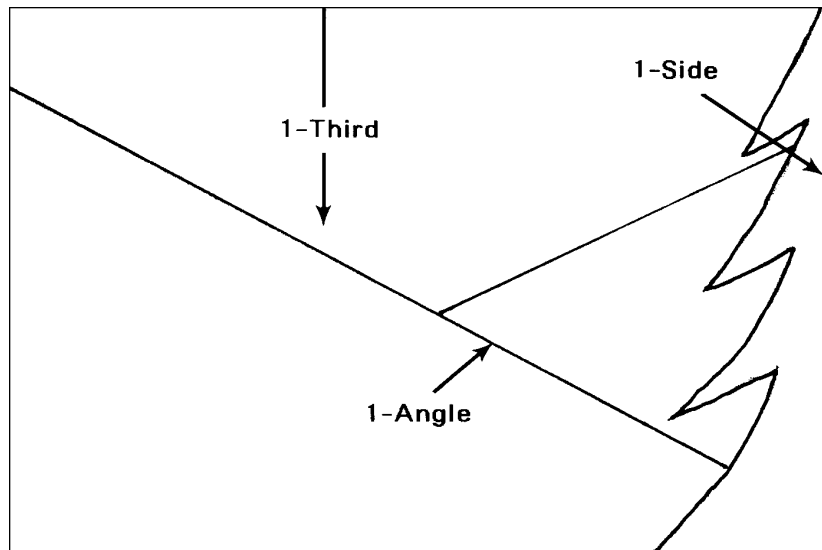


Figure 142—Figures 143 through 147 illustrate the concept of “thirds” (Hedgecoe 1994) or the concept of “one-third, one side, one angle” for placing the topic of interest in a photograph. “One-third” suggests that only one-third of the picture should be sky or land. In figure 142, only one-third is sky. “One side” suggests framing the picture in some way, here with a tree. “One angle” calls for some line in the picture at an angle. This diagram is expanded to a real landscape diagram in figure 143.

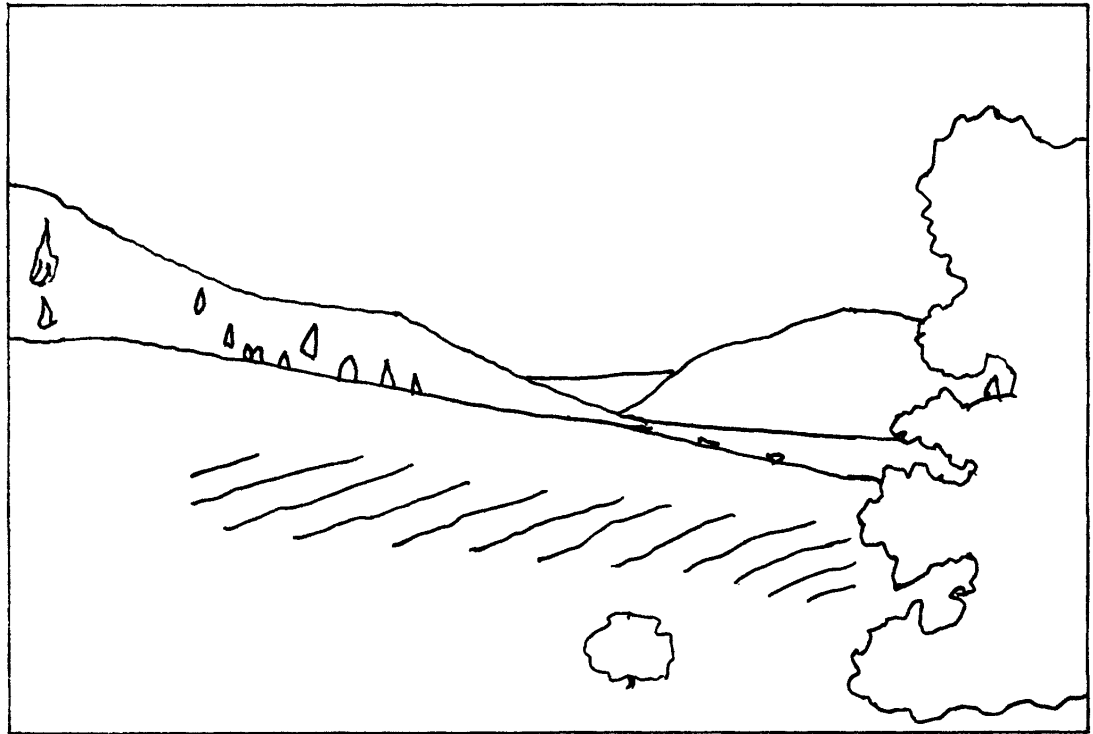


Figure 143—A basic scene. Orientation of the camera will be further illustrated in figures 144 through 146.

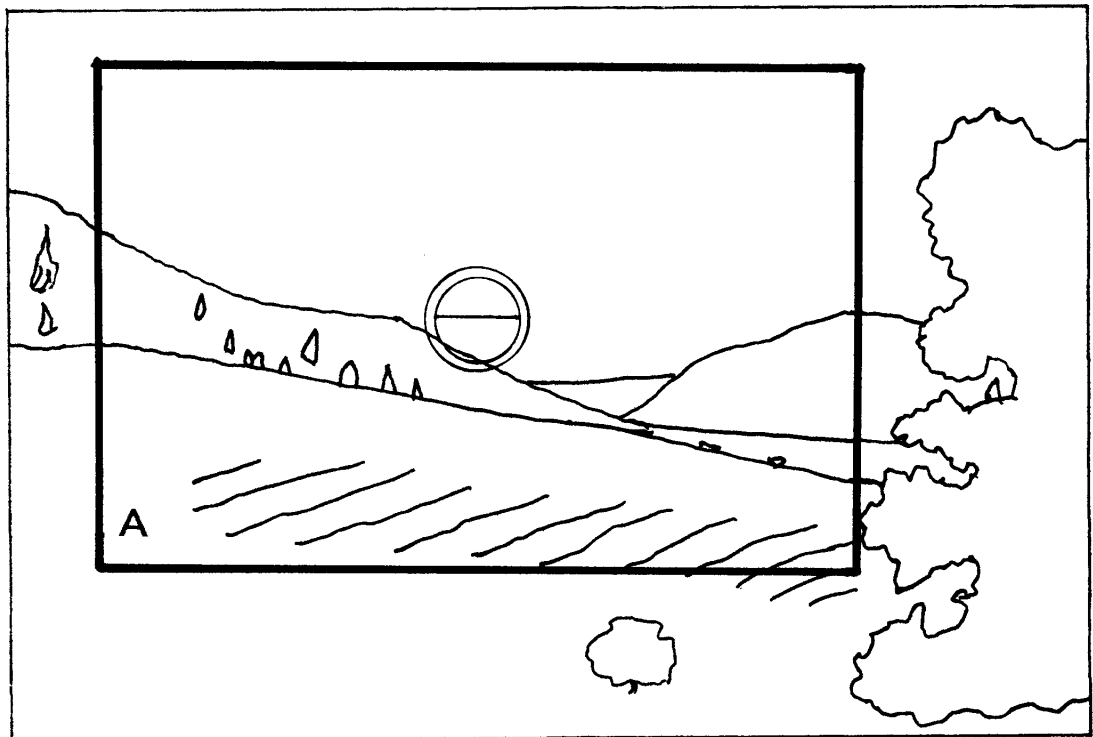


Figure 144—Here the camera focus has been placed on the horizon resulting in half sky and half land. Compare to figure 147A.

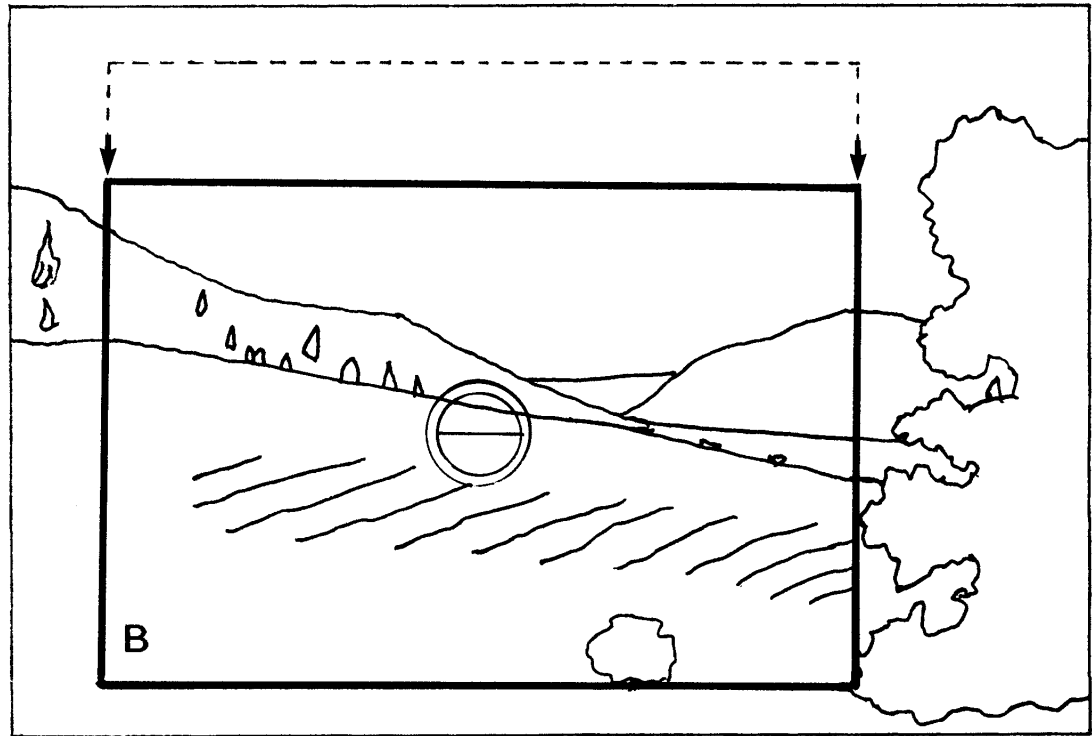


Figure 145—The camera has been lowered to one-third sky providing some focus on the foreground topic of a rippled slope. Compare to figure 147B.

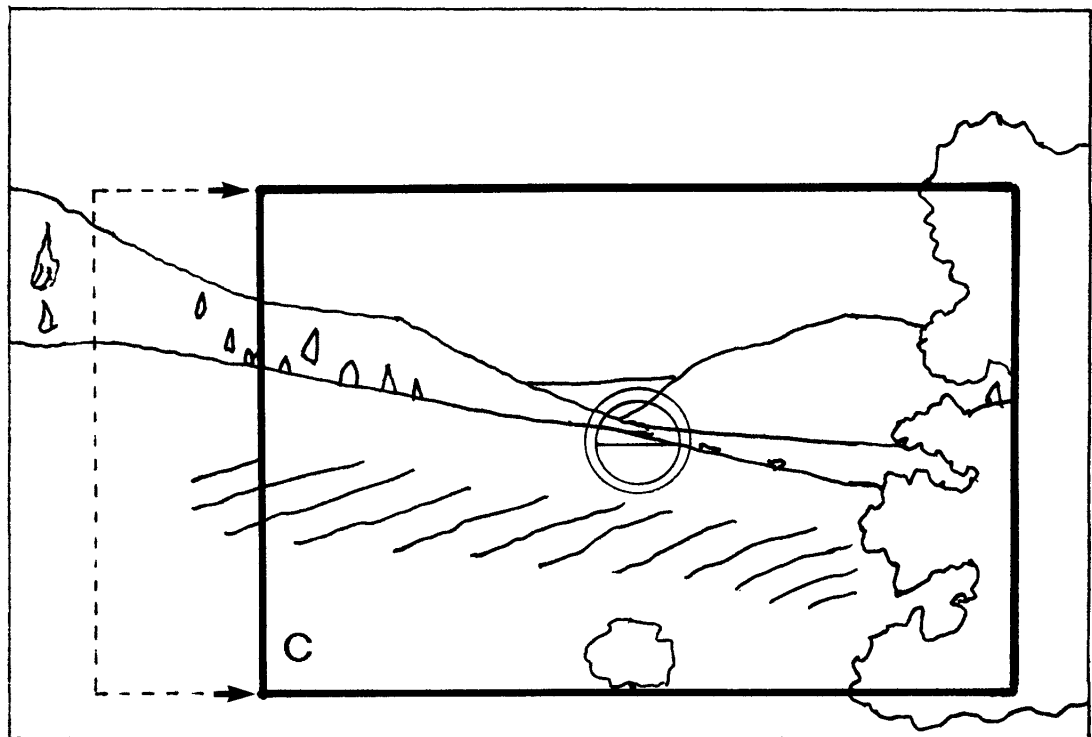


Figure 146—The camera was moved sideways to the right so that a tree would frame the picture. Here, four landscape photography concepts are illustrated: (1) one-third sky; (2) one-side framing; (3) one angle, the crest of the foreground slope; and (4) topic of the foreground rippled slope. The rippling (terracing) was caused by livestock use. These views are shown in figure 147.

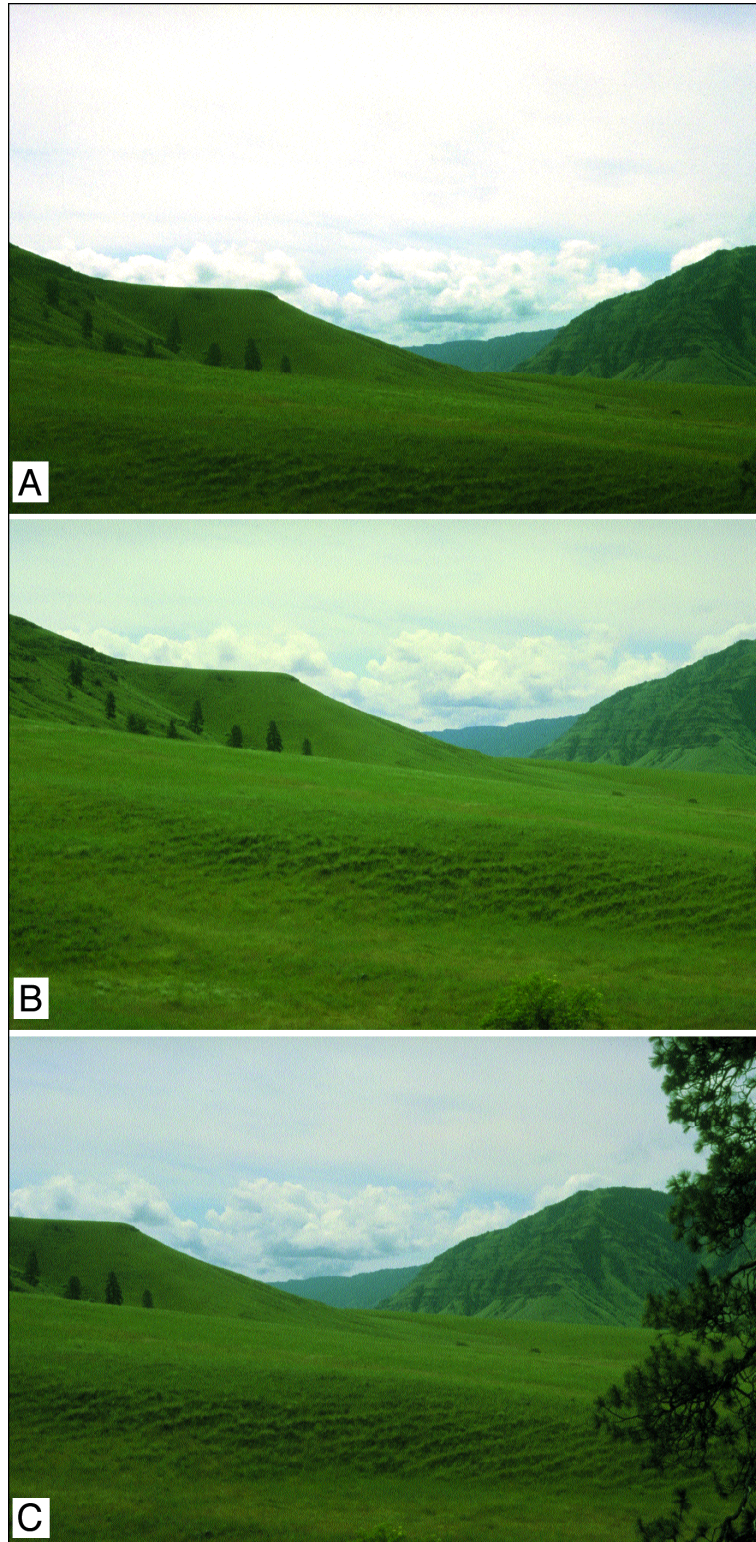


Figure 147—**A**, **B**, and **C** correspond to figures 144, 145, and 146, respectively. Exposure is an important consideration in landscape photography. In **A**, the land has been underexposed because the camera light meter was overly influenced by the bright sky. Expose for the topic of interest. If serious photography is contemplated, always take at least three exposures: one at what the meter says, one an f-stop less, and one an f-stop more.



Figure 148—Reversing the “one-third sky” rule is necessary when the topic is weather. (A) Land was reduced to about 25 percent to emphasize spring rain clouds over the Great Basin. (B) Moving the camera a few feet uphill provided framing with sagebrush and a fence line, which provides scale and an angle. Also see figure 140.



Figure 149—The topic here is a meadow. (A) The horizon halves the picture. (B) The camera was turned 20 degrees to the left and orientation lowered for one-third sky to show an extension of the meadow into the distance. This provided a break in the meadow edge and functions as an “angle.” (C) The scene was framed by a tree. This figure also illustrates pattern by the forested hill and smooth pasture.

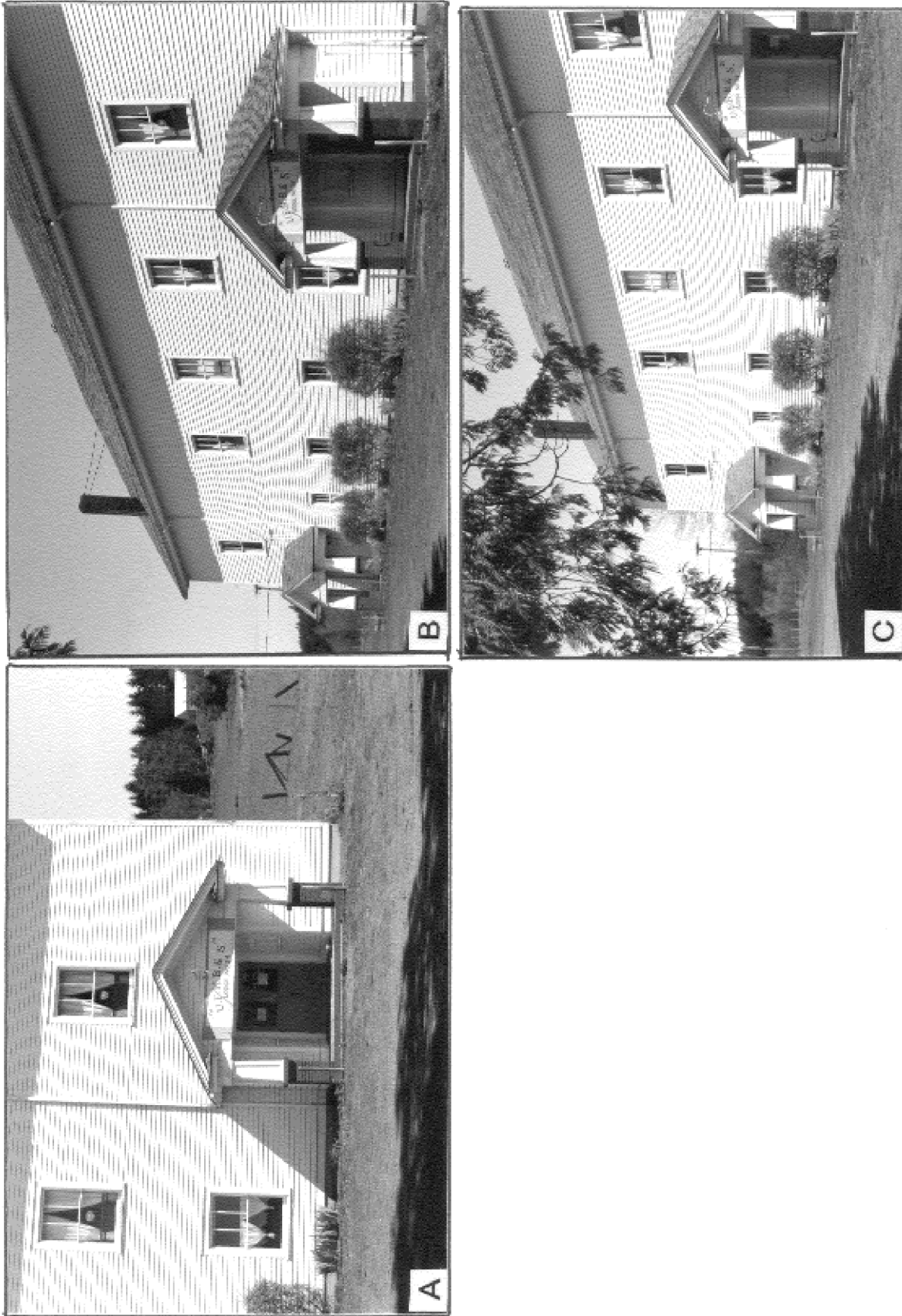


Figure 150—A totally different application to define the topic with one-third, one side, and one angle is shown with a structure. (A) A perfectly nice documentary of a country organizational building with one-third ground. (B) Adds a converging angle while preserving the name. (C) Simply frames the picture.



Figure 151—A framed landscape view is shown with the topic of a farmstead. Buildings are used to provide scale as is the fence. Backlight (sun shining towards the camera) creates a halo effect around each tree below the farm to give a three-dimensional effect.

Perspective or scale is provided by objects of known size; for example, the farm buildings in figure 151. In figure 148B, the fence line provided both an angle and a sense of perspective. Figure 149 could have been enhanced by an object in the meadow to indicate how wide it is.

Change in camera focal length is another method for dealing with composition and emphasizing a topic. Figure 152 compares two focal lengths and their effect on emphasis of ponderosa pine savanna. Figure 153 illustrates change in topic with change in focal length. The topic changes from an island in a river to a sweeping bend in the river with an island.

Composition may be summarized as follows: define a topic (What do I want to show?), apply the one-SAT concept (one side, one angle, one-third), use pattern to emphasize the topic, and provide perspective for the topic.

Light

Light is abused more often than used. It may be used to highlight objects, put a three-dimensional effect into a landscape, create unsolvable problems with shadows, and wreak havoc with a topic when sky and ground exposure are being reconciled. Abuse of light results from inattention to exposure and lack of time to photograph in suitable lighting conditions.

Sun may be used to enhance a three-dimensional effect in a two-dimensional photograph (figs. 151 and 154). Sun from behind the topic, particularly vegetation, tends to shine on the outside leaves while making a shadow in back. This forms a “halo” effect setting off individual plants and simulating a three-dimensional effect. Figure 155 illustrates the effect in grass, shrubs, and trees. Notice how the trees stand out as individuals in figure 151. The halo effect is summarized in the proverb of “photograph before 10 and after 3” when the Sun is low enough to create a good halo.

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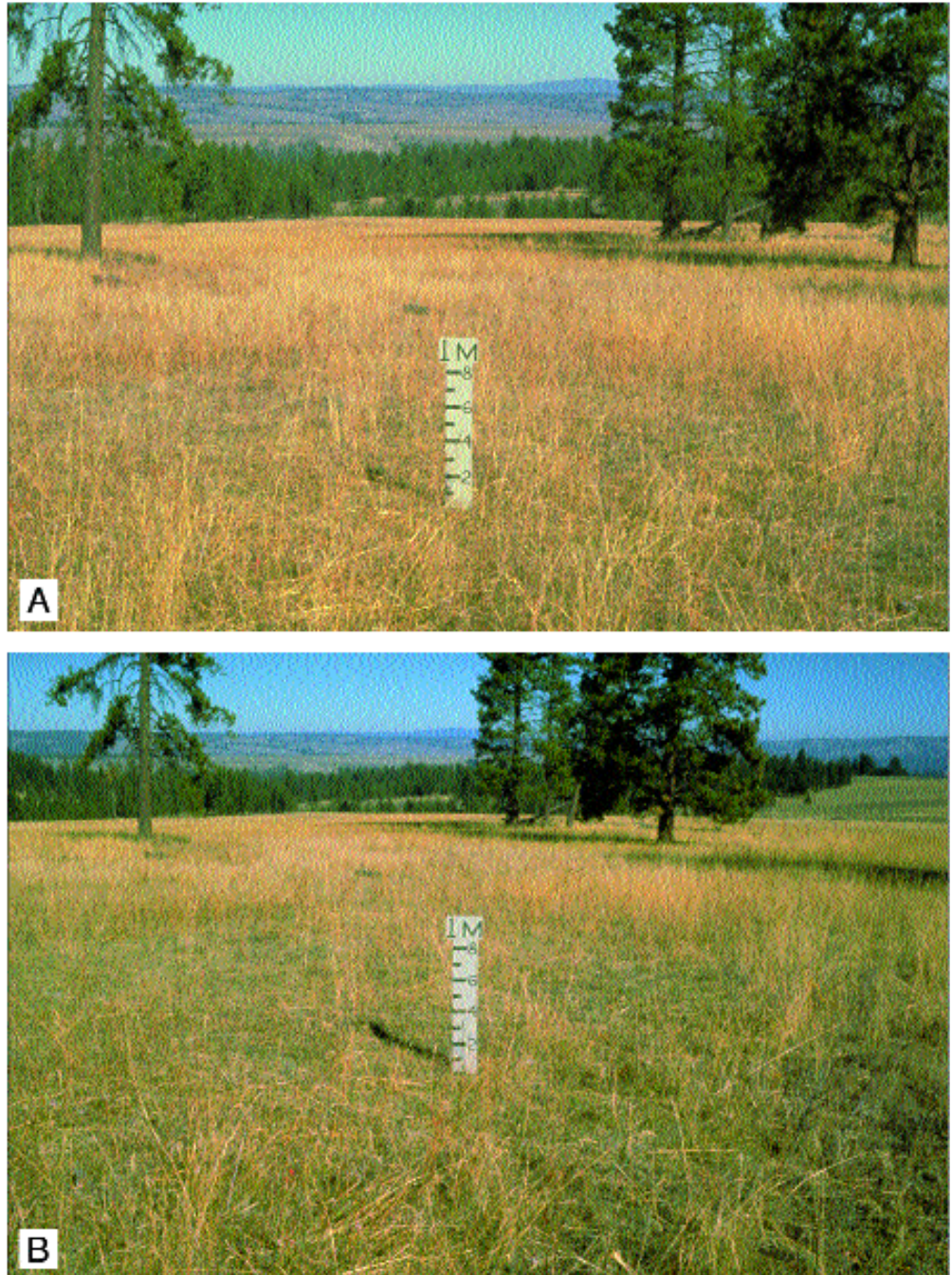


Figure 152—Effect of focal length is important in photograph composition and topic identification: (A) 50-mm lens on a 35-mm camera 10 m from the meter board emphasizing savanna ponderosa pine, and (B) 35-mm lens on the 35-mm camera from the same camera location but the meter board has been moved to 7 m making it the same size as in A. Scale of the grassland has been increased. Which picture more honestly illustrates forest savanna?

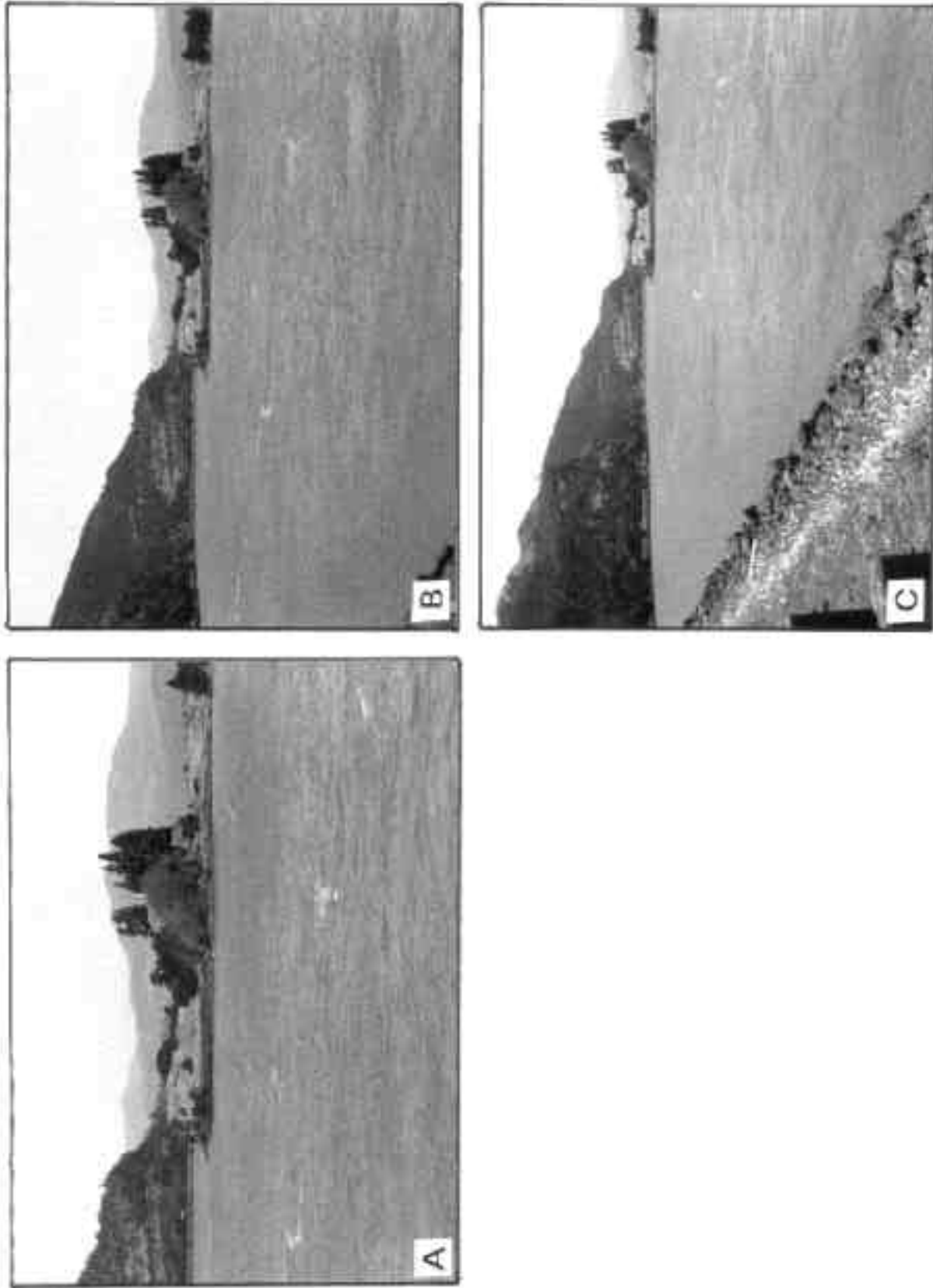


Figure 153— A second use of focal length is to change perspective in a photograph. The setting is an island in the Columbia River. Focal lengths were (A) 70-mm, (B) 50-mm, and (C) 35-mm on a 35-mm camera. In A, the island is the topic; in B, the island and river are both topics (which creates a dull photo); and in C, a sweeping curve of the river is the topic with the setting of an island.

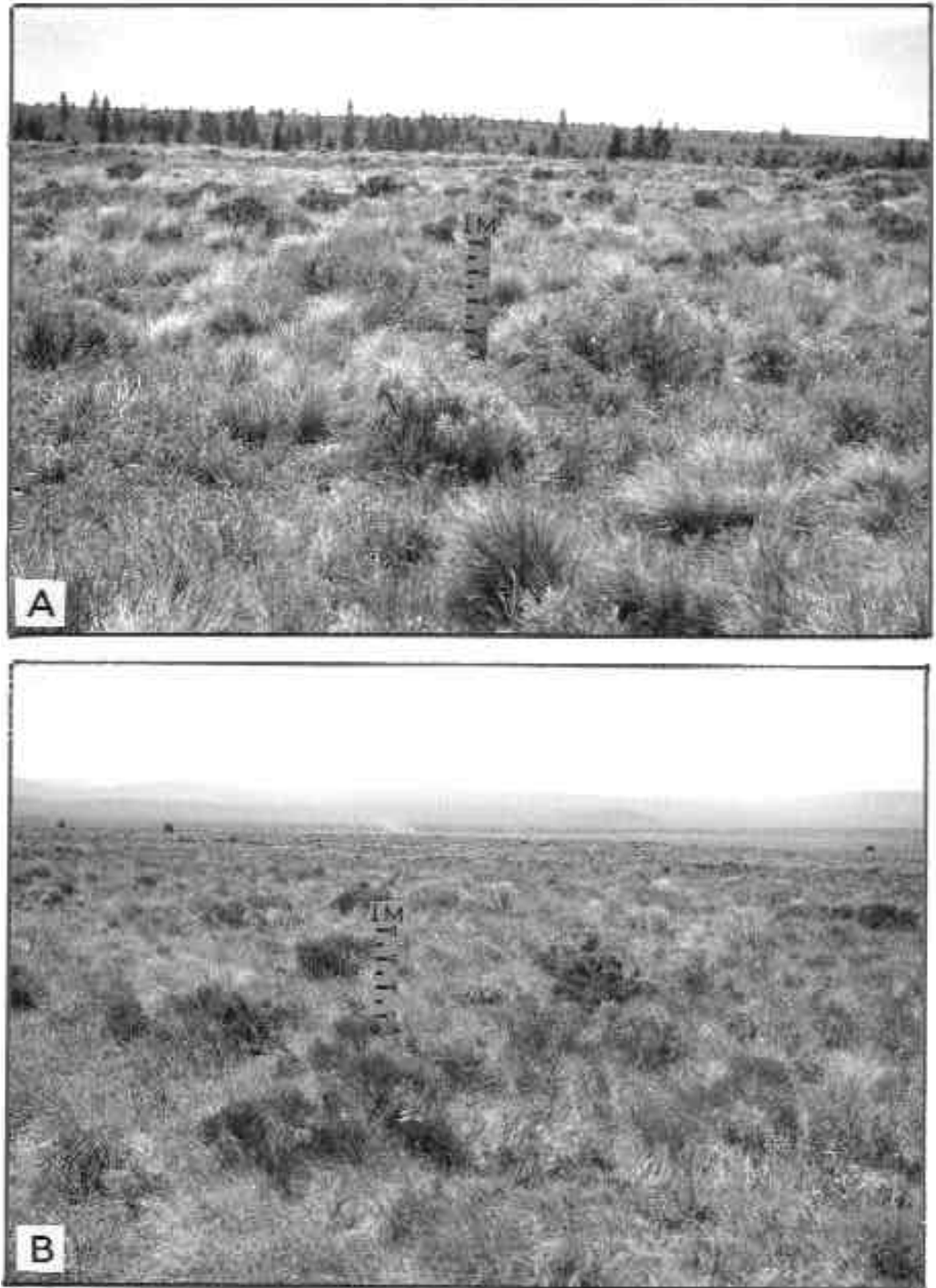


Figure 154—Light position affects emphasis on vegetation. **(A)** Photo taken into the Sun so that the subject is backlit, which produces a “halo” around the edges and a shadow away from the Sun. The halo highlights vegetation and tends to give the picture a three-dimensional effect. An old adage says to photograph “before 10 and after 3” so that the Sun is low enough to enhance the halo effect. **(B)** The Sun is shining on the front of the vegetation (frontlight). Notice in B how the hills in the distance stand apart from each other owing to haze in the air.



Figure 155—A second example of how backlight (**A**) versus frontlight (**B**) affects the highlighting of vegetation. The halo effect is well illustrated by the trees in A.

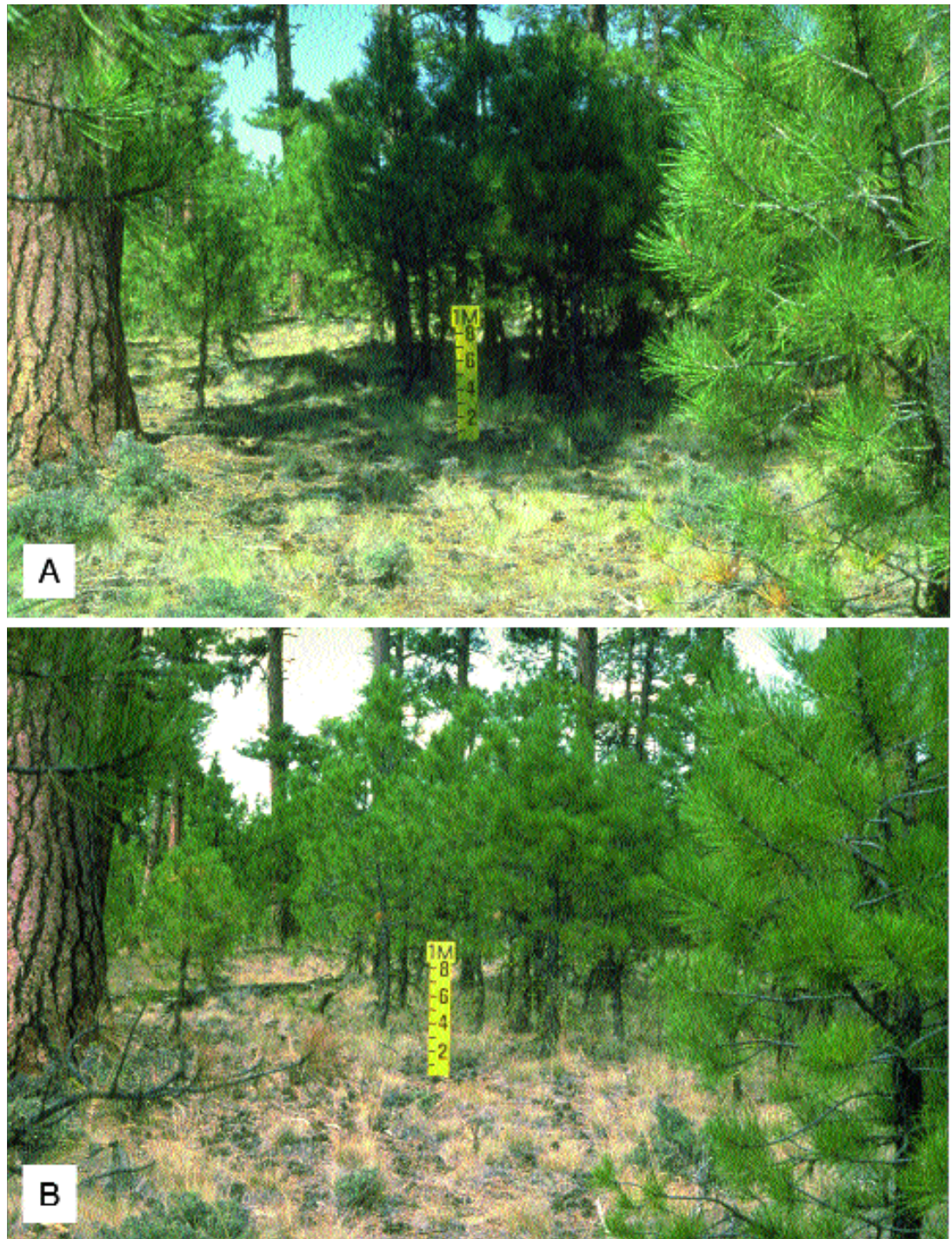


Figure 156—Overcast or full sunlight has major effects in shadow formation, a particularly serious consideration in forests. Overcast days (**B**) produce no shadows. Compare to full sunlight in **A**. With black-and-white film, the shadows may be “dodged” during the enlargement process to bring out much detail. Color film unfortunately has only about half the latitude of black-and-white film for shadows, so particular care must be taken when adjusting exposure. Slides cannot be dodged.

Sunlight compared to overcast skies has advantages and disadvantages. Overcast provides no three-dimensional effect and sunlight produces shadows. Figures 156 and 157 illustrate the disadvantages of shadows.

Camera exposure setting is a key to good use of light. Figure 147, A and B, illustrates the effects. In figure 147A, the exposure was overly influenced by the bright sky, which resulted in underexposure of the land. Determine the camera exposure for the brightest item close to the topic (sky or vegetation in full sunlight) and then for the topic or darkest item at the topic. Average the exposures. If you have any doubt, take three shots: one at the average, one an f-stop under, and one an f-stop over the average. Figures 156 and 157, however, illustrate a problem. The shadow is too dark and the sunlight on the vegetation too bright to be properly exposed, even with black-and-white film. Black-and-white film has about twice the latitude of color; color latitude is about one f-stop above and below average, and black-and-white film is about two f-stops.

Camera exposures in landscape photographs, particularly those showing areas more than 2 mi in the distance, should be set at a minimum of three f-stop settings: the light meter reading and one f-stop below and one above. When distance exceeds 2 mi, haze in the air influences the light meter to indicate less brightness than the land actually is reflecting, which causes overexposure of the land. In these cases, consider taking photos at both one and two f-stops additional exposure. Aerial photography suffers the same problem.

The effect of shadows and poor exposure in photographs may be partially corrected on prints (not slides) by dodging during enlarging. Dodging entails use of a cotton swab $\frac{1}{2}$ to 2 in in diameter or a piece of light cardboard with a hole in it $\frac{1}{2}$ to 2 in in diameter. Both should be very ragged around the edge to avoid creating a harsh edge in the finished print. During enlargement exposure, wave the swab above the overexposed area to cast a shadow and reduce the exposure time for that area. For underexposed areas, use the cardboard with the hole to shade most of the print and allow longer exposure to bring out details. Digital images may be enhanced by computer.

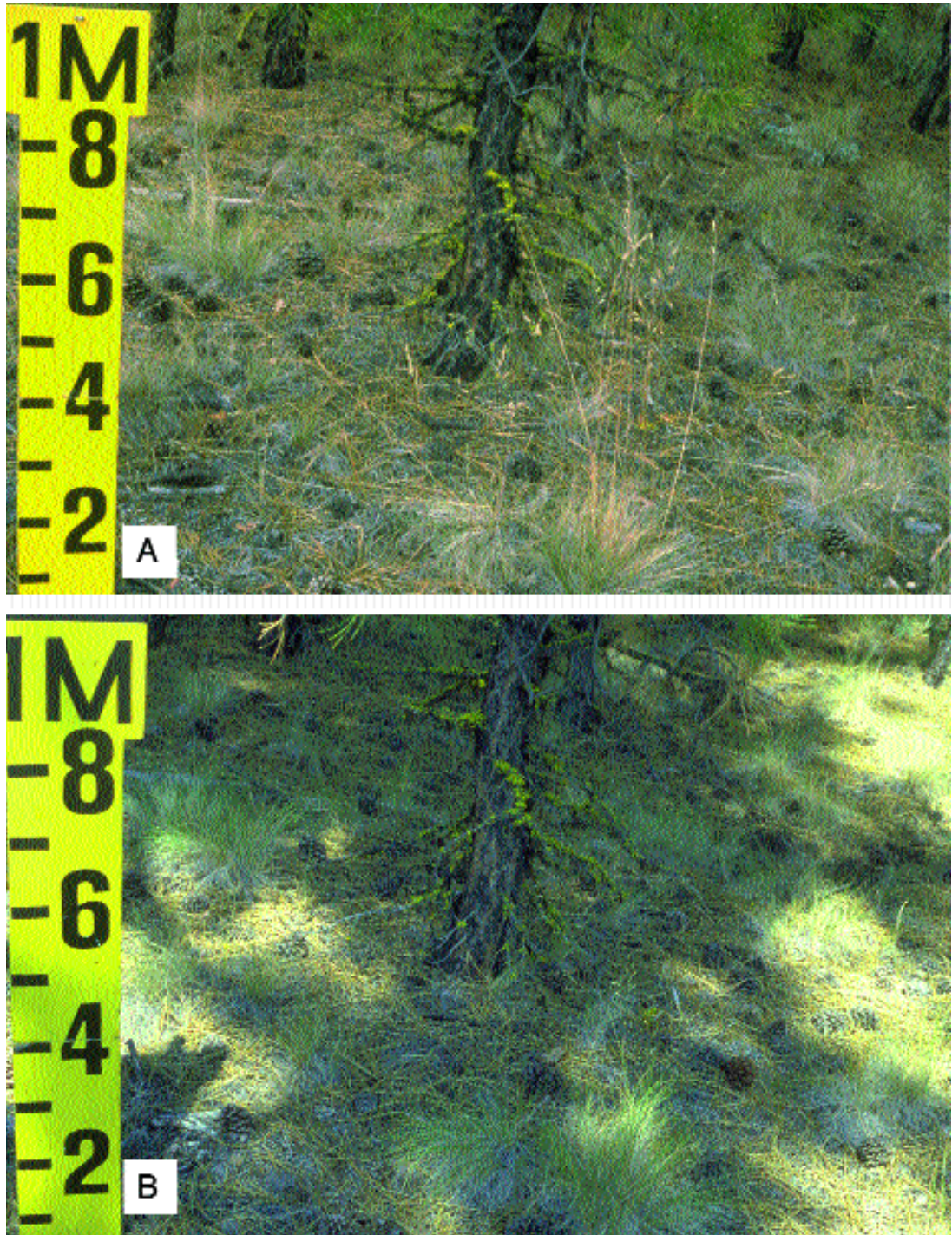


Figure 157—This example is taken at the same photo point as figure 156: (A) overcast and (B) a clear day with full sunlight.

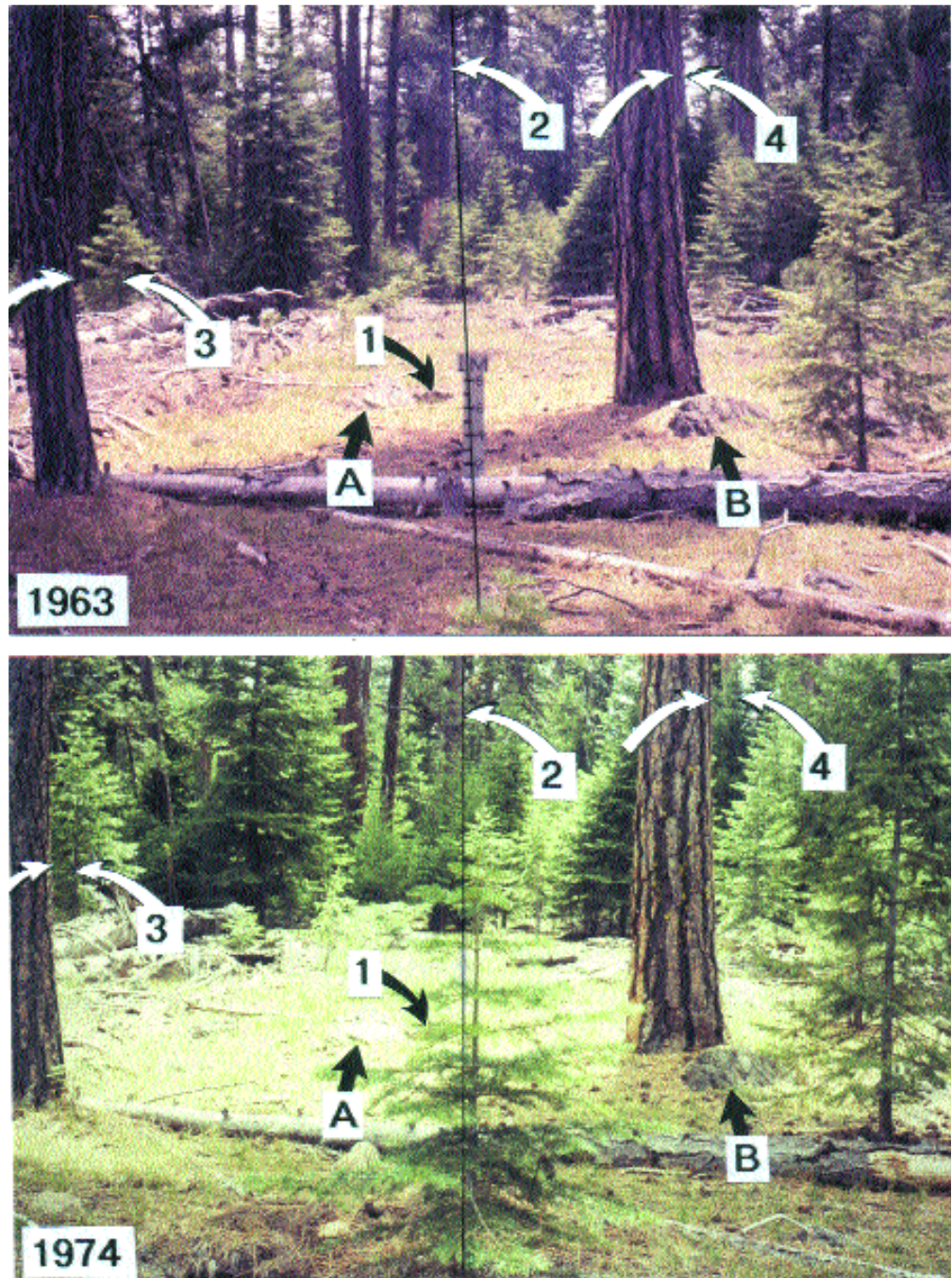


Figure 158—Relocation of photographs may be difficult when disturbance has occurred. In 1963, the centerline was established with a rock at 1 and the side of a large tree at 2. The arrows, A and B, indicate large rocks present in all photographs but not on the centerline; they help to locate the site and to validate the location. Left-side triangulation is identified by arrows at 3 showing the distance between a large tree and a small one. Right-side triangulation at 4 is identified by the side of a large foreground tree and one in the background. These triangulate the camera location. In 1974, the same items are shown without a meter board. Selection cutting occurred after 1974 with results shown in figure 159.

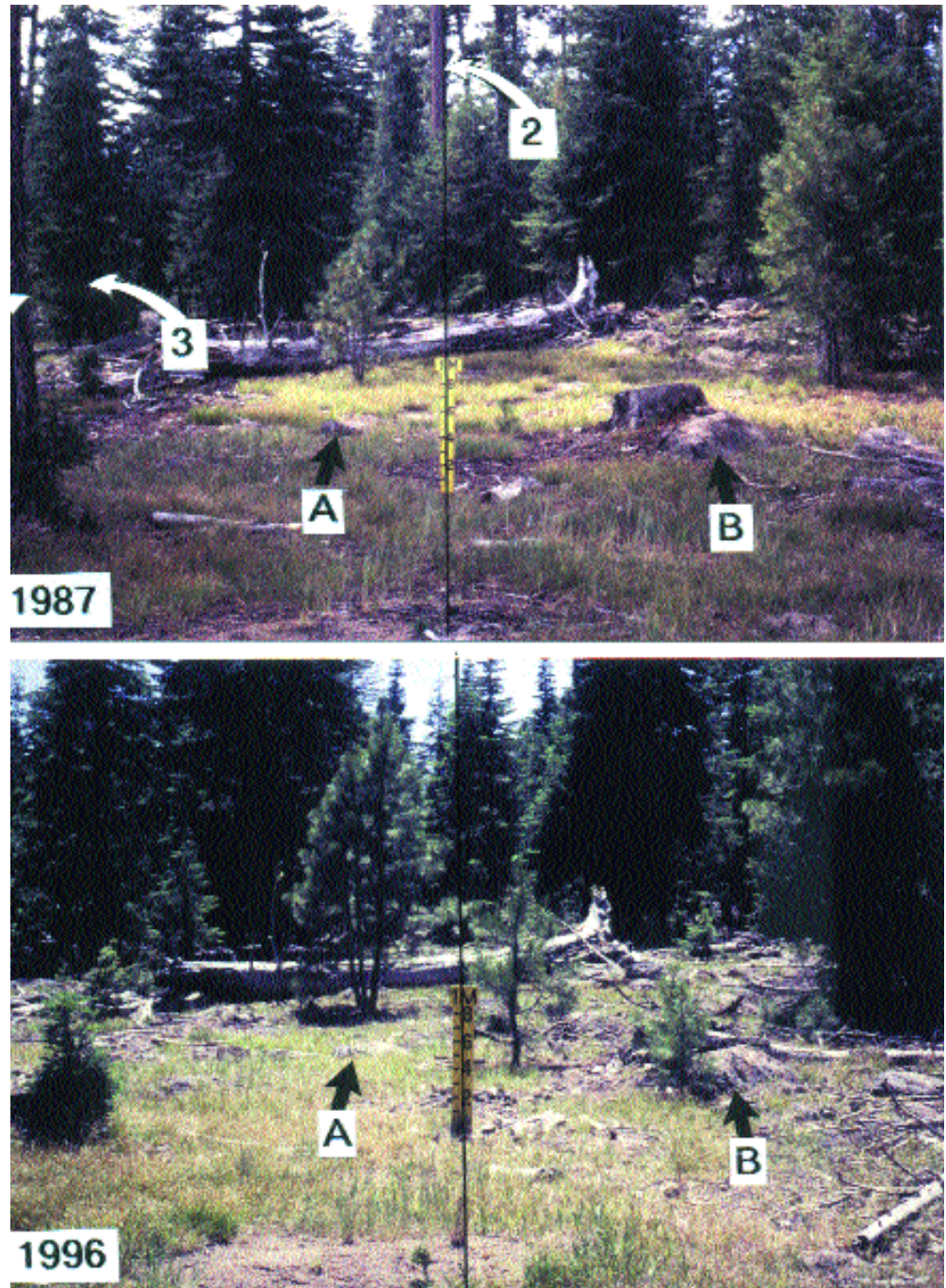


Figure 159—By 1987, selection cutting had removed the right foreground tree and the tree in the background located at 4 in figure 158, which eliminated the triangulation point. The rock at 1 was missing but the large tree in the background at 2 was present. Left-photo triangulation was still identified at 3. By 1996 after final overstory removal, all original vegetation orientation references were missing. Finding the location is facilitated by rocks at A and B, particularly B with its permanent location at the base of a tree. Precise relocation of both camera and photo points (meter board) were possible only from permanent steel stakes in the ground. Note soil hole spoils in the foreground. There has been no colonization of B or C horizon by native species in 33 years.

Relocation of Photographs

Figure 158 illustrates relocation of a camera location and photo point. The procedure is similar to that shown in figure 38. On the original photo (1963), draw a central line. A rock in the foreground and a tree in the background help establish the line. Remember, the meter board will not be in position when the site is next visited, so it cannot be used for the center line. Then establish reference points at the edges of the photograph to triangulate the camera location (fig. 158, 1963, points 3 and 4). For the 1974 photo, walk forward and backward on the center line looking at the left and right sides of the picture, (3) and (4), for triangulation of the camera location. When these side identifications match numbers 3 and 4 in 1963, the camera location has been established. Note change in size of small trees between 1963 and 1974. These changes can be confusing in relocation.

Figure 159, 1987, is 13 years after figure 158 and after a first partial overstory removal. The foreground tree (item 4 in fig. 158) and the background tree are both missing so this triangulation point is no longer usable. On the left of the photo, triangulation point 3 is still available to aid location of the camera location. However, the rock at 1 has been removed and the down tree has shifted position making exact location of the center line difficult. By 1996, after the final overstory removal (fig. 159), all original reference points have been destroyed. Only rocks at arrows A and B remain. They verify that this is the same area, but do not relocate the camera location or photo point.

The moral to this story is to permanently locate, with steel stake or fencepost, both the camera location and the photo point. If disturbance such as this is anticipated, use steel stakes or ½-in-diameter rebar driven flush with the ground. Driving them flush with the ground will help prevent them from being ripped out by equipment. A metal detector will be needed to relocate the stakes.

Any kind of disturbance or vegetation growth can make relocation of photo monitoring points difficult if they are not marked by steel stakes or fenceposts. Figure 160 illustrates the effects of a wildfire where the camera location and photo point were permanently staked. The camera location could have been located approximately by aligning the meter board with a juniper in the background, the pair of junipers on the far right, and juniper branches on the left.

The advantages of using steel stakes are shown in figure 161. This kind of photo point cannot be exactly relocated by referring to general triangulation methods.

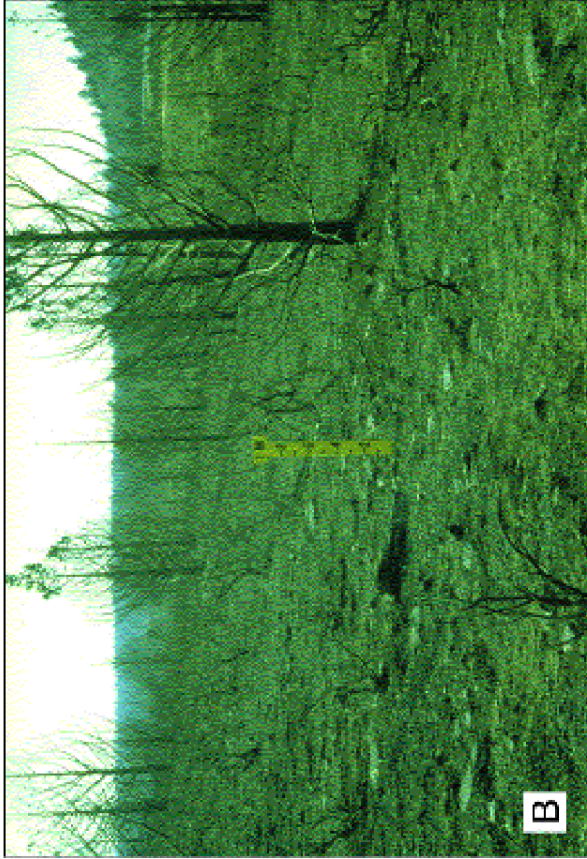


Figure 160 —Rephotography of disturbed areas is illustrated. (A) The preburn vegetation. This sample plot was established as a data source for livestock forage rating guides. It was in the best vegetative condition for juniper/bitterbrush/Idaho fescue (*Juniperus occidentalis* Hook./*Purshia tridentata* (Pursh) DC./*Festuca idahoensis* Elmer). (B) Six years later the area burned by wildfire. (C) The area 4 years after the burn. Approximate relocation would be possible by noting the juniper directly above the meter board, the pair of junipers on the far right, and the branches of a juniper on the far left. Fortunately, the sample plot had been staked. Idaho fescue, killed by the fire, is being replaced by bluebunch wheatgrass (*Agropyron spicatum* vis. *Pseudoroegneria spicata* (Pursh) A. Love).

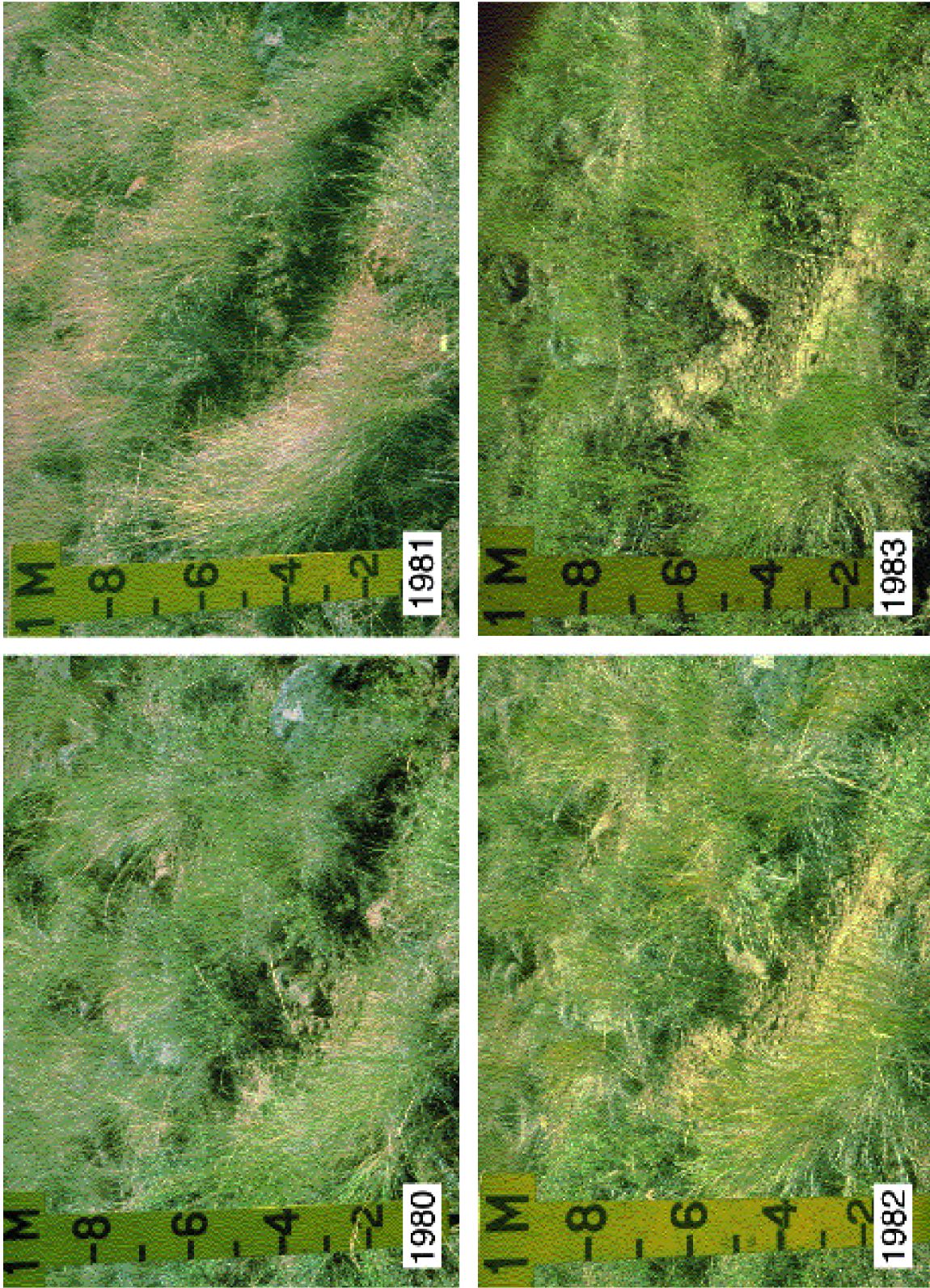


Figure 161—An example of photo monitoring of herbage production in a bluebunch wheatgrass community. Four years of a 25-year study are shown for the first week in August. Three things might be noted: (1) great variability in herbage production, particularly between 1981 and 1983; (2) tremendous difference in seed head production: some in 1980, abundant in 1981, none in 1982, and scattered in 1983; and (3) the difference in greenness of the grass.

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Bold italic = page with an illustration and a major discussion

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Metric and English Conversions

When you know:	Multiply by:	To find:
Millimeters (mm)	0.04	Inches
Centimeters (cm)	0.39	Inches
Decimeters (dm)	3.9	Inches
Inches (in)	2.54	Centimeters
Meters (m)	3.28	Feet
Feet (ft)	0.3	Meters
Square meters (m ²)	10.76	Square feet
Square feet (ft ²)	0.09	Square meters
Meters (m)	1.09	Yards
Kilometers (km)	0.62	Miles
Miles (mi)	1.61	Kilometers
Hectares (ha)	2.47	Acres
Acres	0.4	Hectares
Kilograms per hectare (kg/ha)	0.89	Pounds per acre
Pounds per acre (lb/acre)	1.12	Kilograms per hectare
Grams (g)	0.035	Ounces
Ounces (oz)	28.35	Grams
Celsius (°C)	$(1.8 \times ^\circ\text{C}) + 32$	Fahrenheit
Fahrenheit (°F)	$0.55(^{\circ}\text{F} - 32)$	Celsius

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